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THE IOWA ORTHOPEDIC JOURNAL

2025

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IOWA HEALTH CARE

THE IOWA ORTHOPEDIC JOURNAL

2025 • Volume 45

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2025 IOJ EDITORS' NOTE

From left to right: Drs. Kyle Geiger (Resident Business Manager and Editor), Mary Kate Skalitzky (Resident Editor), J. Lawrence Marsh (Staff Advisor), Jose Morcuende (Staff Advisor), and Brandon Marshall (Resident Editor).

The editors are pleased to present the 45th edition of the Iowa Orthopedic Journal (IOJ). We continue to receive submissions from institutions across the United States and world in high numbers, representing all subspecialties in the field, a true breadth and depth of knowledge.

We would like to recognize our graduating class of senior residents: Drs. Connor Maly, Sarah Ryan, Taylor Den Hartog, Daniel Meeker, Edward Rojas, and Brady Wilkinson. They set a standard for patient care, education, and departmental culture that we can only hope to continue after their departure. We wish them all the best as they complete their training, move onto fellowship, and start their careers. We will miss their teamwork, leadership, and friendship.

We would also like to thank several key individuals without whom the publication of the IOJ would not be possible. We would like to thank Angie Poulsen, who was instrumental in the organization and preparation of this year's IOJ. We thank Dr. Kyle Geiger for his efforts to coordinate corporate sponsors. We also extend thanks to our sponsors for their generous support of the IOJ, as publication would not be possible without their contributions. We thank Dr. Jose Morcuende and Dr. John Lawrence Marsh for their continued guidance as faculty advisors to the journal. Finally, we would like to recognize Dr. Edward Rojas as Resident Reviewer of the Year for the exceptional consistency, quality and quantity of his reviews this year.

It has been a great privilege to serve as this year's editors. The University of Iowa Orthopedics Department provides remarkable training, and we are appreciative of our opportunity to be part of its history and legacy. We are excited for the continued innovation and forward progress in the department, and hope that the readership enjoys this year's publication.

Brandon Marshall, MD
Mary Kate Skalitzky, MD
Kyle Geiger, MD
Editors-in-Chief
Iowa Orthopedic Journal
University of Iowa Hospitals and Clinics

2025 DEDICATION OF THE IOWA ORTHOPEDIC JOURNAL

Kyle W. Geiger, MD, Brandon J. Marshall, MD, Mary Kate Skalitzky, MD

Leland G. Hawkins, MD, University of Iowa Orthopedic Surgery residency (1962).

This year, the Iowa Orthopedic Journal is proud to dedicate its 2025 edition to Dr. Leland G. Hawkins, a pioneering orthopedic surgeon, teacher, scholar, and quintessential Iowa Orthopedist whose work left an indelible mark on the field of orthopedic trauma. His legacy continues to guide generations of surgeons across the globe.

Dr. Hawkins completed his orthopedic surgery residency at the University of Iowa from 1961 to 1965. During this time, he embarked on what would become a defining scholarly contribution to orthopedics: the classification of talar neck fractures, a system that today bears his name—the Hawkins Classification. This framework revolutionized the understanding and treatment of talus fractures, provided insight into the risk of avascular necrosis, and remains foundational in orthopedic education and trauma care worldwide.

A native of Los Angeles, California, Dr. Hawkins brought a quiet diligence and unrelenting curiosity to every endeavor. After earning his undergraduate degree at Beloit College, he began medical school at the University of Chicago, where he distinguished himself not only academically but also through his character and compassion. Described by mentors as industrious, conscientious, and deeply committed to his patients, he embodied the ideals of medicine from the outset.

His time at Iowa marked the beginning of a remarkable academic journey, supported by mentors such as Drs. Larson, Flatt, Bonfiglio, and Ponseti. Upon graduation, he furthered his academic pursuits at the University of Colorado, where he rose to become Associate Professor and Chief of Orthopedic Surgery. He published on a wide variety of topics, from hand infections to intravenous regional anesthesia, but his hallmark remained his unwavering commitment to patient care and education.

In 1973, Dr. Hawkins returned to his roots in Iowa, settling in Cedar Rapids to practice orthopedic surgery with a focus on the hand and upper extremity. There, he also continued his commitment to teaching by leading orthopedic education for local family medicine residency programs. Beyond his clinical practice, Dr. Hawkins was an engaged community member—a beekeeper, farmer, and advocate for environmental stewardship—who initiated the beekeeping program at the Indian Creek Nature Center.

Dr. Hawkins' contributions to orthopedics extended far beyond the OR. His Hawkins Classification has stood the test of time, continuing to guide clinical decisions and research decades after its introduction. The "Hawkins Sign," a radiographic marker of revascularization in the talus, also remains a critical prognostic tool in orthopedic trauma. His work has been cited in hundreds of articles, taught to thousands of trainees, and applied in countless patient encounters.

Above all, Dr. Hawkins was remembered as a thoughtful, humble, and compassionate physician whose commitment to excellence and service defined his career. His untimely passing at the age of 58 was a great loss to the orthopedic community, but his legacy endures through the work of every surgeon who has ever classified a talus fracture using his name.

It is with immense respect and gratitude that we honor Dr. Leland G. Hawkins with this year's Iowa Orthopedic Journal dedication. His life's work exemplifies the very best of Iowa Orthopedics—scholarship, service, and a lasting commitment to improving the lives of others.

-The IOJ Editors

The Hawkins family on vacation in Colorado (1971).

Dr. Hawkins posing with hand sculpture at a park in California, demonstrating his strong interest in orthopedic surgery of the upper extremity.

DEPARTMENT OF ORTHOPEDICS AND REHABILITATION FACULTY 2024-2025


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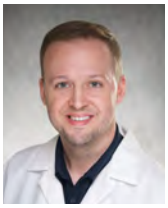
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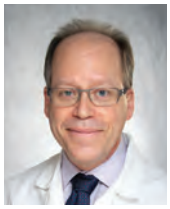
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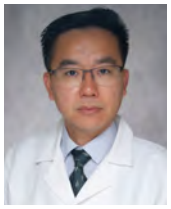
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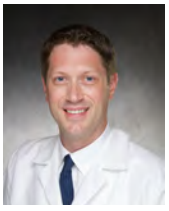
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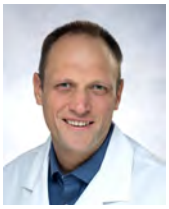
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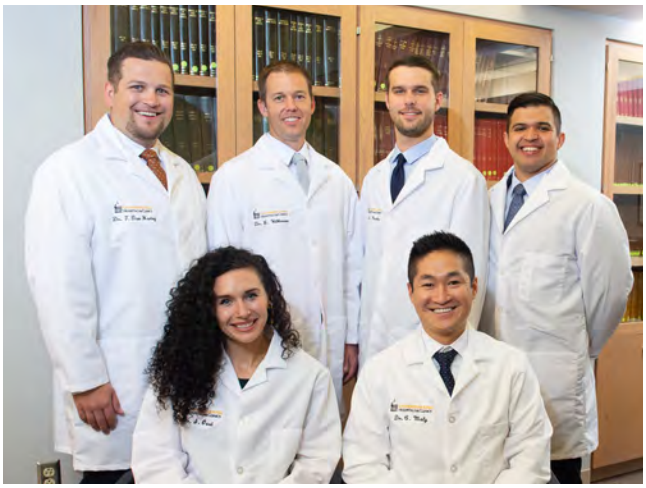
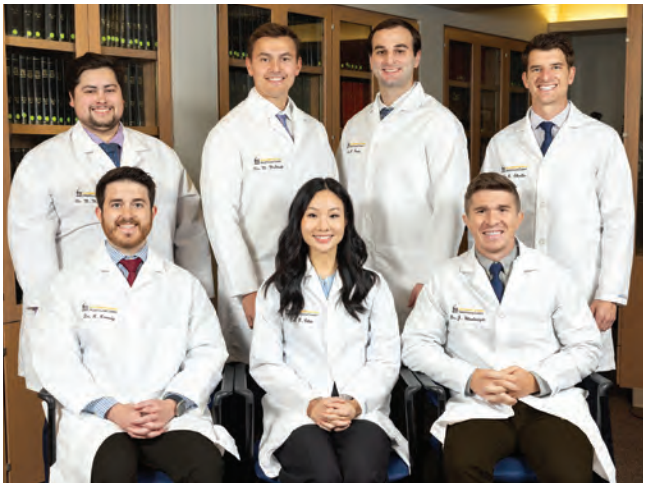


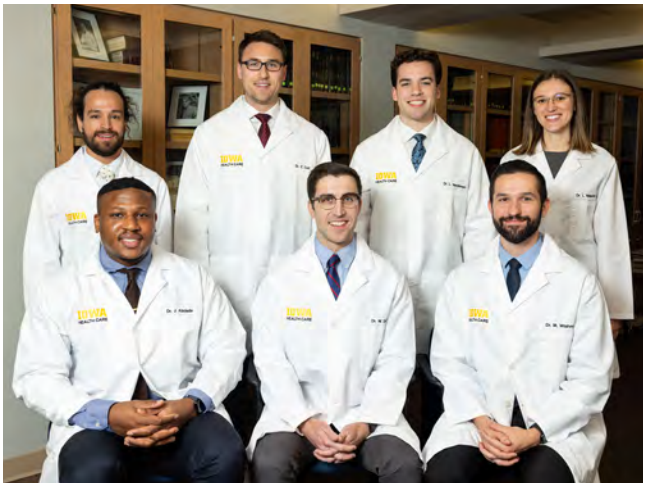
PGY4-Class of 2025. Back row (left to right): Drs. Taylor Den Hartog, Brady Wilkinson, Daniel Meeker, and Edward Rojas. Front row (left to right): Drs. Sarah Ryan and Connor Maly.

PGY3-Class of 2026. Back row (left to right): Drs. Brandon Marshall, Michael Orness, and Garrett Christensen. Front row (left to right): Drs. Joseph Rund, Mary Kate Skalitzky, and Kyle Geiger.

PGY2-Class of 2027. Back row (left to right): Drs. Alex Demers, Josh Vander Maten, and Arianna Dalamaggas. Front row: (left to right): Drs. Steven Leary, Austin Benson, and Ryan Guzek.



PGY1-Class of 2028. Back row (left to right): Drs. Michael Marinier, Matthew McIlrath, Bison Woods, and Christopher Eberlin. Front row (left to right): Drs. Robert Roundy, Erin Choi, and John Wheelwright.



PGY1-Class of 2029. Back row (left to right): Drs. John Davison, Cory Call, Luke Nordstrom, Lindsey Malecha. Front row (left to right): Drs. Jeremy Abolade, William Dodd, Mark Wishman.

2025 GRADUATING ORTHOPEDIC RESIDENTS

Taylor J. Den Hartog, MD

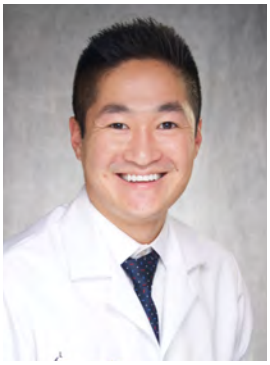
Taylor was born in Des Moines, Iowa to Bryan and Nancy Den Hartog. His family moved to Rapid City, South Dakota at the age of three where he grew up along-side his two older brothers, Addison and Jordan. Taylor participated in multiple sports while spending a lot of time golfing, hiking, skiing, and getting out on the lake. He grew up a Hawkeye fan and could always be found cheering for the Black & Gold. Taylor is passionate about cooking which he learned from his mother. He grew up shadowing his orthopedic surgeon father and graduated high school planning to become a physician too.

He attended Colorado State University where he met his future wife, Haley. Here he continued to work with multiple foundations to give back to the community. Taylor married Haley the summer after earning his degree in Biomedical Sciences in 2010. They then moved to Iowa City, IA where he worked as a research assistant with the University of Iowa Sports Medicine Department.

In 2016, he began medical school at the University of South Dakota. Shortly after the start of medical school Taylor and Haley welcomed their son Bennett. While he was inspired by his father to enter the field of medicine, he did consider multiple other specialties but always found himself returning to the field of orthopedics. During his second year of medical school, Taylor and Haley welcomed their second child, Eleanor. After completing a number of sub-internships during his third year, Taylor was thrilled to match at the University of Iowa.

As a resident, Taylor has been involved in research in multiple subspecialties but soon found that arthroplasty was his passion and has focused research interests in prosthetic joint infection. As a resident, Taylor and Haley welcomed their third and fourth child, Laurel and Howard ("Howie"). While at Iowa Taylor has been able to pursue his other interests including golf, cooking, beer-brewing, spending time with his co-residents and most importantly family. Following graduation Taylor will complete the Atlanta Adult Reconstruction Fellowship at Total Joint Specialists in Cumming, GA. Following fellowship he will return to Des Moines, Iowa to join Des Moines Orthopedic Surgeons (DMOS).

Taylor has a number of people to thank for his support throughout his training. First, he thanks his co-residents for always being there for him. He credits his parents, Bryan and Nancy, for instilling their work ethic and passion for serving others. His journey would not have been possible without their endless love and support. He thanks his brothers, Addison and Jordan, for always being there for him when he needed them and providing comic relief along the way. He is forever grateful for his four children, Bennett, Eleanor, Laurel, and Howie for they are undoubtedly his greatest accomplishments. And finally, to his wife Haley, who has been his best friend, coach, sounding board, and love of his life. It is only with her unwavering support that his journey through medical school and residency has been possible.



Connor Maly, MD

Connor Maly's journey began in Incheon City, South Korea, where he was born. His birth mother made the significant decision to place him for adoption, giving him the opportunity for a new life in the United States. Had she chosen otherwise, Connor's life might have unfolded in a fishing community in Incheon. Instead, he was adopted by James and Jane Maly and grew up in Lincoln, Nebraska, alongside three siblings. Although they were not biologically related, their bond was and remains strong. He feels forever indebted to the sacrifices of his parents and credits them for every accomplishment.

In Lincoln, Connor was inspired by his father to consider a career in medicine. After graduating from high school, he attended Creighton University in Omaha, majoring in Chemistry. There, he delved into research in an HIV lab under Dr. Michael Belshan's mentorship, which nurtured his curiosity and passion for science. He graduated Phi Beta Kappa and Summa Cum Laude in 2014.

Connor pursued his medical education at Georgetown University School of Medicine in Washington, DC. During this time, he lived with his fraternity brother who was also entering orthopedics, which helped inspire him to enter the field. At Georgetown, he met Aya, a fellow medical student and anatomy course teaching assistant. In time, their relationship blossomed, leading to an engagement during medical school. They were fortunate to couples match into OBGYN and Orthopedic Surgery specialties in Iowa and married in his second residency year.

His wife, Dr. Aya Iwamoto completed her OBGYN residency and currently is in fellowship for reproductive endocrinology and infertility. She has been a constant source of support during Connor's residency. He appreciates her unwavering love and encouragement through the demanding times.

After completing residency, Connor will do a sports medicine fellowship at the Cleveland Clinic, which he gained entrance with the help of great faculty support from Dr. Westermann and Dr. Wolf. He is deeply grateful to his parents, Jim and Jane, for their support and opportunities provided throughout his journey. He aspires to honor them with a lifetime of gratitude. Connor also thanks Aya for her steadfast support, reflecting on their shared experiences and dedication during their professional growth.

Daniel G. Meeker, MD, PhD

Daniel was born in Olathe, Kansas, a suburb of Kansas City, to Randy and Glenda Meeker. As the youngest (and often celebrated as the greatest) of five kids, Daniel grew up sharing in the interests of his siblings as well as developing many of his own. Daniel was very active in sports from a young age, often playing for teams coached by his father.

At a young age, he developed a keen interest in biology and science, likely contributing to his career decisions later in life.

Daniel began to develop an interest in medicine, and specifically orthopedic surgery, after he sustained a knee injury while playing soccer in high school and underwent multiple knee surgeries.

After graduating high school, Daniel left his home state of Kansas to attend Harding University in Searcy, Arkansas. While at Harding, he majored in Biochemistry and Molecular Biology and further fostered his interests in medicine and biomedical research, completing multiple summer undergraduate research fellowships.

After graduating from Harding, Daniel matriculated into the M.D./Ph.D. program at the University of Arkansas for Medical Sciences. While at UAMS, he completed his first two years of medical school before beginning his graduate research in the laboratory of Mark Smeltzer, Ph.D. studying Staphylococcus aureus, biofilms, and implant-associated infections. His primary thesis work explored the use of novel nanotechnology-based approaches for the treatment of implant- associated orthopedic infections. This research from the Smeltzer lab represented an emerging field within infectious disease and resulted in a number of peer-reviewed publications, invited podium presentations, and committee positions.

Upon his return to medical school, Daniel continued to develop an interest in orthopedics and ultimately matched into residency at the University of Iowa. While at Iowa, he has continued his research interests in basic science biofilm work, obtaining an OREF grant and partnering with the laboratory of Eric Nuxoll, Ph.D. His senior research project represents a continuation of his graduate work, evaluating novel approaches to treating orthopedic implant-associated infections, including the use of nanotechnology. These experiences have enabled him to pursue an Adult Reconstructive – Lower Extremity Surgery fellowship at the Mayo Clinic following residency and ultimately provide him with the foundation for a career as a physician-scientist in academia.

Daniel would like to acknowledge all the amazing support that he has had throughout this process including his family, friends, co-residents, and mentors along the way. He is looking forward to continuing his training for his chief year at the University of Iowa before continuing toward his ultimate goal of becoming an academic, fellowship-trained arthroplasty surgeon.

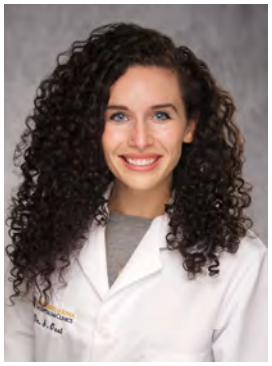
Edward Rojas, MD

Edward was born and raised in the Los Angeles, CA area to Octavio and Estela. He is the middle child of three, with his older sister, Leslie, and a younger brother, Daniel. Edward spent his childhood pestering his parents asking "why" about anything and everything around him. Although at times annoying, this thirst for knowledge, and persistent need to understand everything around him, helped him excel in and out of the classroom. When he was not in school, he could be found working on cars with his dad. His work ethic and love for learning helped him graduate with distinction from Warren High School and earned him a scholarship to the University of California, Berkeley.

Edward became interested in healthcare when he was in first grade after his brother lodged a calculator battery in his frontal sinus requiring surgical removal. Witnessing his father's profound gratitude towards the treating surgeon ignited Edward's desire to serve others in a similar capacity and set him on his path towards pursuing a career in medicine. During his undergraduate years, Edward remained deeply involved in healthcare volunteering, solidifying his commitment to the field. Thanks to his continued work during and after undergrad, he was fortunate enough to earn the Dean's and Wall Scholarship to attend the University of Iowa Carver College of Medicine.

While in medical school, Edward delved into research, collaborating with several faculty within the orthopedic department. His passion for research flourished during a gap year working in the orthopedic department under the mentorship of Dr. Chris Anthony. Edward worked on projects ranging from patient reported outcome measures to healthcare costs, pain/narcotic utilization, and even surgical education evaluation. His dedication to clinical duties, academia, and the mentorship from both residents and staff helped him stay at Iowa for residency. Throughout his residency, he's remained engaged in research and developed his passion for education. Looking ahead, Edward will be completing an Adult Hip and Knee Reconstruction Fellowship at Colorado Joint Replacement and is thrilled to return to Iowa as faculty afterward. He looks forward to establishing his academic practice as part of the Adult Hip and Knee Reconstruction team along with his mentors, and hopes to make meaningful contributions to patient care, research, and resident education.

Edward extends his heartfelt gratitude to his family, especially his wife Kayla, for their unwavering support. He is also incredibly thankful for the invaluable mentorship he has received from UIHC staff, and faculty members, including Drs. Elkins, Karam, Kowalski, Marsh, Pugely, Weinstein, and countless others, whose guidance has been instrumental in shaping his journey thus far. He hopes to continue making them proud of their belief in him throughout his career.



Sarah Ryan, MD

Sarah was born in Chicago, Illinois to parents Daniel and Ana Ryan and grew up alongside her younger brother Ian. As a child, Sarah enjoyed participating in school and playing sports. Her early interest for both athletics and medicine was greatly influenced by her mother, a former division-1 collegiate diver turned pathologist. Sarah was involved in competitive gymnastics as a child and when not in school or following her mother around the lab, she could usually be found in the gym.

The Ryan family later relocated to rural southern Iowa where Sarah attended Ottumwa High School and graduated as valedictorian. She also participated in volleyball and Track & Field throughout her high school years.

Sarah attended college at the University of Iowa where she obtained a degree in Microbiology and competed in Track & Field. She was a Big 10 Distinguished Scholar from 2012-2014 and earned marks on the all-time top 10 performance lists in the pentathlon, heptathlon, and long jump. As an undergraduate, she maintained a passion for service and served as a Spanish-English interpreter at the Iowa City Free Medical clinic.

She then continued her education in Iowa City, attending medical school at the University of Iowa Carver College of Medicine. She developed interests in anatomy and pathology and contributed to curriculum development and tutoring within these areas. She then spent a year in the UIHC Department of Pathology between years 2 and 3 of medical school and considered careers in both Pathology and OB/GYN before ultimately finding a passion in Orthopedics, and she was thrilled to match into residency at the University of Iowa.

During medical school and residency, Sarah's research focused on socioeconomic determinants of healthcare and, more recently, body composition parameters in the spine surgery population. In her free time, she enjoys playing the piano, weightlifting, rock climbing, and spending time with friends and family. Sarah will be completing a spine fellowship at the University of Wisconsin following residency.

Sarah is thankful to her parents for their unconditional love, to her brother Ian for the continued support, weekly pasta nights, and frequent venting sessions, and to her five classmates who have supported her through the highs and lows of residency. She is grateful to the staff at UIHC that have invested in her surgical education and personal growth, and particularly to Drs. Pugely, Igram, and Olinger for their constant teaching and encouragement.

Brady R. Wilkinson, MD

Brady was born and raised in Provo, Utah. He is the son of Richard and Tami Wilkinson. He attended Provo High School where he developed a love for anatomy and science. Following high school, he received a Bachelor of Science degree in Zoology from Brigham Young University. Between his first and second year of college he decided to serve a 2-year proselyting mission for the Church of Jesus Christ of Latter-day Saints, in Denmark. These were formative years when he not only learned the Danish language, but reinforced characteristics taught by his parents including hard work, diligence, and perseverance. While in college he was given the opportunity to attend Stringham School of Real Estate where he received his residential real estate license. He worked for Coldwell Banker Residential Brokerage and kept his license active for the next 10 years.

Despite his interest in real estate, he followed his desire to attend medical school at the University of Utah. He was particularly interested in trauma which led him to a career in emergency medicine. He never completed an orthopedic rotation while in medical school. He was active in student government, advocacy and was a member of the admissions selection committee. He received several scholarships and was the Lowell S. Glasgow research award recipient. Following medical school he completed an emergency medicine residency at Michigan State University/ Grand Rapids Medical Education Partners. During his intern year he completed his first rotation in orthopedic surgery. This was the beginning of his interest in orthopedic surgery but would not become a reality for another decade.

After completing his first residency, he joined Utah Emergency Physicians covering multiple emergency departments in Salt Lake City for Intermountain Healthcare. The ER provided a platform to see the breadth of medicine and home in on his true interest, orthopedics. He also experienced first-hand the adverse effects of opioid pain medications igniting his research interest. Finding himself limited he embarked on a several years journey which resulted in a match in orthopedics at the University of Iowa. He does not regret and will always remain grateful for his training in the ER. In fact, his love for the trauma bay was influential in his decision to pursue an orthopedic trauma fellowship at the R. Adams Cowley Shock Trauma Center.

Brady is thankful to his orthopedic mentors, including Dr. Weinstein, Dr. Marsh, and Dr. Karam for being willing to look outside of the traditional mold for an orthopedic resident and take a chance on the unknown. Without them, he would have likely remained an unmatched orthopedic candidate, and his orthopedic career would have never become a reality. He is also grateful to his brother, Brandon Wilkinson, who helped pave the path for his orthopedic career and to his co-residents who will remain life-long friends and colleagues. And finally, to his wife Chay and their four children (Kesly, Brock, Jayde and Capri) who supported him all along the way.

2025 GRADUATING FELLOWS

Mahmoud Ayche, MD

Mahmoud Ayche is currently the Musculoskeletal Oncology Fellow at the University of Iowa. He earned his undergraduate degree in Biology and his medical degree from the Lebanese University. He completed his orthopedic residency at the Lebanese University in Lebanon and Grenoble University in France.

Following his training, Dr. Ayche moved to Dubai, UAE, where he practiced general orthopedics for two years before joining the University of Iowa for his fellowship. Upon completion, he plans to return to the UAE and practice orthopedic oncology both there and in his home country, Lebanon.

Dr. Ayche extends his sincere thanks to Dr. Miller and every member of the orthopedic oncology team for their unwavering support, mentorship, and training. He is also deeply grateful to the entire orthopedic department for welcoming him with open arms.

John Green, MD

John is the current Adult Reconstruction fellow at the University of Iowa. He received his undergraduate degree in Biology from Gonzaga University. He went on to complete his medical school and residency training at Saint Louis University. He has a wife, Margaret, and two daughters, Dottie and Charlotte. Next year, he will be moving to Omaha, Nebraska to start an academic practice associated with Creighton University.

John is thankful for the opportunity to work with the incredible arthroplasty faculty here at the University of Iowa. He would like to thank Drs. Elkins, Noiseux, and Vanorny for dedicating their time and effort to provide mentorship and training over the course of the year. He looks forward to applying this training to his future practice and will always hold a special place in his heart for his year here.

Jonathan Dawkins, MD

Jonathan is the current Orthopedic Sports Medicine fellow at the University of Iowa. He received his undergraduate degree in Biochemistry at Texas A&M University. He then went to medical school at Texas A&M Health Science Center prior to completing residency in orthopedic surgery in Dallas at Baylor University Medical Center. He then came to Iowa for fellowship. He is joined by his wife (Melissa), dog (Olaf), and cat (Rose). He will be returning to Texas after fellowship to join a practice in Cypress.

Jonathan is sincerely grateful for all of the guidance, mentorship, time, and effort that all of the attendings and staff have put into his training this year. It has been a year of tremendous growth and too many opportunities to count, from the OR to the clinic setting to Iowa Hawkeye sports coverage. Thank you all for the amazing experience and go hawks!

John Massoud, MD

John is the current Foot and Ankle fellow at University of Iowa. He grew up in Luxor, Egypt, a famous city with its Ancient Egyptian Monuments. He earned his medical degree with honors from Ain Shams University, Cairo, Egypt. He did his orthopedic surgery residency training and completed a Master's Degree in Orthopedic Surgery. After his residency, he moved to Oman, where he practiced in Khoula Hospital, the only Level I trauma hospital in Oman and the educational center recognized by the Royal Society of Orthopedics. He was awarded a fellowship in Germany from the SICOT International Society for his dedication and hard work.

Driven by his desire for excellence and research, he moved to the USA with his wife and kids. He completed a Foot and Ankle Orthopedic fellowship at Cleveland Clinic, Ohio, and a Pediatric Orthopedic Fellowship at Massachusetts General Hospital-Harvard Medical School before starting his fellowship at the University of Iowa.

John is grateful for his year at University of Iowa with Dr. Femino and Dr. Chrea. He enjoyed the discussions at the Thursday foot and ankle conference, attending clinic, and operating in the OR. He is thankful for the great mentorship and support from the attendings, and the lovely and friendly environment from the whole team and department. The University of Iowa will be always remembered as a leading institute in research and training. Iowa will have a place in my heart and my family's memories forever.

Richard VanTienderen, DO

Richard VanTienderen, DO is the current Orthopedic Sports Medicine research fellow at the University of Iowa. After obtaining his bachelor's degree from the University of Utah, he went on to medical school at the Arizona College of Osteopathic Medicine. He then completed his Orthopedic residency at the William Beaumont Army Medical Center/Texas Tech University Health Sciences Center program in El Paso, TX. Following residency, he was stationed for four years at Irwin Army Community Hospital, Fort Riley, KS. During that time, he was deployed with the 402nd FST to CL Dwyer, Afghanistan in support of Operation Freedom's Sentinel, spent 2 years as Chief of Orthopedics and 1 year as Director, Surgical Services. He is joined by his wife, Aubree, and three children, Claire, Coen and Lily.

Richard would like to thank Drs. Wolf, Bollier, Westermann, and Duchman for their support and mentorship. He would also like to thank the whole Orthopedic department for welcoming him with open arms. He is looking forward to an additional year of training at the University of Iowa as the 2025-2026 Orthopedic Sports Medicine clinical fellow.

NEW ORTHOPEDIC FACULTY

Joshua M. Eisenberg, MD

Dr. Joshua Eisenberg grew up in Spring Grove, IL. He completed his undergraduate education at Augustana College and competed in Track and Field. He continued his medical education at Loyola University of Chicago and then completed his orthopedic residency at the University of Iowa. Following residency he traveled to Atlanta, GA where he had the opportunity to continue his training at the prestigious Emory University Orthopedic Spine fellowship. Upon completing fellowship, Dr. Eisenberg joined the orthopedic faculty at the University of Iowa in 2024. He lives in Solon, IA with his wife Taylor who is also a nurse at the North Liberty campus.

Kendall Keck, MD

Dr. Kendall Keck grew up in Carlisle, IA. He completed his biomedical engineering degree and medical school here in Iowa City. He then went on to complete his general surgery training at UIHC, including two years as a T32 research fellow. He continued his training at UIHC for another three years in the Plastic Surgery Fellowship Program, where he further developed his interest in hand and reconstructive surgery.

Following this fellowship, he left UIHC for a year to attend Southern Illinois University in Springfield, IL, where he completed a fellowship in Hand and Microsurgery. Dr. Keck joined the orthopedic faculty at the University of Iowa in August 2024. He lives in Coralville, IA, with his wife of 11 years, Ceric, and their two daughters, Ayla (9) and Talia (6).

Dr. Keck enjoys all aspects of hand and upper extremity care, with a special interest in limb salvage and reconstruction. His research interests include lower extremity free flap reconstruction and salvage, CMC biomechanics, and device development.

Jill Scholz, DPM

Dr. Jill Scholz is an instructor in the Department of Orthopedics and Rehabilitation at the University of Iowa, joining the foot and ankle team in March 2025. Prior to this, she was in private practice in Coralville and a member of Mercy Iowa City medical staff for 28 years. She went to college at Iowa State University and got her Doctorate in Podiatric Medicine at Des Moines University. Post graduate training was done at University of Illinois at Chicago and Mercy Iowa City. Her areas of interest include the at risk foot, wound medicine and general podiatry. She is a past Board Chair of the Iowa Podiatric Medical Examiners and is active in the American Association of Women Podiatrists and the Iowa City Free Medical Clinic. As the daughter of a University of Iowa physician, she grew up in Iowa City. Dr. Scholz lives in Iowa City with her husband Dave. They have three adult children who live in various places around the country.

Dallas Vanorny, MD, PhD

Dr. Dallas Vanorny is a native of Cedar Rapids, IA. He graduated from the University of Iowa before completing his PhD at Northwestern University. He then went on to complete his medical education at the University of Illinois College of Medicine. He completed his residency training in orthopedic surgery at Baylor College of Medicine, and his fellowship training in adult hip and knee reconstruction at the University of Pittsburgh Medical Center. He joined the staff at the University of Iowa Hospitals and Clinics in August 2023 as a Clinical Assistant Professor. He specializes in complex primary and revision hip and knee arthroplasty. He uses the direct anterior approach for primary and revision hip replacements and uses robotic technology for total and partial knee replacements. His research is focused on outcomes in joint arthroplasty. He lives in North Liberty, IA with his wife Lindsey and their two sons Andrew and James.

The 2025 Michael Bonfiglio Award for Student Research in Orthopedic Surgery

The 2025 Mary Van Zee Award for Musculoskeletal Research

Hannah Zeller, M4
Michael Bonfiglio Recipient

Jared Hill, M2
Mary Van Zee Recipient

The University of Iowa Department of Orthopedics and Rehabilitation, along with the Iowa Orthopaedic Society, sponsors two research awards involving medical students.

The Michael Bonfiglio Award originated in 1988 and is named in honor of Dr. Bonfiglio who had an avid interest in students, teaching, and research. The award is given annually and consists of a certificate and a $1000 stipend. It is awarded to a senior medical student in the Carver College of Medicine who has done outstanding orthopedic research during his or her tenure as a medical student. The student has an advisor in the Orthopedic Department. However, the student must have played a major role in the design, implementation, and analysis of the project. He or she must be able to defend the manuscript in a public forum. The research project may have been either a clinical or basic science project, and each study is judged based on originality and scientific merit. The winner presents their work at the spring meeting of the Iowa Orthopaedic Society as well as at a conference in the Department of Orthopedics and Rehabilitation. This award is supported through the generosity of the Iowa Orthopaedic Society.

The Mary Van Zee Award for Musculoskeletal Research is an award for a student in the Carver College of Medicine who completes a research project involving orthopedic surgery during one of his or her first three years of medical school. The award consists of a $500 stipend, which is intended for the student purchase of books. The student must provide an abstract and a progress report on the ongoing research. The aim is to stimulate research in the field of orthopedic surgery and musculoskeletal problems. In addition, the student presents his or her work at the spring meeting of the Iowa Orthopaedic Society and at a conference in the Department of Orthopedics and Rehabilitation. This award is supported through the generosity of the Iowa Orthopaedic Society.

This year the selection committee consisted of Drs. Charles R. Clark, Joseph A. Buckwalter IV, Heather Kowalski and Benjamin Miller. They recommended that Hannah Zeller, M4, receive the 2025 Michael Bonfiglio Student Research Award. Hannah's award was based on her project, "Defining Normal Joint Space Width Values of Essential Foot and Ankle Joints." Her advisor was Don Anderson.

The selection committee recommended that the 2025 Mary Van Zee Award for Musculoskeletal Research be given to Jared Hill, M2, for his research titled "Surgical Training Reimagined: A Comparative Assessment of OR Evaluation Methods." His advisor was Dr. Matt Karam.

The Michael Bonfiglio Award and the Mary Van Zee Award for Musculoskeletal Research are very prestigious, recognizing student research on the musculoskeletal system. These awards have indeed attained their goal of stimulating such research and have produced many fine projects over the years.

-Heather Kowalski, MD
Director of Orthopedic Medical Student Education

GENDER DIFFERENCES IN MEDICAL STUDENT INTEREST IN ARTHROPLASTY

Annabelle P. Davey, MD[1]; Lisa M. Tamburini, MD[1]; James C. Messina, MD[1]; Ian Wellington, MD[1]; Francine Zeng, MD[1]; Olga Solovyova, MD[1]

ABSTRACT

Background: The majority of orthopaedic residents match into fellowship in the subspecialty they are most interested in at the start of residency, however there is a lack of understanding of medical student interest in orthopaedic subspecialties. Our objective was to determine interest in arthroplasty among medical students interested in orthopaedic surgery, and to identify factors contributing to student interest and disinterest..

Methods: An anonymous online survey was developed and distributed to medical students interested in orthopaedic surgery at 23 United States allopathic and osteopathic medical schools through their school administrators. Descriptive statistics were calculated, and a Fisher's exact test was used for categorical variables.

Results: 183 medical students (56% female) completed the survey for an estimated 29% response rate. Significantly fewer female medical students were interested in adult reconstruction compared to their male counterparts (10% versus 29%, p = 0.004). The most commonly identified factors contributing to interest by female students were interest in the subject matter (100%) and patient population (70%), while male students most commonly identified clinical experience (74%) and presence of a mentor (63%). Significantly fewer female medical students received the suggestion to pursue arthroplasty compared to males (0% versus 11%, p = 0.002).

Conclusion: Female medical students are significantly less interested in arthroplasty and receive significantly less encouragement to consider arthroplasty than their male counterparts. Factors influencing both interest and disinterest in orthopaedic subspecialties differ between male and female medical students.

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Level of Evidence: V

Keywords: gender, diversity, equity, medical education

INTRODUCTION

Considerable progress has been made in recent years to increase gender diversity in orthopaedic surgery.[4,8,9,18] However, there still remains a large disparity between the proportion of male and female orthopaedic surgeons, with women making up just 6.5% of practicing orthopaedic surgeons.[2,8,18]

The lack of gender diversity becomes more pronounced when orthopaedics is broken down by subspecialty, with arthroplasty remaining among the most male-dominated with women accounting for only 3% of practicing arthroplasty surgeons.[2,7,8] Additionally, as the proportion of women in orthopaedics overall has increased, there has been no corresponding change in the proportion of women in arthroplasty.[2]

There have been efforts to identify factors influencing resident subspecialty choice to address this gender disparity. Prior research has indicated that over 50% of residents ultimately pursue the subspecialty that they are most interested in at the start of residency, suggesting that medical student perceptions of orthopaedic subspecialties have a significant implication on future career trajectory.[19] However, there has been limited research regarding medical student interest in orthopaedic subspecialties and what influences these preferences. The goal of the present study was to characterize medical student interest in orthopaedic subspecialties, and to determine factors contributing to interest.

METHODS

After obtaining approval of institutional review board exempt status (23X-112-1), publicly available medical school administrative email addresses were collected for each United States allopathic and osteopathic medical school. Emails were sent to each medical school with the request to participate in the present study. An anonymous survey was developed (Appendix A). Schools agreeing to participate were asked to distribute the survey to students at their institution who were interested in orthopaedic surgery.

Questions asked in the survey included basic demographic information and year in medical school. Respondents were asked to select if they were interested in, disinterested in, or not sure of each of the orthopaedic subspecialties (adult reconstruction/arthroplasty, foot and ankle, hand, pediatrics, shoulder and elbow, spine, sports, trauma, and tumor/oncology). For each subspecialty of interest or disinterest, they were asked to select contributing factors and the most important factor. Respondents were also asked if they had ever received the suggestion that they should or should not consider any of the orthopaedic subspecialties, and to select what reasons had been given for this suggestion.

Research Electronic Data Capture (REDCap) (version 13.1.27; Vanderbilt University, Nashville, TN, USA), which is hosted at the authors' institution and approved by the institutional review board and information security, was used to collect study data. The survey remained open for a total of 8 weeks, after which time responses stopped being accepted.

Response rate was estimated based on the number of applicants to orthopaedic residency in 2022. Descriptive statistics were calculated. Fisher's exact test with 2x2 contingency tables was used to compare proportions.

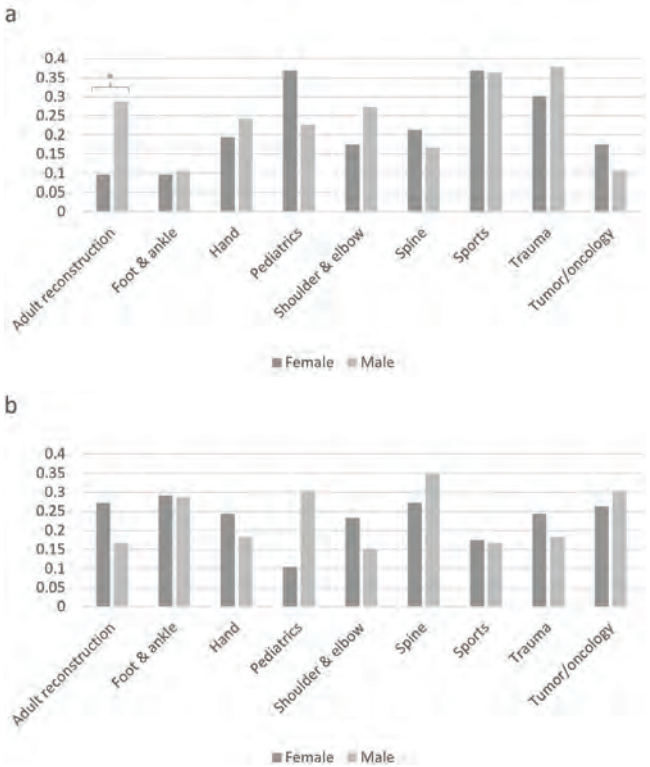

Figure 1A to 1B. Proportion of female and male survey respondents (1A) interested in each subspecialty and (1B) disinterested in each subspecialty.

RESULTS

214 US allopathic and osteopathic medical schools were initially contacted. 23 schools agreed to participate. Participating schools included 11 public and 12 private institutions and were felt to represent good geographic variability (26% Northeast, 13% Midwest, 26% Southeast, 13% Southwest, 13% West).

183 responses were collected. The estimated number of medical students interested in orthopaedic surgery across all four years of medical education was 5880, based on the number of orthopaedic surgery residency applicants in 2022.[1] Given the participation rate of 11% of medical schools, our estimated response rate was 29%. 58.9% of survey respondents were female. 65%, 17.5%, and 4.4% were white, Asian, and Black or African American, respectively. 9.8% were Hispanic or Latinx. Survey respondents were in all years of medical school, with 35%, 27.3%, 21.3%, and 11.5% in first, second, third, and fourth years, respectively.

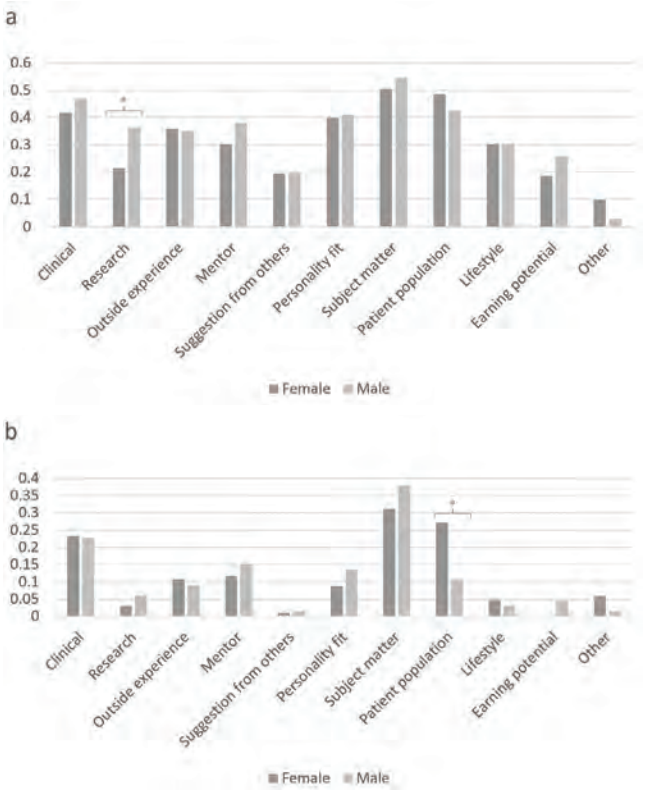

Figure 2A to 2B. (2A) Factors contributing to female and male survey respondents' interest in any subspecialty and (2B) factors identified by female and male respondents as most important in contributing to subspecialty interest, including clinical experience, research experience, prior experience with the subspecialty outside of work in the medical field, presence of a mentor in the subspecialty, suggestion of others to consider the subspecialty, perceived personality fit, interest in the subject matter, interest in working with the specific patient population, lifestyle factors, earning potential, and other factors.

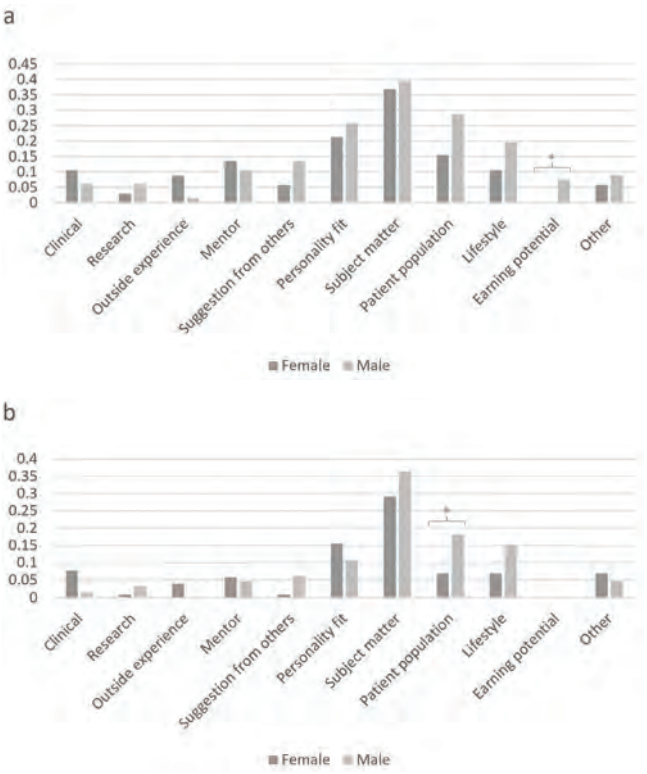

Figure 3A to 3B. (3A) Factors contributing to female and male survey respondents' disinterest in any subspecialty and (3B) factors identified by female and male respondents as most important in contributing to subspecialty disinterest, including clinical experience, research experience, prior experience with the subspecialty outside of work in the medical field, absence of a mentor in the subspecialty, suggestion of others to avoid the subspecialty, perceived lack of personality fit, disinterest in the subject matter, disinterest in working with the specific patient population, lifestyle factors, earning potential, and other factors.

Figure 1 details medical student subspecialty interest and disinterest based on gender. The only significant difference in interest was in adult reconstruction/arthroplasty (9.7% female versus 28.8% male, p = 0.0029). There was a trend towards greater proportion of female medical students interested in pediatrics, although this did not reach statistical significance (36.9% female versus 22.7% male, p = 0.0623). There were no significant differences in subspecialty disinterest based on gender.

Factors contributing to interest and disinterest based on gender are reported in Figure 2 and Figure 3, respectively. Subject matter was most frequently selected as a factor contributing to interest or disinterest, and as the most important factor contributing to interest or disinterest among both male and female respondents. A significantly higher proportion of male respondents selected research experience as a factor contributing to interest (21.4% female versus 36.4% male, p = 0.0355). Patient population was selected by significantly more female respondents as the most important factor contributing to interest (27.2% female versus 10.6% male, p = 0.0111),

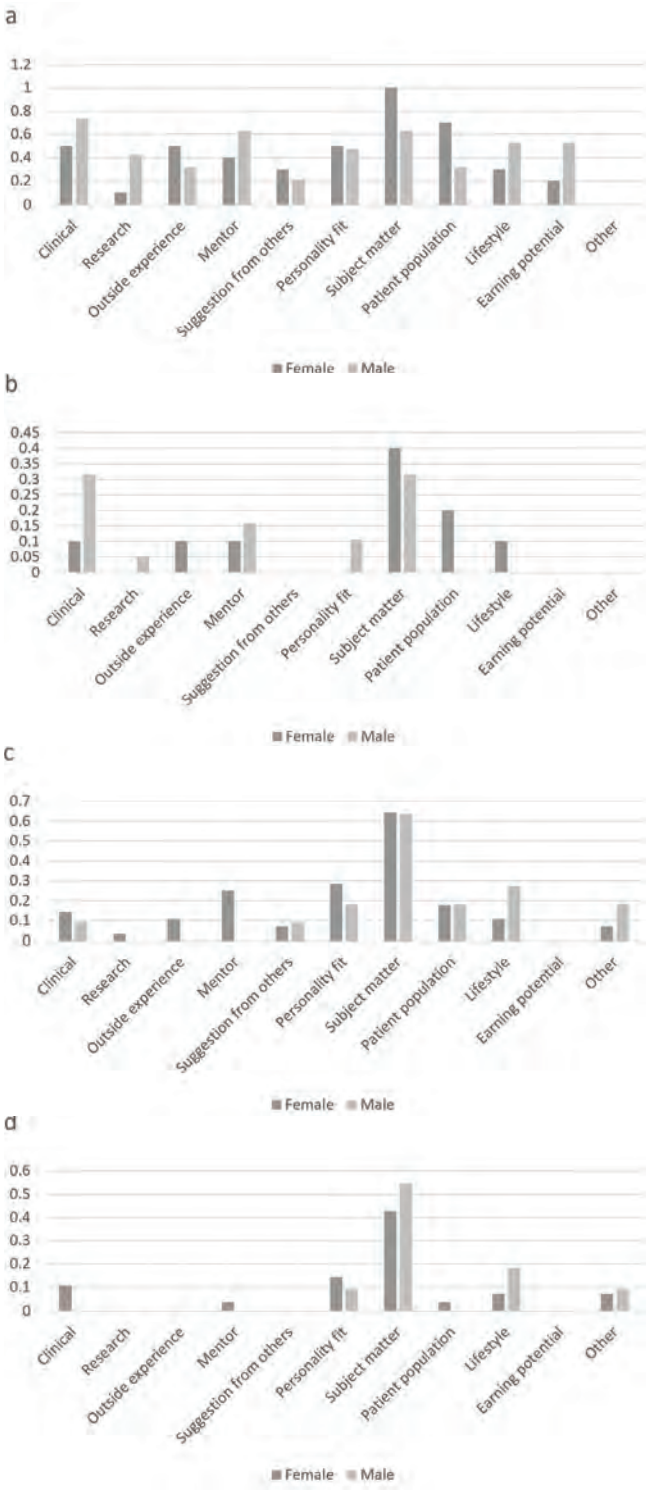

Figure 4A to 4D. (4A) Factors contributing to female and male survey respondents' interest in arthroplasty, (4B) factors identified by female and male respondents as most important in contributing to interest in arthroplasty, (4C) factors contributing to female and male respondents' disinterest in arthroplasty, and (4D) factors identified by female and male respondents as most important contributing to disinterest in arthroplasty, including clinical experience, research experience, prior experience with the subspecialty outside of work in the medical field, presence of a mentor in the subspecialty, suggestion of others to consider the subspecialty, perceived personality fit, interest in the subject matter, interest in working with the specific patient population, lifestyle factors, earning potential, and other factors.

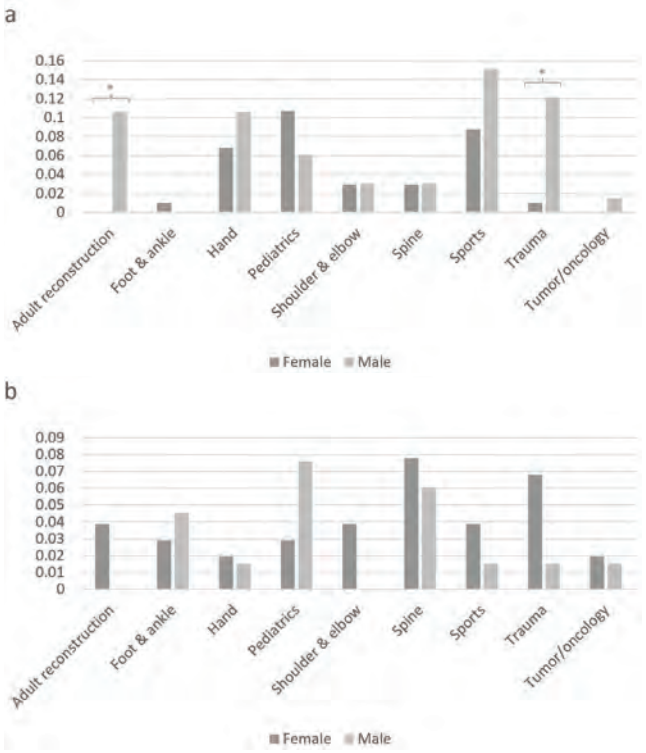

Figure 5A to 5B. Proportion of female and male respondents encouraged to (5A) pursue or (5B) avoid a subspecialty.

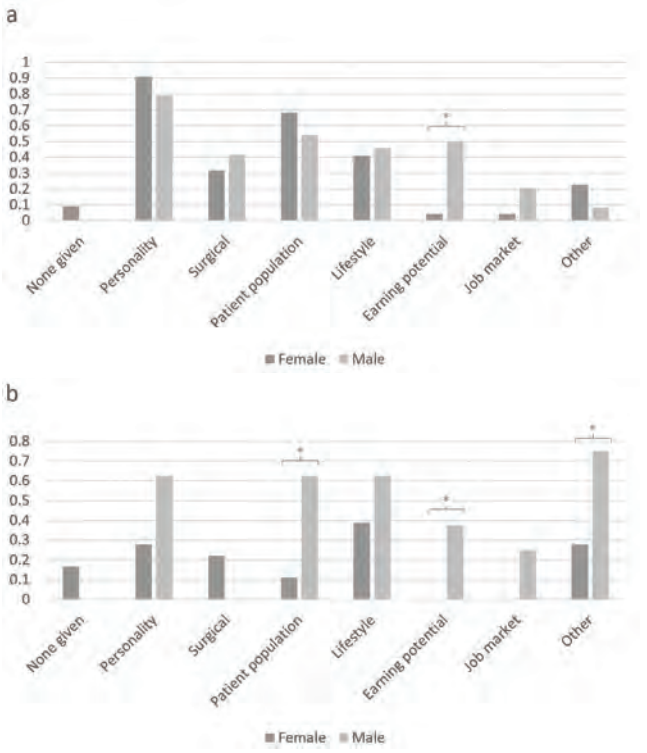

Figure 6A to 6B. Reasons given to female and male respondents to (6A) pursue or (6B) avoid a subspecialty, including no reason given, personality fit, ability, or lack thereof, to perform surgical procedures, patient population, lifestyle factors, earning potential, job market, or other factors.

and by significantly more male respondents as the most important factor contributing to disinterest (6.8% female versus 18.2% male, p = 0.0266). Earning potential contributed to disinterest in significantly more male respondents (0% female versus 7.6% male, p = 0.0083).

Factors considered by respondents interested and disinterested in arthroplasty are presented in Figure 4. The most commonly selected factors contributing to interest by female respondents were subject matter (100%) and patient population (70%), while male respondents most frequently selected clinical experience (73.7%) and presence of a mentor (63.2%). There was no significant difference in number of female and male respondents selecting any factor as contributing to interest or disinterest in arthroplasty.

Significantly fewer female respondents reported having received the suggestion to pursue any orthopaedic subspecialty (21.4% female versus 36.4% male, p = 0.0355), adult reconstruction (0% female versus 10.6% male, p = 0.0011), or trauma (1% female versus 12.1% male, p = 0.0025) (Figure 5). There were no significant differences in respondents told to avoid any subspecialties (Figure 5). Reasons respondents were given to pursue or not pursue any subspecialty are presented in Figure 6. Of respondents who had been told to consider any subspecialty, significantly more male respondents had received the suggestion to consider earning potential (4.5% female versus 50% male, p = 0.0008). Among respondents who had been told to avoid any subspecialty, significantly more male respondents had received the suggestion to consider patient population (27.8% female versus 62.5% male, p = 0.0138), earning potential (0% female versus 37.5% male, p = 0.0215), and other factors not asked about in our survey (27.8% female versus 75% male, p = 0.0384).

DISCUSSION

Despite efforts to increase gender diversity, females currently make up just 14% of current orthopaedic residents and 6.5% of practicing orthopaedic surgeons, with a projected 326 years required to reach gender parity at the current growth rate.[2,8] This disparity is particularly notable in arthroplasty despite increases in the number of women pursuing adult reconstruction fellowship in recent years.[4] As of 2018, women make up just 2.6% of the American Association of Hip and Knee Society, 0.6% of the Hip Society, and 0.5% of the Knee society – the lowest proportion of female membership of any national subspecialty society.[8] The majority of orthopaedic residents ultimately pursue a fellowship in the subspecialty

area that they identified as being of interest at the beginning of residency.[12,19] The finding from this study that female medical students are less interested in adult reconstruction suggests that factors contributing to the gender disparity in arthroplasty are at play even before orthopaedic residency training begins.

Interest in the subject matter was the most important factor for survey respondents, both among students interested in adult reconstruction and among respondents as a whole. This is consistent with previous studies which have reported intellectual interest playing a major role in subspecialty preference among residents and in ultimate subspecialty choice.[5,10,12-15]

Mentorship has previously been identified as highly influential in medical student choice of orthopaedics, with the presence of female mentors increasing the number of female medical students interested in orthopaedic surgery.[9,17] Additionally, mentorship is a key factor in helping medical students match to orthopaedic residency, and in influencing career choices within orthopaedics.[3,6,10,15] However, in our study the presence of a mentor in arthroplasty was among the most commonly cited factors contributing to interest among men, but not among women. Similarly, a prior study of female orthopaedic surgeons found that influence of a mentor was not one of the major factors considered in subspecialty choice.[12] However, a different study surveying the same population of female orthopaedic surgeons in the same year found that presence of a strong mentor was one of the top-ranked factors cited as influencing subspecialty choice.[5] While it may be that mentors play less of a role in female orthopaedic surgeons' choice of subspecialty, it may also be due to decreased availability of mentorship for women. There are fewer female role models available in arthroplasty, and women in medicine tend to face more challenges than their male counterparts in finding mentorship regardless of gender of the mentor.[11,16,20]

Previous studies have suggested that medical student specialty interest is largely related to experiences during medical school. Female medical students who are exposed to orthopaedic surgery – either through clerkship rotations or through programming such as the Perry Initiative – pursue orthopaedic residency at an increased rate.[9,17] This suggests that early exposure and specific encouragement during medical school has the potential lead to more women pursuing orthopaedic surgery. Our finding that fewer female medical students had received the suggestion to pursue adult reconstruction can be seen as an opportunity – female medical students are less interested, but they have also received less encouragement. Active encouragement of female medical students to consider arthroplasty could spark an interest that persists throughout residency training and onwards.

There are considerable limitations to this study. The voluntary nature of an anonymous survey increases the possibility of sampling and response bias. Additionally, the demographic makeup of survey responders was different from that of orthopaedic applicants, and therefore the survey responders may not be a representative sample of medical students interested in orthopaedic surgery. Nonbinary students were not considered in the analysis due to low number of respondents, however it is important to note that these students should not be overlooked. Despite these limitations, we believe this study provides insight into the factors that influence the complicated process of choosing a subspecialty.

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APPENDIX A. Anonymous Survey

Demographic information		
What year of medical school are you currently in	1. 1 2. 2 3. 3	4. 4 5. Research year
What is your gender identity	1. Female 2. Male 3. Nonbinary	
What is your race	1. American Indian or Alaska Native 2. Asian 3. Black or African American 4. Native Hawaiian or other Pacific Islander	5. White 6. Other 7. Prefer not to say
What is your ethnicity	1. Hispanic or Latinx 2. Not Hispanic or Latinx 3. Prefer not to say	
Subspecialty interest		
Please indicate your interest in each of the following subspecialties (interested, not interested, unsure/not enough exposure or information)	1. Adult reconstruction/ arthroplasty 2. Foot and ankle 3. Hand 4. Pediatrics 5. Shoulder and elbow	6. Spine 7. Sports 8. Trauma 9. Tumor/Oncology
	(For each subspecialty indicated as "interested") Did any of the following factors influence your interest	1. Positive experience with the subspecialty through clinical experience 2. Positive experience with the subspecialty through research 3. Positive prior experiences outside of work in the medical field (e.g. as a patient, through a family member, etc.) 4. Presence of a mentor in the subspecialty 5. Suggestion from others to consider the subspecialty 6. Personality fit within the subspecialty 7. Interest in the subject matter 8. Interest in caring for the specific patient population 9. Lifestyle factors 10. Earning potential
	(For each subspecialty indicated as "interested") Which factor is the most important	1. Positive experience with the subspecialty through clinical experience 2. Positive experience with the subspecialty through research 3. Positive prior experiences outside of work in the medical field (e.g. as a patient, through a family member, etc.) 4. Presence of a mentor in the subspecialty 5. Suggestion from others to consider the subspecialty 6. Personality fit within the subspecialty 7. Interest in the subject matter 8. Interest in caring for the specific patient population 9. Lifestyle factors 10. Earning potential
	(For each subspecialty indicated as "not interested") Did any of the following factors influence your disinterest	1. Negative experience with the subspecialty through clinical experience 2. Negative experience with the subspecialty through research 3. Negative prior experiences outside of work in the medical field (e.g. as a patient, through a family member, etc.) 4. Absence of a mentor in the subspecialty 5. Suggestion from others to avoid the subspecialty 6. Lack of personality fit within the subspecialty 7. Lack of interest in the subject matter 8. Lack of interest in caring for the specific patient population 9. Lifestyle factors 10. Earning potential

	(For each subspecialty indicated as "not interested") Which factor is the most important	1. Negative experience with the subspecialty through clinical experience 2. Negative experience with the subspecialty through research 3. Negative prior experiences outside of work in the medical field (e.g. as a patient, through a family member, etc.) 4. Absence of a mentor in the subspecialty 5. Suggestion from others to avoid the subspecialty 6. Lack of personality fit within the subspecialty 7. Lack of interest in the subject matter 8. Lack of interest in caring for the specific patient population 9. Lifestyle factors 10. Earning potential
Advice from others		
Have you ever been told you should pursue a specific orthopaedic subspecialty (select all that apply)	1. Adult reconstruction/arthroplasty 2. Foot and ankle 3. Hand 4. Pediatrics 5. Shoulder and elbow	6. Spine 7. Sports 8. Trauma 9. Tumor/Oncology
	(For each subspecialty indicated) What reasons have been given that you should pursue this subspecialty	1. None given 2. Personality fit 3. Ability to perform surgical procedures 4. Patient population 5. Lifestyle factors 6. Earning potential 7. Job market 8. Other factors
Have you ever been told you should not pursue a specific orthopaedic subspecialty (select all that apply)	1. Adult reconstruction/arthroplasty 2. Foot and ankle 3. Hand 4. Pediatrics 5. Shoulder and elbow	6. Spine 7. Sports 8. Trauma 9. Tumor/Oncology
	(For each subspecialty indicated) What reasons have been given that you should not pursue this subspecialty	1. None given 2. Personality fit 3. Ability to perform surgical procedures 4. Patient population 5. Lifestyle factors 6. Earning potential 7. Job market 8. Other factors

FLUOROSCOPY IN HIP FRACTURE SURGERY: AN ANALYSIS OF RESIDENT UTILIZATION

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ABSTRACT

Background: Fluoroscopy is a critical tool in operative fracture reduction and fixation that residents begin using early in their careers. Judiciously managing fluoroscopy use in a procedure should be a focus in training. Total radiation dose is routinely recorded, but the distribution of fluoroscopy use throughout a procedure has not been well researched. This study aimed to determine how much fluoroscopy residents use in cephalomedullary nail (CMN) fixation of hip fractures. The study further sought to identify distinct tasks in the procedure that require more or less fluoroscopy.

Methods: Eighty-five CMN cases for which complete sets of fluoroscopic images were available were studied. Nine distinct tasks were analyzed in each case: set up, reduction, entry point navigation, reaming, nail placement, femoral head navigation, proximal screw placement, distal screw(s) placement, and final checks. Image use and time elapsed during tasks was recorded and attributed to the most-junior resident, who would typically be most hands-on at our institution for this procedure.

Results: Residents completed CMN placement in an average of 66.2 minutes (± 31.7) using an average of 185 images (± 113). Entry point navigation required the most time, 14 ± 10.8 minutes, and images, 49 ± 42. This was a significantly greater use of time ($t(121) = 4.96$, $p < 0.001$) and images ($t(133) = 3.45$, $p < 0.001$) than other tasks.

Conclusion: These data highlight the sheer volume of fluoroscopy used by residents in a common procedure. The sub-task analysis indicates that the freehand entry point navigation requires the greatest use of fluoroscopy and time, suggesting residents may benefit from additional laboratory-based training on this portion of the procedure.

Clinical Relevance: Orthopedic surgeons utilize fluoroscopy in a wide array of procedures. These findings emphasize the need to be intentional in the use of intra-operative fluoroscopy over a decades long career to prevent its potentially harmful effects. These results can also be used to improve education by creating objective metrics to evaluate resident fluoroscopy use and provide feedback.

Keywords: surgical training, fluoroscopy, education, skill assessment

INTRODUCTION

Hip fractures are common and present well-known treatment challenges–over 340,000 visits to emergency departments were reported for hip fracture in 2018.[1] Treating hip fractures constitutes a substantial portion of general orthopedic care and is considered a fundamental skill in orthopedic resident training. The Accreditation Council for Graduate Medical Education (ACGME) requires that orthopedic residents perform a minimum of 30 hip fracture cases prior to successful completion of residency.[2] However, simple participation in cases does not ensure skill acquisition. The ACGME and resident educators continue to look for strategies to enhance resident and fellow training through data-driven, competency-based educational curricula.[3]

Fluoroscopy is a critical tool used in the operative reduction and fixation of hip fractures that residents begin using early in their training. Our residency program offers a one-day skills session on the use of C-arm fluoroscopy in orthopedic care. Further education is gained from real world operative experience. The amount of radiation exposure associated with use of intra-operative fluoroscopy (IOF) is one objective and readily obtainable measurement of surgical skill with direct patient safety

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implications.[4] Investigating how residents use IOF is important because fluoroscopy use carries a variety of risks for both patient and practitioner. Both intensity and duration of exposure to ionizing radiation influences the risk of developing cancer later in life.[5] Increased IOF use correlates with increased procedure and anesthesia time. In certain procedures, patients in the top quintile of anesthesia duration had the highest rates of complications, including pulmonary, wound infection, and return to the OR for follow-up procedures.[6] More strategic and efficient use of IOF could aid in reducing total OR time and subsequent complications.

Cephalomedullary nail (CMN) fixation is a widely accepted surgical treatment for hip fractures. The reduction of a fracture and placement of a CMN consists of several steps that range in difficulty and require different skills and knowledge. IOF enables surgeons to see and confirm the 3D location of the fracture and either temporary or permanent implants. Our central hypothesis is that some surgical tasks require a greater number of fluoroscopic images and consume more time than other tasks. Using this analysis to identify subtasks with high fluoroscopy use we hope to improve surgical education and management for fluoroscopic guided procedures.

This study aims to understand when and how frequently residents obtain fluoroscopic images during CMN fixation of hip fractures. The intended outcome of this analysis is to produce a method for providing targeted, quantitative feedback that can help residents improve their efficiency and be mindful of their fluoroscopy use. This study reviews the use of fluoroscopy during CMN fixation of hip fractures to understand which tasks require the most IOF use and to explore the connection between orthopedic resident experience level and IOF use.

METHODS

A retrospective review of all cases in the University of Iowa Hospitals and Clinics' electronic medical record was conducted using the criteria listed in Table 1. All fluoroscopic images obtained during a case were collected for analysis. CMN fluoroscopic image sequences were subdivided into discrete, temporally adjacent subtasks in the order typical of this surgery: setup, fracture reduction, entry point wire navigation, reaming, nail placement, femoral head wire navigation, proximal screw placement, distal screw placement, and final checks (Figure 1). These subtasks each had clearly observable behaviors and discrete tools used, and the sequence was repeated based on standard surgical technique.[7]

Table 1. Specific Case Types Were Used in EPIC Surgical Case Report Search

Criteria	
Search Term	• Intramedullary Nail Femur • Intramedullary Rodding Femur AO Trochanteric Fixation Nail • Intramedullary Nail Femur Antegrade • Intramedullary Nail Femur Cephalomedullary Nail (CMN)
Search Date	12/1/2020-3/31/2023

Defining Sub-tasks

Each procedure began with image 1 in the sequence and ended with the last image focused on the femur. The first subtask, setup, included all images preceding the first manipulation of the fracture. The second subtask, reduction, began with the first fracture manipulation and ended before a starting K-wire was brought into frame at the incision site. The third task, entry point wire navigation, began with the first K-wire in the incision and included both the drill-driven wire and the flexible, button-tip wire. These two wire-driving tasks usually had a brief reaming step between them, but the reaming and wire navigation tasks were counted separately. It should be noted that between reduction and the entry point navigation there was a gap in time while the incision was being made above the hip. A standard 2-4 cm incision was made proximal to and in line with the femur in all cases. Since there was no IOF utilized during this step, this intermission was removed from the time count.

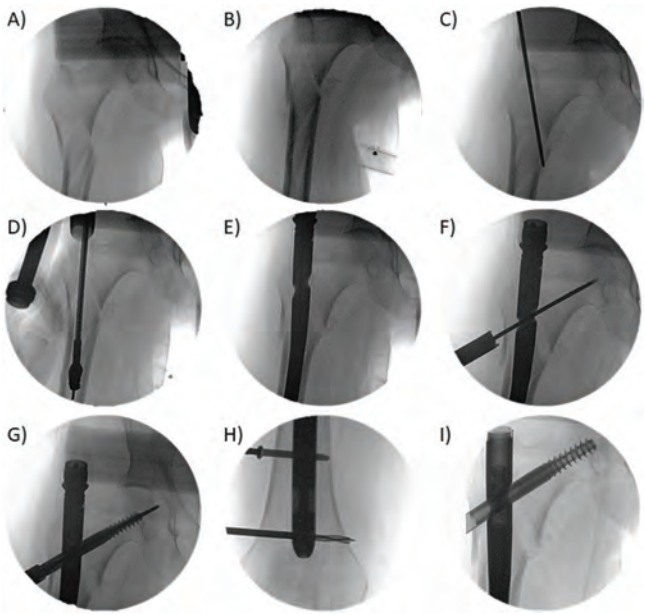

Figure 1A to 1I. Examples of starting images for each step in a CMN case. (1A) Setup, (1B) Reduction, (1C) Entry Point Navigation, (1D) Reaming, (1E) Nailing, (1F) Femoral Head Navigation, (1G) Proximal Screw, (1H) Distal Screw, (1I) Final Checks.

The fourth task, reaming, included a set of images for both the rigid wire and the flexible wire, counted together. The fifth task, nail placement, began when the CMN appeared in frame and continued until the nail was seated within the intramedullary canal. The sixth task was the femoral head navigation task, which began when the second K-wire appeared to place the proximal screw(s). The seventh task, the proximal screw, incorporated all reaming and images while a proximal locking screw or screws were being placed in the femoral head. The eighth task, distal locking screw, began with the shift of the C-arm away from the proximal femur and ended when the driver was removed from the screwhead. All remaining images were included in the ninth task, denoted simply as final checks, where surgeons inspected their work before completing the procedure.

Data Collection

The electronic medical record search performed using criteria listed in Table 1 yielded 293 surgeries (Figure 2). Although a "save all" images protocol had been put in place for CMN cases, this was sometimes overlooked or forgotten by OR surgeons/staff. Cases without full fluoroscopic image sequences, with unexpected jumps in time, or that lacked continuity were excluded from analysis. Ultimately, 85 CMN cases were identified and analyzed for this study.

For each procedure the following data were recorded: the attending physician, the resident(s) on the case, the date, and the procedure time. Patient-specific factors, such as BMI were not considered in this analysis, and all severities of intertrochanteric fractures were evaluated together. Images from each case were separated according to the task categories listed in Figure 1. The number of images and the duration of each task was recorded (Appendix 1 – 2). These data, displayed in Appendix 1-2, were separated based on resident experience level as expressed by the number of weeks into the residency program. Based on convention at our institution the most-junior resident navigates the wires and places the implant under the guidance of the attending or other, more experienced residents.

In the context of this study, total task duration was calculated between the first and last images taken from a case. Another measure of fluoroscopy time was the procedure summary page. This summary page reported the total run time of the C-arm at the end of the case in seconds, and the amount of radiation released in milligrays.

RESULTS

The average procedure duration (time from the first image to last) was 66.2 minutes (± 31.7) per case and ranged from 20 to 175 minutes. Figure 3 illustrates the duration of each subtask. The first entry point navigation task had the greatest average duration and second largest standard deviation, 14.1 minutes (± 10.8). The nail placement step had the second-highest average duration of 9.3 minutes (± 6.2), a significant difference ($t(133) = 3.45$, $p < 0.001$).

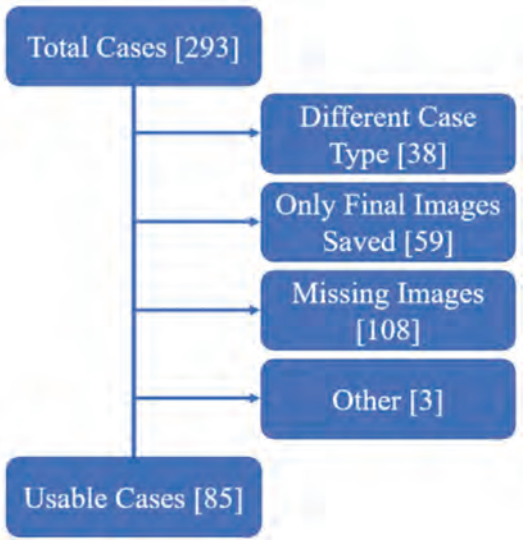

Figure 2. Intermedullary nail cases considered for the study and the frequency of different exclusion conditions.

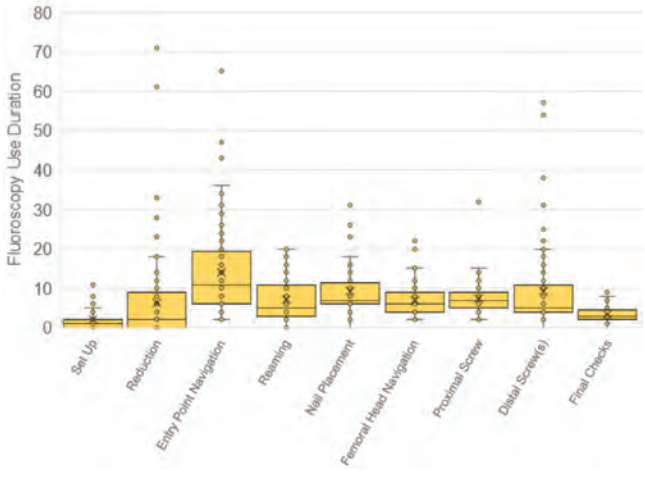

Figure 3. Box and whiskers plot of the duration of each subtask for each case. The boxes represent the second and third quartiles, the horizontal line in the box represents the median, the lines extend to the final point within 1.5 times the interquartile range. The circles represent individual performances.

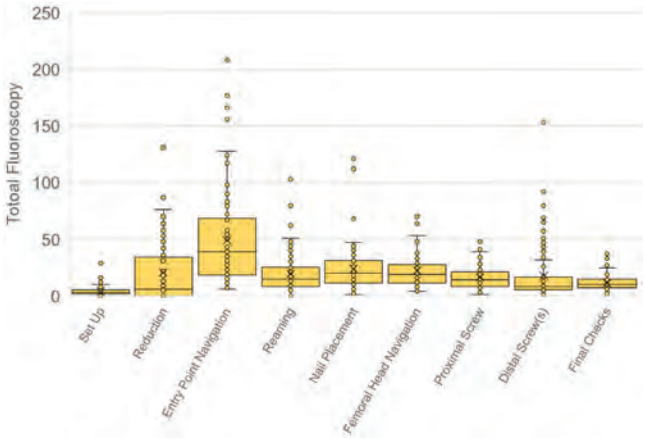

Figure 4. Box and whiskers plot of the fluoroscopic images in each subtask in each case.

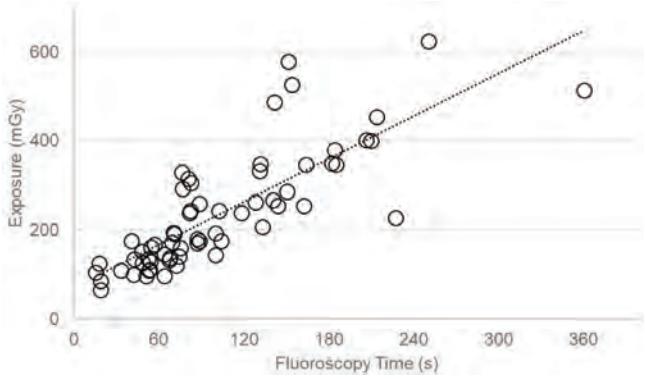

Figure 5. A correlation of the total C-arm time and radiation exposure, based on data gathered from the fluoroscopy summary page.

The average number of fluoroscopic images acquired for each case was 184.5 (± 113.0), ranging from 26 to 588 images. Figure 4 presents the number of images used in each subtask. The entry point navigation task utilized the highest number of images (mean of 49.0 images, ± 42.0). The combined average of entry point and femoral head navigation was 71.2 images. The nail placement step used the second-most images, an average of 23.8 images (± 20.2). The first entry point navigation task was found to require significantly more IOF than the nail placement ($t(121) = 4.96$, $p < 0.0001$).

The 85 cases were performed by 29 different residents, 21 of whom were between their first and third years in residency, and 8 of whom were in their fourth year or higher. A majority (76/83) of case records included a junior resident, 9 cases included only senior residents, and one case included only a faculty surgeon. Figure 5 displays fluoroscopy use as reported by the C-arm unit. The average exposure and run time were 237.2 mGy (± 128.8) and 103.2 s (± 64.8), respectively.

DISCUSSION

The results of the present study indicate that the wire navigation portion (entry point and femoral head navigation) of a hip fracture surgery account for a substantial portion of the overall operative time. Up to 64.2% of the total images were utilized in the combined entry point and femoral head wire navigation portions of the procedure in collected cases, with an average of 39.3% of images taken (25.4% for entry point and 13.9% for femoral head navigation).

The entry point navigation task had the greatest average image count and variance of all fluoroscopy subtasks (49.0 images, ± 42.0), nearly twice as many images as the next largest subtask, nail placement (23.8 images). It took the longest time for completion and, excluding the reduction step, the greatest time variance (14.1 minutes, ± 10.8) of all subtasks. The high IOF average and variance indicates that this step is critical and requires more training to standardize performances. Despite it being entirely freehand, it represents the starting point for all subsequent tasks, many of which are then constrained by guides based on the initial wire. In addition, it is almost entirely responsible for the end position of the entire implant. It is for this reason that we should make this subtask the focus of future education and training. Initial studies developing training aides for these tasks have shown promising results. A simulator-based study established construct validity, or the ability to distinguish between novice and expert performance, on a hybrid reality simulator for training on the entry point navigation task.[8]

Radiation exposure carries risks for both patients and staff in the OR, especially surgeons that routinely use C-arm fluoroscopy. The International Commission on Radiological Protection sets limits on annual acceptable exposure for different sections of the body to minimize risk to staff using equipment and in the affected area.[9] In 2016, the annual exposure limit for the hands was 500 mSv.[9] A study conducted in 2014 followed hand surgeons over a period of 14 months and tracked the cumulative exposure to their off hands. The total exposure averaged out to 0.05 mSv (or mGy) per case with an average fluoroscopy time of 38 seconds.[10] Following the annual limit, it would take 10,000 cases in a year to reach the maximum acceptable. However, the data collected from CMN cases in Figure 5 shows that the average CMN procedure will use 2.7 times more fluoroscopy time than the hand surgeries reported.

Previous studies analyzed how much fluoroscopy these types of procedures used. One study found that intertrochanteric fractures used an average of 111.4 ±

2.44 seconds of fluoroscopy time, only about 8 seconds more than that reported by this study's average.[11] That study also found senior residents operating alone used slightly more fluoroscopy time than cases with only junior residents.[11] Another found that cases had an average fluoroscopy time of 119.6 ± 65.0 seconds when residents were under direct supervision compared with 106 ± 65.2 seconds when under indirect supervision.[12] It is encouraging that the results of prior work so closely reflect the output of this study, 103.2 ± 64.8 seconds (see Appendix 1). However, this study expands upon this radiation use analysis by not only reporting cumulative fluoroscopy use, but also where in the procedure radiation exposure is concentrated.

The images collected in this dataset showed the efficiency and distribution of fluoroscopy in hip fracture cases, while also providing insights into behaviors present in orthopedic residents, there are many factors that are not captured in the fluoroscopic images. Each step of the procedure has its own set of challenges and risks, and there are a variety of complications that can arise from improper technique. Poor entry points can result in fracture malreduction and perforation of the femoral shaft more distal in the femur.[13] If the final construct is out of position, it could lead to secondary injuries later. To mitigate these risks a surgeon must be knowledgeable and efficient.

This study was not without limitations. Despite a protocol attempting to collect all IOF images, of all cases performed in the collection window, 208 cases were deemed to be unusable for assessment. Reasons for exclusion include missing images, cases labeled incorrectly or having used different hardware that would have interfered with the data analysis. Significant turnover of C-arm technicians was noted during the collection period, which interfered with adherence to established image saving protocols for these types of cases. It is conceivable that this non-consecutive series could have introduced bias. In this study, all CMN cases over the evaluation period were reviewed. More displaced or comminuted fractures are likely to require more fluoroscopy during the reduction step, and shorter nails will typically have targeted distal screws. Additionally, patient-specific factors such as body habitus can play a role in the difficulty of the procedure through all subtasks. However, this information is not captured by the IOF image sets. These variabilities may have influenced the results of their respective subtasks.

Another limitation is the lack of information saved in the case file, such as which residents performed which steps of the procedure, and how much the faculty surgeons assisted or advised. While it was assumed that the least experienced resident was typically the one performing the initial wire-navigation, based on typical practice at our institution, this was not verified in the operative report for every case. Our results suggest that as demand for quantitative measures of performance increases, and data storage, processing, and security improve, there will be value in saving all fluoroscopic images from surgical cases.

CONCLUSION

The placement of a CMN for a hip fracture is a common procedure. However, we identified substantial variability in C-arm fluoroscopy use by residents throughout this procedure. Not surprisingly, the entry point navigation task required the greatest average time and fluoroscopy, 14.1 minutes and 49.0 images, respectively. Of the total, this single task (entry point navigation) required an average of 25.4% (± 11.5%) of all images acquired in a case, which was found to be significantly greater than for other subtasks. It also showed the greatest variance in image count and second highest variance in time (± 10.8 minutes and 42.0 images). This variability indicates an opportunity for focused education. It is not uncommon for junior residents to take time to understand how their movements in space translate to movements of the wire position on bone. We may infer that there may be an opportunity that skill training in wire navigation to acquire a starting point is a latent opportunity.

While it is intuitive that freehand activities presented a greater challenge and better differentiate performances than more constrained steps, this study is the first to offer objective data indicating the high volume of fluoroscopic images being used by surgical residents in the procedure. Understanding where and when residents use fluoroscopy presents an opportunity to identify learners who are struggling. To improve consistency and efficiency, more practice time should be allocated to wire navigation activities in a radiation free environment. This type of practice is difficult to replicate in simple surrogate bones models. While it can be done in cadaveric models and standard C-arm, it is also a target area for surgical simulation. Paired with other assessment tools and direct feedback from supervising faculty surgeons, fluoroscopy analysis can provide quantitative information and improve the standard of education and training for orthopedics residents.

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Appendix 1. Image Use for All Cases, as Well as the Radiation Exposure and C-Arm Fluoroscopy Time That Was Provided on the Summary Sheets for Some Cases

Case	Exposure (mGys)	Fluoroscopy Time (seconds)	Setup	Reduction	Entry Point	Reaming	Nail Placement	Femoral Head Navigation	Proximal Screws	Distal Screws	Final Checks	Total Images
10_leftCMN_full	N/A	N/A	4	37	31	18	26	11	5	5	12	149
10_rightCMN_full	N/A	N/A	5	16	19	23	17	27	19	92	15	233
11_rightCMN_full	292.6	76.72	3	12	58	103	68	32	18	26	15	335
13_leftCMN_full	345.8	163.7	0	58	177	40	17	27	37	11	19	386
13_rightCMN_full	329.3	76.1	6	76	156	20	46	29	31	8	5	377
14_leftCMN_full	244.1	102.69	10	21	83	49	24	15	24	37	12	275
14_rightCMN_full	172.6	69.03	0	2	17	15	21	39	23	7	7	131
15_leftCMN_full	111.6	53.57	1	33	17	17	13	13	10	9	16	129
15_rightCMN_full	578.8	151.79	3	131	60	46	112	27	44	153	12	588
16_leftCMN_full	121.2	72.37	3	42	16	12	22	19	8	7	13	142
16_rightCMN_full	N/A	N/A	8	0	128	48	9	27	37	14	16	287
17_leftCMN_full	175.1	40.72	7	19	26	23	29	26	21	32	3	186
17_rightCMN_full	N/A	N/A	9	24	57	25	21	21	26	14	14	211
18_leftCMN_full	N/A	N/A	2	5	31	13	27	49	9	7	11	154
18_rightCMN_full	N/A	N/A	6	0	44	14	40	11	15	18	10	158
19_leftCMN_full	306	82.48	2	72	59	51	27	30	7	80	13	341
19_rightCMN_full	64.8	18.56	2	0	12	8	14	10	8	3	5	62
20_leftCMN_full	259.4	88.37	0	51	118	21	68	11	18	7	5	299
20_rightCMN_full	315.3	80.47	2	0	7	9	10	6	13	16	15	78
21_leftCMN_full	228.7	227.21	7	13	52	35	23	29	14	10	37	220
21_rightCMN_full	135.2	52.16	2	0	33	20	17	20	17	9	6	124
22_leftCMN_full	402	206.51	3	64	208	37	36	38	30	43	7	466
22_rightCMN_full	487.9	141.52	1	21	9	0	13	10	3	1	6	64
23_leftCMN_full	262.3	128.45	4	8	83	37	20	25	39	69	11	296
24_leftCMN_full	181.2	86.92	2	70	30	18	44	6	14	13	7	204
24_rightCMN_full	108.6	52.81	4	22	21	9	14	13	4	3	9	99
25_leftCMN_full	192.3	70.699	3	53	101	17	47	19	19	34	11	304
25_rightCMN_full	152.6	47.87	3	7	50	8	13	15	29	8	3	136
26_leftCMN_full	207.1	133.24	1	36	27	13	16	33	20	5	10	161
26_rightCMN_full	379.3	184.33	5	6	11	5	7	6	1	2	10	53
27_leftCMN_full	399.5	210.15	1	44	46	80	29	36	19	66	19	340
27_rightCMN_full	195	70.32	6	0	43	15	40	11	15	18	10	158
28_leftCMN_full	239.1	81.73	4	0	75	30	28	41	41	14	14	247
28_rightCMN_full	347.5	131.5	4	0	12	5	1	5	7	14	2	50
29_leftCMN_full	N/A	N/A	5	58	54	51	45	70	31	5	8	327
29_rightCMN_full	127.2	48.26	1	48	72	14	14	21	23	7	16	216
3_leftCMN_full	N/A	N/A	1	5	26	2	5	4	20	6	8	77
30_leftCMN_full	N/A	N/A	0	22	72	6	33	19	21	9	9	191
30_rightCMN_full	99.1	41.88	0	0	35	9	24	21	14	9	33	145

31_leftCMN_full	134.7	42.46	4	0	33	12	45	21	7	7	6	135
31_rightCMN_full	171	87.12	3	0	10	11	4	53	13	7	6	107
32_leftCMN_full	130.5	54.05	0	23	25	6	10	16	20	13	12	125
32_rightCMN_full	347.1	185.46	9	0	41	10	20	14	9	5	16	124
33_leftCMN_full	N/A	N/A	3	11	98	44	32	25	21	65	27	326
34_leftCMN_full	N/A	N/A	6	0	166	30	44	10	19	17	8	300
34_rightCMN_full	N/A	N/A	6	0	8	2	2	10	4	1	4	37
35_leftCMN_full	N/A	N/A	5	0	12	11	7	19	12	3	10	79
35_rightCMN_full	85.5	18.67	1	0	8	5	5	9	6	8	8	50
36_leftCMN_full	N/A	N/A	4	0	51	5	21	22	26	4	15	148
36_rightCMN_full	141.7	74.22	2	0	42	5	7	7	6	2	7	78
37_leftCMN_full	96.2	50.85	16	0	26	15	18	32	12	2	7	128
37_rightCMN_full	138.5	67.69	13	0	26	8	12	21	7	5	7	99
38_rightCMN_full	349.5	182.13	1	20	70	18	21	17	19	39	10	215
39_leftCMN_full	161.1	54.38	3	43	15	26	19	48	21	2	9	186
39_rightCMN_full	109.2	33.19	2	0	17	8	11	4	10	3	12	67
4_leftCMN_full	N/A	N/A	0	0	39	26	22	15	8	10	6	126
4_rightCMN_full	N/A	N/A	2	131	41	36	34	11	10	35	21	321
40_leftCMN_full	243.9	82.05	3	51	90	20	36	14	28	4	15	261
40_rightCMN_full	145.6	63.96	9	9	44	10	41	14	11	16	8	162
41_leftCMN_full	160.2	74.99	4	0	23	5	9	25	10	8	4	88
41_rightCMN_full	175.2	88.67	1	0	21	6	11	18	7	7	5	76
42_leftCMN_full	514.5	360.87	2	0	7	1	5	26	10	12	0	63
42_rightCMN_full	266.7	140.83	2	0	118	26	38	20	16	40	6	266
43_leftCMN_full	624.9	250.47	2	1	67	22	27	17	7	57	7	207
43_rightCMN_full	N/A	N/A	14	0	57	3	6	6	5	3	4	98
45_leftCMN_full	N/A	N/A	5	0	19	11	7	19	12	3	10	86
47_leftCMN_full	192.4	99.77	1	9	6	19	11	27	9	3	9	94
49_leftCMN_full	287.1	150.54	3	5	14	9	3	8	5	0	7	54
5_rightCMN_full	N/A	N/A	1	89	83	23	121	48	34	7	25	431
50_leftCMN_full	527.3	153.85	6	0	11	30	31	15	18	12	8	131
51_leftCMN_full	239.5	118.2	3	6	41	32	16	9	14	14	8	143
52_leftCMN_full	104	15.39	1	0	20	20	3	22	8	12	15	101
53_leftCMN_full	144.5	99.93	0	0	8	0	3	5	3	2	5	26
54_leftCMN_full	168.2	56.86	0	0	25	3	10	26	14	47	11	136
55_leftCMN_full	254.4	144.24	3	48	124	19	26	31	15	7	9	282
56_leftCMN_full	331.8	131.09	2	18	50	16	10	32	12	36	16	192
57_leftCMN_full	175.1	103.8	12	0	79	3	14	27	12	13	27	187
58_leftCMN_full	255	162.32	2	70	84	7	26	72	15	4	9	289
59_leftCMN_full	133.5	67.03	2	0	39	12	16	12	16	6	12	115
6_rightCMN_full	N/A	N/A	3	18	25	16	22	41	29	10	17	181
60_leftCMN_full	96.6	63.92	4	0	26	6	12	6	7	2	11	74
62_leftCMN_full	125.2	17.68	29	0	39	3	20	16	22	7	7	143
7_rightCMN_full	N/A	N/A	2	31	10	16	31	9	12	5	19	135
8_rightCMN_full	454.4	214.11	5	87	117	62	44	64	48	51	12	490
9_leftCMN_full	N/A	N/A	3	15	17	11	11	29	18	4	11	119

Appendix 2. The Fluoroscopy Use Duration for All Cases and the Experience of Level of the Most-Junior Resident Participating in the Procedure, Reported in Order of Collection (Minutes and Weeks, Respectively)

Case	Setup	Reduction	Entry Point	Reaming	Nail Placement	Femoral Head Navigation	Proximal Screws	Distal Screws	Final Checks	Total Time	Week
10_leftCMN_full	1	12	3	3	9	2	4	4	3	41	145
10_rightCMN_full	1	4	7	15	11	6	7	18	2	71	105
11_rightCMN_full	1	2	13	18	14	8	6	6	5	73	106
13_leftCMN_full	0	10	34	8	6	6	7	5	3	79	198
13_rightCMN_full	1	13	29	2	9	11	7	4	1	77	216
14_leftCMN_full	2	6	19	17	8	7	11	14	1	85	96
14_rightCMN_full	0	1	3	5	6	5	8	3	2	33	116
15_leftCMN_full	1	9	4	3	6	3	3	6	10	45	148
15_rightCMN_full	0	61	10	11	32	6	13	38	4	175	64
16_leftCMN_full	1	13	4	5	9	5	3	4	3	47	148
16_rightCMN_full	8	0	22	14	3	5	13	4	6	75	121
17_leftCMN_full	1	5	6	6	5	5	6	7	1	42	149
17_rightCMN_full	2	7	11	7	7	6	9	3	3	55	126
18_leftCMN_full	1	1	6	4	11	13	4	6	3	49	45
18_rightCMN_full	8	0	9	7	15	3	8	8	5	63	79
19_leftCMN_full	1	12	15	16	11	5	4	17	1	82	150
19_rightCMN_full	1	0	2	4	5	2	5	4	1	24	140
20_leftCMN_full	0	13	29	9	18	3	8	3	2	85	151
20_rightCMN_full	1	0	13	11	14	6	11	25	4	85	141
21_leftCMN_full	1	2	10	7	7	6	7	4	7	51	47
21_rightCMN_full	1	4	3	10	7	5	2	5	2	39	136
22_leftCMN_full	1	18	43	14	6	11	8	10	2	113	152
22_rightCMN_full	0	33	13	0	0	12	5	7	3	73	57
23_leftCMN_full	2	2	26	16	6	15	15	22	4	108	260
24_leftCMN_full	1	18	8	7	16	2	7	5	3	67	106
24_rightCMN_full	1	3	6	1	5	2	5	3	2	28	222
25_leftCMN_full	1	11	21	6	10	4	7	10	2	72	56
25_rightCMN_full	0	2	12	3	5	4	5	5	2	38	118
26_leftCMN_full	0	9	6	4	6	6	11	5	3	50	56
26_rightCMN_full	7	9	18	20	8	13	12	31	9	127	76
27_leftCMN_full	1	23	11	20	7	10	7	20	4	103	110
27_rightCMN_full	8	0	9	7	15	3	8	8	5	63	79
28_leftCMN_full	0	0	11	5	7	9	8	5	2	47	114
28_rightCMN_full	1	0	16	14	2	6	14	19	2	74	151
29_leftCMN_full	0	12	10	12	7	12	7	4	2	66	116
29_rightCMN_full	0	18	18	9	6	8	11	10	5	85	100
3_leftCMN_full	2	11	36	1	8	4	32	13	2	109	82
30_leftCMN_full	0	4	13	1	10	5	9	4	2	48	121
30_rightCMN_full	0	0	6	2	5	5	4	3	8	33	258

31_leftCMN_full	1	0	10	3	13	5	3	3	2	40	226
31_rightCMN_full	4	0	3	6	6	22	4	6	4	55	108
32_leftCMN_full	0	8	9	4	6	5	8	5	4	49	122
32_rightCMN_full	4	0	21	13	16	5	11	14	10	94	110
33_leftCMN_full	0	7	20	11	8	6	8	16	7	83	73
34_leftCMN_full	3	0	65	12	17	4	8	16	2	127	236
34_rightCMN_full	8	0	13	3	14	12	6	6	4	66	66
35_leftCMN_full	12	0	15	5	8	7	4	2	6	59	84
35_rightCMN_full	0	0	2	1	3	2	2	4	6	20	67
36_leftCMN_full	0	0	9	3	6	5	6	4	2	35	38
36_rightCMN_full	2	0	14	1	4	5	6	5	2	39	122
37_leftCMN_full	2	0	6	3	6	6	6	2	3	34	144
37_rightCMN_full	8	0	7	5	6	8	6	6	2	48	122
38_rightCMN_full	0	5	27	10	14	8	8	22	4	98	72
39_leftCMN_full	1	5	3	5	5	10	3	5	1	38	59
39_rightCMN_full	5	0	5	2	4	2	7	4	6	35	76
4_leftCMN_full	0	0	10	12	10	6	6	12	2	58	86
4_rightCMN_full	1	71	9	14	13	2	4	10	6	130	145
40_leftCMN_full	0	11	47	5	11	7	13	9	6	109	222
40_rightCMN_full	1	3	11	2	12	2	5	6	3	45	128
41_leftCMN_full	6	0	6	3	5	8	4	4	2	38	121
41_rightCMN_full	0	0	14	4	9	8	7	6	2	50	26
42_leftCMN_full	1	0	21	4	31	20	10	54	0	141	77
42_rightCMN_full	1	0	23	10	9	3	6	14	3	69	134
43_leftCMN_full	5	1	31	17	23	9	12	57	4	159	132
43_rightCMN_full	4	0	20	4	12	10	9	4	1	64	85
45_leftCMN_full	12	0	15	5	8	7	4	2	6	59	136
47_leftCMN_full	0	4	5	5	6	9	7	4	7	47	152
49_leftCMN_full	7	8	19	12	7	11	9	0	10	83	108
5_rightCMN_full	1	14	16	5	31	9	8	5	4	93	146
50_leftCMN_full	11	0	20	20	26	3	9	18	4	111	108
51_leftCMN_full	0	2	9	14	4	4	10	8	4	55	109
52_leftCMN_full	0	0	3	8	2	5	4	7	4	33	61
53_leftCMN_full	0	0	6	0	4	3	6	4	1	24	69
54_leftCMN_full	0	0	9	3	16	6	11	20	2	67	71
55_leftCMN_full	0	10	24	5	7	7	5	5	2	65	124
56_leftCMN_full	1	4	15	6	9	15	11	4	6	71	125
57_leftCMN_full	2	0	15	1	3	6	4	5	6	42	76
58_leftCMN_full	0	2	26	2	8	21	5	3	2	69	76
59_leftCMN_full	1	0	10	4	6	3	6	4	3	37	76
6_rightCMN_full	1	4	6	5	8	10	9	4	2	49	42
60_leftCMN_full	1	0	4	2	6	3	4	6	4	30	234
62_leftCMN_full	7	0	9	1	5	4	6	4	2	38	134
7_rightCMN_full	1	6	4	3	7	3	6	2	4	36	148
8_rightCMN_full	2	28	22	10	16	10	10	14	2	114	152
9_leftCMN_full	1	4	4	4	6	8	5	5	2	39	0

EVALUATING IF CHATGPT CAN ANSWER COMMON PATIENT QUESTIONS COMPARED TO ORTHOINFO REGARDING LATERAL EPICONDYLITIS

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ABSTRACT

Background: As online medical resources become more accessible, patients increasingly consult AI platforms like ChatGPT for health-related information. Our study assessed the accuracy and appropriateness of ChatGPT's responses to common questions about lateral epicondylitis, comparing them against OrthoInfo as a gold standard.

Methods: Eight frequently asked questions about lateral epicondylitis from OrthoInfo were selected and presented to ChatGPT at both standard and sixth-grade reading levels. Responses were evaluated for accuracy and appropriateness using a five-point Likert scale, with scores of four or above deemed satisfactory. Evaluations were conducted by two fellowship-trained Shoulder and Elbow surgeons, two Hand surgeons, and one Orthopaedic Sports fellow. We utilized the Flesch-Kincaid test to assess readability, and responses were statistically analyzed using paired t-tests.

Results: ChatGPT's responses at the sixth-grade level scored lower in accuracy (mean = 3.9 ± 0.87, p = 0.046) and appropriateness (mean = 3.7 ± 0.92, p = 0.045) compared to the standard level (accuracy = 4.7 ± 0.43, appropriateness = 4.7 ± 0.45). When compared with OrthoInfo, standard responses from ChatGPT showed significantly lower accuracy (mean difference = -0.275, p = 0.004) and appropriateness (mean difference = -0.475, p = 0.016). The Flesch-Kincaid grade level was significantly higher in the standard response group (mean = 14.06, p < 0.001) compared to both OrthoInfo (mean = 8.98) and the sixth-grade responses (mean = 8.48). No significance was noted between the Flesch-Kincaid grades of OrthoInfo and the sixth-grade responses.

Conclusion: At a sixth-grade reading level, ChatGPT provides oversimplified and less accurate information regarding lateral epicondylitis. Although standard level responses are more accurate, they still do not meet the reliability of OrthoInfo and exceed the recommended readability for patient education materials. While ChatGPT cannot be recommended as a sole information source, it may serve as a supplementary resource alongside professional medical consultation.

Level of Evidence: IV

Keywords: chatGPT, lateral epicondylitis, reading level, patient education

INTRODUCTION

Lateral epicondylitis (LE) is the most common cause of adult lateral elbow pain.[1] Though the literature shows that up to 90% of cases of LE resolve within a year, the incidence in the US remains steady causing patients to seek further treatment information.[2] Studies have shown that millions of Americans use the internet to learn about their orthopaedic problems. Specifically, regarding lateral epicondylitis, Google search analytics found the majority of its online searches related to treatment and management of the condition.[1] With an increasing number of patients seeking medical knowledge online, comes the need for reliable and accessible patient-oriented resources.[3-5] Recent studies have shown that patients use the internet more than their doctor to obtain health information.[6]

There have been numerous publications exploring ChatGPT's potential role in clinical decision-making and patient education. While orthopaedic health information is readily available online, many studies have demonstrated patient-oriented orthopaedic literature is too complex for the recommended reading level of the average American.[7-11] This discrepancy between health literacy and patient materials has the potential to negatively impact patient outcomes. Previous literature has highlighted the significance of health literacy in determining patient outcomes, with lower health literacy associated with higher complications,[12] hospitalizations,[12-14] and poorer outcomes.[15,16] With this in mind, the National Institutes of Health (NIH) and American Medical Association (AMA) recommend that patient education material be published at a sixth-grade level or lower.[17,18]

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Considering NIH and AMA recommendations, we aimed to ascertain whether ChatGPT could deliver accurate, suitable, and easily understandable information in response to frequently asked questions about lateral epicondylitis. We hypothesized that ChatGPT can provide responses that are medically precise, appropriate, and readable regarding lateral epicondylitis.

METHODS

Publicly available sources of patient information have been shown to lack scientific accuracy.[19] Utilizing a publicly available peer-reviewed source of information as a benchmark is necessary for determining accuracy of responses generated by ChatGPT. The American Academy of Orthopaedic Surgeons (AAOS) provided a public peer-reviewed source of patient information that is updated and reviewed by experts. We utilized OrthoInfo as the gold standard for patient-oriented information for this study. Using the subheadings from the OrthoInfo Tennis Elbow (Lateral Epicondylitis) web page,[20] we crafted eight questions to pose to the chatbot. For example, for the subheading "Anatomy" we developed the question "What is the anatomy involved in tennis elbow?". These questions can be seen in Figure 1. The eight questions were posed to ChatGPT outright and the response was recorded. Each question was also posed to ChatGPT with a qualifying statement meant to produce a sixth-grade reading level response. For example, ChatGPT was asked "What is the anatomy involved in tennis elbow?" and was also asked "What is the anatomy involved in tennis elbow? Explain at a sixth-grade reading level". The response to the former question was determined to be the Standard response and the response to the latter question was determined to be the sixth-grade response. Each question was proposed via a separate query to eliminate potential contextual bias from chatbot responses.

Question 1	What is tennis elbow?
Question 2	What is the anatomy involved in tennis elbow?
Question 3	What are the causes of tennis elbow?
Question 4	What are the symptoms of tennis elbow?
Question 5	How does the doctor know if I have tennis elbow?
Question 6	What are the treatments for tennis elbow?
Question 7	What tests can the doctor do to rule out other problems when evaluating for tennis elbow?
Question 8	When is surgery for tennis elbow indicated? What is the surgery?

Each question was crafted based on subheadings 333 found on the OrthoInfo webpage.

Figure 1. Questions Proposed to ChatGPT. Each question was crafted based on subheadings found on the OrthoInfo Webpage.

To assess accuracy and appropriateness of ChatGPT responses, two fellowship trained Orthopaedic Hand surgeons, two fellowship trained Shoulder and Elbow Surgeons, and one Orthopaedic Sports fellow analyzed each response. Each rater was provided the OrthoInfo Tennis Elbow information page as well as the Standard and sixth-grade ChatGPT responses. The raters were asked to rate the accuracy and appropriateness of each response on a one to five Likert scale (Figure 2), using OrthoInfo as the reference. Each numerical rating had an associated description. As the peer-reviewed reference, OrthoInfo was rated 5/5 on accuracy and appropriateness by default. A rating of 4/5 was determined to be adequate information as per the Likert Scale description "Mostly medically accurate with some inaccurate information" for accuracy, and "Adequately addresses with room for improvement" for appropriateness. The Flesch-Kincaid Grade Level was used as our measure of readability. The FK score was calculated for the OrthoInfo, Standard, and sixth-grade responses.

Statistical analysis included paired t-test, interrater reliability, and descriptive statistics. Individual surgeon ratings to Standard and sixth-grade level responses were compared using the paired t-test. Mean rating values of Standard and sixth-grade level responses for each question were calculated. These were first compared to each other and then to OrthoInfo using the paired t-test. Interrater reliability was calculated using Cronbach's alpha and percent agreement.

Accuracy – Compared to OrthoInfo, the response presented is medically accurate.

1 - Completely medically inaccurate	2 - Mostly medically inaccurate with some accurate information	3 - About half mix of accurate and inaccurate information	4 - Mostly medically accurate with some inaccurate information	5 - Completely medically accurate

Appropriateness – Compared to OrthoInfo, the response appropriately addresses the patient's question.

1 - Not at all addressing the question	2 - Partially relevant but inaccurate	3 - Somewhat related but lacks clarity	4 - Adequately addresses with room for improvement	5 - Thoroughly and precisely answers the question

Each response was followed by these 2 Likert scales. Surgeons circled a score 1-5 to determine each response's accuracy and appropriateness score.

Figure 2. Example of Likert Scales Provided to Physicians. Each response was followed by these two Likert scales. Surgeons circled a score 1-5 to determine each response's accuracy and appropriateness score.

RESULTS

Complete responses provided by ChatGPT can be found in Appendix 1. Standard ChatGPT responses were rated significantly more accurate and appropriate compared to the sixth-grade ChatGPT responses (Table 1). On average, standard ChatGPT responses were above the adequacy cutoff of 4/5. Conversely, physicians found responses provided at the sixth-grade level to be unsatisfactory and were below the adequacy cutoff, on average. OrthoInfo responses were found to be significantly more accurate (5.0 ± 0.0 vs 4.7 ± 0.43; p = 0.004) and appropriate (5.0 ± 0.0 vs 4.7 ± 0.45; p = 0.02) when compared to standard ChatGPT responses. OrthoInfo responses were also found to be rated significantly more accurate (5.0 ± 0.0 vs 3.9 ± 0.87; p < 0.001) and appropriate (5.0 ± 0.0 vs 3.7 ± 0.92; p < 0.001) compared to sixth-grade ChatGPT responses.

Reliability statistics can be found in Table 2. Physicians' ratings of sixth-grade ChatGPT responses showed an intraclass correlation coefficient (ICC) of 0.754 for accuracy and 0.752 for appropriateness, indicating good interrater reliability of response gradings. In response groups with low variability, percent agreement and descriptive statistics provide a more authentic analysis of reliability. Physicians' ratings of standard ChatGPT responses showed a 55% agreement for accuracy and 77.5% agreement for appropriateness, indicating adequate and favorable reliability. Descriptive statistics for standard ChatGPT responses consistently approached the rating 5/5 and had low variability between mean, median, mode.

Table 3A shows the Flesch-Kincaid Grade Level for each question and average score for each reading level. Table 3B shows the direct comparison between all groups. Responses provided at the standard level were at a statistically significant higher grade level when compared to both sixth-grade (FK Standard = 14.06 vs FK sixth-grade = 8.48; p < 0.001) and OrthoInfo responses (FK Standard = 14.06 vs FK OrthoInfo = 8.98; p < 0.001). Of note, there was no statistically significant difference found between the FK Grade Level of sixth-grade responses and OrthoInfo responses (p = 0.421).

DISCUSSION

We sought to evaluate ChatGPT's utility in providing accurate and appropriate responses to common patient questions about lateral epicondylitis. Standard ChatGPT responses were recorded as well as responses at a sixth-grade level to account for patient literacy. Overall, standard responses were mostly accurate and appropriate. They were significantly lower rated than OrthoInfo and had significantly lower readability. When sixth-grade level responses were analyzed, there was no significant difference in FK reading level compared to OrthoInfo, but accuracy and appropriateness were significantly lower compared to Standard and OrthoInfo responses.

Standard ChatGPT responses were rated as mostly accurate and appropriate by our rating surgeons as determined by our adequacy cutoff. We set four on the Likert scale as our adequacy cutoff based on the wording of the Likert scale descriptions. A 4/5 on the accuracy scale was described as "mostly medically accurate with some inaccurate information". A 4/5 on the appropriateness scale was described as "adequately addresses with room for improvement". (Figure 2). We considered responses at or above this threshold as meeting the minimum criteria to provide accurate and appropriate medical information. With a mean accuracy and appropriateness

Table 1. Mean Ratings for Each Question Provided by ChatGPT at both Reading Levels

Question	Sixth-Grade ChatGPT Accuracy	Standard ChatGPT Accuracy	Sixth-Grade ChatGPT Appropriateness	Standard ChatGPT Appropriateness
Q1	4.4 (± 0.89)	4.4 (± 0.55)	3.8 (± 0.84)	4.6 (± 0.55)
Q2	3.4 (± 1.14)	4.6 (± 0.55)	3.6 (± 0.55)	4.2 (± 0.84)
Q3	3.8 (± 1.1)	4.8 (± 0.45)	3.6 (± 1.14)	5.0 (± 0.0)
Q4	4.4 (± 0.55)	4.6 (± 0.55)	4.8 (± 0.45)	4.8 (± 0.45)
Q5	4.4 (± 0.89)	5.0 (± 0.0)	3.8 (± 1.1)	4.8 (± 0.45)
Q6	4 (± 0.71)	4.8 (± 0.45)	3.8 (± 1.1)	4.8 (± 0.45)
Q7	3.8 (± 0.45)	4.8 (± 0.45)	3.4 (± 1.14)	4.6 (± 0.89)
Q8	3 (± 1.22)	4.8 (± 0.45)	2.8 (± 1.1)	5.0 (± 0.0)
Average Score	3.9 (± 0.87)	4.7 (± 0.43)	3.7 (± 0.92)	4.7 (± 0.45)
p value		p = 0.046*		p value = 0.045*

Shows mean rating of accuracy and appropriateness for questions 1-8 at both sixth-grade and standard reading levels. Each value provided is the mean score of the five surgeons' ratings.
*Denotes significant difference between sixth-grade ChatGPT Responses and standard ChatGPT responses.

Table 2. Reliability Statistics for Physician Ratings of ChatGPT Responses

Measurement	Sixth-Grade ChatGPT Accuracy	Sixth-Grade ChatGPT Appropriateness	Standard ChatGPT Accuracy	Standard ChatGPT Appropriateness
Intraclass Correlation Coefficient	0.754	0.752	0.106	0.158
Percent Agreement	57.5%	55%	75%	77.5%
Mean ± SD	3.9 (± 0.87)	3.7 (± 0.92)	4.73 (± 0.43)	4.73 (± 0.45)
Median	4	3.875	4.875	4.875
Mode	4	3.75	4.875	4.875

Various reliability ratings were used to ensure consensus on accuracy and appropriateness. This includes the Intraclass Correlation Coefficient, Percent Agreement, and descriptive statistics. SD, Standard Deviation.

Table 3A. Flesch-Kincaid Grade Reading Levels of all Responses

Question	FK – Sixth-Grade	FK - Standard	FK - OrthoInfo
Question 1	6.8	13.5	9.9
Question 2	9.1	13.4	9.8
Question 3	8.9	15	9.6
Question 4	8.3	12.2	8
Question 5	7.3	13.9	9.1
Question 6	9.8	13.8	9.4
Question 7	9.5	14.5	7
Question 8	8.1	16.2	9
Average (± SD)	8.475 (± 1.06)	14.0625 (± 1.19)	8.975 (± 0.998)

The Flesch-Kincaid Grade Level for individual responses at each level, as well as the mean Flesch-Kincaid Grade Level. The number is representative of the U.S. grade level.

Table 3B. Statistical Analysis Comparing Mean Flesch-Kincaid Grade Level of each Response Group

FK Grade Level Comparison	Mean Difference	P - value
Sixth-Grade vs Standard	-5.5875	< 0.001*
Sixth-Grade vs OrthoInfo	-0.5	0.421
Standard vs OrthoInfo	5.0875	< 0.001*

The mean differences of Flesch-Kincaid scores between response groups calculated using paired t-tests.
*Denotes a statistically significant difference was found between standard responses compared to sixth-grade and OrthoInfo responses. No difference was found between sixth-grade and OrthoInfo responses. SD, Standard Deviation.

of 4.7/5, we can consider standard ChatGPT responses to be both accurate and appropriate. Previous literature has reached similar conclusions. Mika et al. and Johns et al. used a similar methodology of a Likert Scale to assess ChatGPT accuracy and found ChatGPT was able to provide mostly accurate responses.[21,22] Other published literature has assessed ChatGPT using the DISCERN score and found its score to be between 55-60, where scores above 50 indicate its ability to provide accurate information (Hurley, Warren).[23,24] These reports align with our findings.

Previous analyses of online orthopaedic patient education material found that it is published at a mean grade reading level of 10.5, far higher than the recommended grade level set by the National Institutes of Health and American Medical Association.[17,18] In fact, 97% of patient-facing articles by the AAOS were found to have a reading level more complex than the sixth-grade level, with 81% of articles having a reading level above the eighth-grade level.[10] This trend is becoming ever more concerning, with patients now utilizing the internet as their primary source of medical information.[6] Our analysis of the reading level of standard ChatGPT responses coincides with this previously published literature, with standard ChatGPT responses having a mean FK Grade Level of 14.06. The value presented by FK Grade Level is representative of the U.S. grade level. A FKGL of 14.06 surpasses high school level education and is more appropriate for those with a college or graduate level education. This is far greater than what is recommended and would likely be understood by a minority of the population. As a result, while standard ChatGPT responses were able to provide accurate and appropriate information, a minority of readers may be able to understand and learn from the information provided. Interestingly, our analysis of OrthoInfo found the mean FK Grade Level of 8.98 to be slightly lower than the previously reported mean of 10.5. Although this is still slightly greater than recommended, it was equivalent with sixth-grade ChatGPT responses while providing far more accurate and appropriate answers.

Responses provided by ChatGPT at the sixth-grade level were found to occasionally omit crucial details, and sometimes provided incorrect information. Questions 2,

3, 6, 7, and 8 all fell below the adequacy cutoff of 4/5, with questions 2 and 8 having the lowest average scores. Question 2 asked about the anatomy involved in lateral epicondylitis, where surgeons agreed that the sixth-grade ChatGPT response provided a non-descriptive and cursory answer. It specifically failed to identify lateral epicondylitis as extra-articular in nature, frequently referring to the condition as "pain in the elbow joint". Question 8 asked "when is surgery for tennis elbow indicated? What is the surgery?" The rating surgeons found the sixth-grade ChatGPT response completely failed to specify for how long conservative management should be attempted before transitioning to surgery. ChatGPT also provided no valuable information on what the surgery entails, only stating "fixing the damaged part of the tendon in your elbow". Overall, ChatGPT failed to properly provide simplified and succinct responses while accounting for the sixth-grade reading level. We found that in an effort to improve readability, it often oversimplified the response, causing the chatbot to omit necessary information.

Both the standard and sixth-grade accuracy and appropriateness ratings were found to be inferior to those of OrthoInfo. We selected OrthoInfo as our benchmark due to its designation as the official patient information website by the AAOS. OrthoInfo offers clinicians a variety of handouts for patient distribution, covering extensive topics such as disease information, treatment options, and recovery protocols.[25] Moreover, the information and recommendations on OrthoInfo are peer-reviewed and periodically updated by surgical experts, bolstering its reliability and credibility. Consequently, we awarded the responses from OrthoInfo a perfect score of 5/5 for accuracy and appropriateness.

To ensure the dependability of physicians' responses, we used several statistical methods to analyze interrater reliability. Interrater reliability was measured with the intraclass correlation coefficient (Cronbach's alpha), percent agreement, and descriptive statistics. Overall, the physicians agreed that the sixth-grade level responses were mostly inaccurate and inappropriate. This is evident from the mean, median, and mode for these responses, which generally fell below the adequacy score of 4/5. On the other hand, the physicians tended to agree that the standard level responses were accurate and appropriate. Although the Cronbach's alpha values for standard responses initially showed low agreement for accuracy and appropriateness (0.106 and 0.158, respectively), this was likely due to the low variance in the physicians' scores, which can reduce the reliability score. Importantly, the median and mode for standard responses were both 4.88, indicating general agreement on high scores. Therefore, it is safe to conclude that the physicians generally agreed on the high accuracy and appropriateness of the standard responses.

Our study's results partially supported our hypothesis regarding ChatGPT's effectiveness in providing accurate and appropriate patient information about lateral epicondylitis. While the standard responses scored significantly higher in accuracy and appropriateness compared to the sixth-grade level responses, both were inferior to the benchmark set by OrthoInfo. Our analysis underscored ChatGPT's difficulty in delivering comprehensive information while maintaining simplicity suitable for a sixth-grade reading level. Additionally, the broader issue of patient education materials often exceeding the average American's reading comprehension level highlights the need to balance readability and accuracy in AI-driven healthcare communication. As technology advances, further research and refinement are necessary to fully leverage AI's potential in enhancing patient education while ensuring accessibility and understanding for diverse patient populations.

Limitations

First, as AI technology advances rapidly, the conclusions drawn from this study may not be definitive, given its relatively novel nature. Future updates and developments in AI algorithms could potentially alter the effectiveness and accuracy of AI-driven healthcare communication, thereby impacting our conclusions. Our study focused solely on the default ChatGPT 3.5 version and did not incorporate the premium ChatGPT4 version, which may offer more suitable and updated responses. This was not chosen because it is limited to paid subscribers, which is a minority of ChatGPT users. Another limitation is the subjective nature of each physician's gradings. While the ChatGPT responses were to be compared to OrthoInfo, there is some amount of subjectivity due to diversity in background and prior training for each physician. Surveys given to surgeon raters were not blinded, which may introduce some level of bias.

Another explanation for the discrepancy between standard ChatGPT and sixth-grade ChatGPT responses is the effect of the additional prompt "explain at a sixth-grade level." The initial prompting of a large language model, such as ChatGPT, is paramount in the quality of responses it provides. A proper prompt sets the context of the conversation and determines what information should be considered important.[26] Kaarre et al.[27] conducted a similar study in which ChatGPT questions were crafted using "prompt engineering", with guidelines provided by White et al.[26] They prompted ChatGPT 4.0 to provide information as an expert orthopaedic surgeon to two target groups: patients and medical doctors. Specific criteria for each target group were listed, such

as length of AI response, use of medical jargon, and knowledge of anatomy. This study found ChatGPT was able to provide accurate responses 65% of the time, for both target demographics. However, it also found that without either prompt, ChatGPT provided much longer answers, reduced adaptability for both groups, and increased the possibility of providing misinformation. This suggests ChatGPT may provide accurate and appropriate information for the target demographic, but it requires greater responsibility on the user to provide detailed and extensive prompting. They concluded that it is reasonable to assume the average patient would not use such extensive prompting when asking medical questions, leading to sub-par responses. Wright et al. analyzed ChatGPT prompting with regards to THA and TKA questions. They found that prompting the chatbot by telling it to make it "easier to understand" maintained accuracy and decreased FK reading level, though still at a reading level far above American Medical Association recommendations.[28] Further investigation is needed to determine prompting that improves readability without compromising accuracy. Overall, we cannot currently recommend ChatGPT as a sole source of patient-oriented information.

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APPENDIX 1. ChatGPT Responses

Evaluating if ChatGPT Can Answer Common Patient Questions Regarding Lateral Epicondylitis

Question 1: What is tennis elbow?

6th Grade:
Tennis elbow is a condition that can happen to your arm, specifically the outer part of your elbow. It's not just for tennis players – anyone can get it. Imagine your arm is like a machine with lots of moving parts. Sometimes, if you use your arm too much in certain ways, like gripping or twisting, it can cause the parts near your elbow to get sore. That soreness is what people call tennis elbow. It's important to take breaks and not overuse your arm to help prevent it. If it happens, resting and sometimes doing special exercises can help make it feel better.

Standard:
Tennis elbow, also known as lateral epicondylitis, is a condition characterized by pain and inflammation on the outer part of the elbow. Despite its name, tennis elbow is not limited to tennis players and can affect anyone who engages in repetitive arm and wrist motions. The condition typically results from overuse or strain of the forearm muscles and tendons that attach to the lateral epicondyle, a bony prominence on the outer side of the elbow.

Common causes of tennis elbow include:
1. **Repetitive wrist and arm movements:** Activities such as playing tennis, typing, using a computer mouse, painting, or gripping tools can lead to overuse and strain on the forearm muscles and tendons.
2. **Poor technique:** Using improper technique or equipment during sports or activities can contribute to the development of tennis elbow.
3. **Age:** Tennis elbow is more common in individuals aged 30 to 50, but it can occur at any age.

Symptoms of tennis elbow may include pain and tenderness on the outer part of the elbow, weakened grip strength, and difficulty with certain arm movements. Rest, ice, and over-the-counter pain medications are often recommended for initial treatment. In more severe cases, physical therapy, braces, and corticosteroid injections may be used. It's essential to address the underlying causes and modify activities to prevent further strain on the affected tendons. If conservative measures are ineffective, surgical intervention may be considered in some cases.

Question 2: What is the anatomy involved in tennis elbow?

6th Grade:
Sure, let's break it down in simple terms. Tennis elbow is a condition where the outer part of the elbow becomes painful and tender. It happens because of overuse of the muscles and tendons in the forearm that connect to the outer part of the elbow.

Now, let's understand the key players in this:
1. **Muscles and Tendons:** Imagine your arm as a team of workers. The muscles and tendons are like the team members doing their job. In tennis elbow, these team members are working too hard, especially the ones on the outer side of the elbow.
2. **Elbow Joint:** The elbow joint is like the meeting point where all the team members gather to get their tasks done. In tennis elbow, this meeting point (outer part of the elbow) gets sore and hurts.
3. **Repetitive Movements:** Just like doing the same homework over and over again can make your hand tired, doing repetitive movements in tennis or other activities can tire out the muscles and tendons around the elbow. This can lead to the discomfort known as tennis elbow.

So, in simpler terms, tennis elbow is like having tired and sore team members (muscles and tendons) around the meeting point (elbow) because they've been working too hard, especially with repetitive movements.

Standard:
Tennis elbow, clinically known as lateral epicondylitis, is a condition that involves inflammation or damage to the outer part of the elbow. Despite its name, tennis elbow is not limited to tennis players; it can affect anyone who engages in repetitive arm and wrist motions. The key anatomical structures involved in tennis elbow include:

1. **Lateral Epicondyle:** This is the bony prominence on the outer part of the elbow where the forearm muscles attach. The inflammation or damage typically occurs at the origin of the extensor carpi radialis brevis muscle.
2. **Extensor Carpi Radialis Brevis (ECRB):** The ECRB is a muscle responsible for extending and stabilizing the wrist. Overuse or repetitive strain on this muscle, as seen in activities such as gripping, lifting, or repetitive wrist extension, can lead to microscopic tears or inflammation in the tendon where it attaches to the lateral epicondyle.
3. **Tendons:** Tendons are tough, fibrous tissues that connect muscles to bones. In tennis elbow, the tendons attached to the lateral epicondyle, especially the extensor carpi radialis brevis tendon, are affected.
4. **Common Extensor Tendon:** The extensor carpi radialis brevis is part of the common extensor tendon, which is a shared tendon.

Question 3: What are the causes of tennis elbow?

6th Grade:
Tennis elbow, also known as lateral epicondylitis, happens when the outer part of the elbow becomes painful and tender. It's not only caused by playing tennis; other activities can lead to it too. Let's break down the causes in a way a 6th grader can understand:

1. **Repetitive Movements:** Doing the same arm movements over and over again, like swinging a tennis racket or playing video games, can strain the muscles and tendons around the elbow.
2. **Gripping too Hard:** Holding onto things too tightly, whether it's a tennis racket, a video game controller, or even carrying heavy bags, can put stress on the elbow.
3. **Incorrect Technique:** Using the wrong technique while playing sports or doing activities can contribute. It's like trying to ride a bike without learning how first – you might end up hurting your elbow.
4. **Overusing Muscles:** Sometimes, if you use your arm muscles too much without giving them enough time to rest, it can lead to tennis elbow. It's like running a race without stopping to catch your breath.

Remember, even though it's called tennis elbow, you don't have to play tennis to get it. It's more about how you use your arm and whether you're giving it the right kind of care. If your elbow starts hurting, it's essential to take a break and let it rest.

Standard:
Tennis elbow, also known as lateral epicondylitis, is a condition characterized by pain and inflammation on the outer side of the elbow. Despite its name, tennis elbow is not limited to tennis players and can affect anyone who repeatedly uses their forearm muscles and tendons, particularly in activities involving gripping and wrist extension. The exact cause of tennis elbow is not always clear, but several factors may contribute to its development:

1. **Overuse or Repetitive Strain:** The most common cause is repetitive use of the forearm muscles and tendons, leading to small tears in the tendons that attach to the lateral epicondyle (the bony bump on the outer side of the elbow). This overuse can result from activities such as tennis, other racquet sports, weightlifting, typing, or using tools like screwdrivers.
2. **Incorrect Technique:** Poor technique in sports or other activities can increase the risk of developing tennis elbow. This includes improper grip size, poor form, or using equipment that is not suited to your physical capabilities.
3. **Muscle Imbalances:** Weakness or imbalances in the muscles of the forearm, wrist, and shoulder can contribute to the development of tennis elbow. These imbalances can place excessive stress on the tendons.

4. **Age:** Tennis elbow is more common in individuals between the ages of 30 and 50, but it can affect people of any age.
5. **Occupational Factors:** Certain occupations that involve repetitive hand and wrist movements, such as carpentry, plumbing, painting, or cooking, may increase the risk of developing tennis elbow.
6. **Lack of Warm-up or Improper Conditioning:** Inadequate warm-up before engaging in physical activities or insufficient conditioning of the muscles and tendons can contribute to the development of tennis elbow.
7. **Previous Injuries:** A history of injuries to the elbow or forearm can increase the likelihood of developing tennis elbow.

It's important to note that while these factors may contribute to the development of tennis elbow, the condition can sometimes occur without any obvious cause. If you experience persistent elbow pain, it's advisable to consult with a healthcare professional for a proper diagnosis and appropriate treatment. Treatment options may include rest, physical therapy, bracing, anti-inflammatory medications, and in some cases, surgical intervention.

Question 4: What are the symptoms of tennis elbow?

6th Grade:
Tennis elbow, also known as lateral epicondylitis, is a condition that causes pain and discomfort on the outer part of the elbow. The symptoms of tennis elbow can be explained at a 6th-grade reading level:

1. **Pain:** People with tennis elbow feel pain on the outside of their elbow. It might hurt when they grip or lift things.
2. **Weakness:** The affected arm may feel weaker than usual. It might be harder to hold objects or do activities that involve the hand and wrist.
3. **Tenderness:** The outer part of the elbow might be tender to touch. It could feel sore when pressed.
4. **Difficulty with Movements:** Simple movements, like turning a doorknob or shaking hands, may become challenging and cause discomfort.
5. **Stiffness:** The elbow might feel stiff, making it less flexible than usual.

It's important to rest the affected arm, apply ice, and avoid activities that worsen the pain. If the symptoms persist, it's advisable to consult a doctor for proper evaluation and treatment.

Standard:
Tennis elbow, also known as lateral epicondylitis, is a condition characterized by pain and inflammation on the outer part of the elbow. While the name suggests a connection to tennis, this condition can affect anyone who repeatedly uses their forearm muscles and tendons, not just tennis players. The symptoms of tennis elbow may include:

1. **Pain:** The primary symptom is pain on the outer part of the elbow. The pain may range from mild to severe and often develops gradually.
2. **Tenderness:** The outer part of the elbow may be tender to the touch.
3. **Weak grip:** You may experience weakness in your grip, making it difficult to hold objects or perform certain activities.
4. **Stiffness:** Stiffness in the elbow joint, especially after periods of inactivity or upon waking up in the morning.
5. **Difficulty with wrist movements:** Activities that involve gripping, lifting, or twisting the wrist can exacerbate the pain.
6. **Worsening pain with certain movements:** Pain may increase when shaking hands, turning a doorknob, or lifting objects, for example.

It's important to note that if you suspect you have tennis elbow or are experiencing persistent elbow pain, it's advisable to seek medical attention. A healthcare professional can provide an accurate diagnosis and recommend appropriate treatment options, which may include rest, ice, physical therapy, braces, or in some cases, medication.

Question 5: How does the doctor know if I have tennis elbow?

6th Grade:
When a doctor thinks you might have tennis elbow, they ask you questions about your arm and how it feels. They also check your arm by gently moving it and pressing on certain spots to see if it hurts. Sometimes, they might order special pictures of your arm, like an X-ray or an MRI, to get a closer look. All these things help the doctor understand what's going on and if it's really tennis elbow. Tennis elbow happens when the outer part of your elbow hurts, usually from doing the same arm movements over and over. If the doctor thinks you have it, they can suggest treatments to help you feel better.

Standard:
Diagnosing tennis elbow typically involves a combination of a medical history review, a physical examination, and sometimes imaging tests. Here's an overview of the process:

1. **Medical History:** Your doctor will ask you about your symptoms, including when they started, the nature of the pain, and any activities or movements that aggravate or alleviate the pain. They may inquire about your daily activities, work, and any sports or repetitive motions that could contribute to the development of tennis elbow.
2. **Physical Examination:** The doctor will perform a physical examination, focusing on the affected arm. They may apply pressure to specific areas, like the outer part of the elbow or forearm, to assess for pain and tenderness. Range of motion and strength tests may be conducted to evaluate the function of the affected arm.
3. **Resistive Tests:** To diagnose tennis elbow, the doctor may perform resistive tests, asking you to resist certain movements while they apply force. Pain during resisted wrist extension, for example, is a common indicator of tennis elbow.
4. **Imaging Tests:** In some cases, imaging tests such as X-rays or MRI (Magnetic Resonance Imaging) may be ordered. These tests can help rule out other potential causes of elbow pain and confirm the diagnosis by revealing inflammation or damage to the tendons.
5. **Differential Diagnosis:** The doctor may also consider other conditions that can cause similar symptoms, such as arthritis, nerve compression, or other tendon injuries.

It's essential to consult with a healthcare professional for an accurate diagnosis. Self-diagnosis based solely on symptoms is not recommended, as other conditions can mimic tennis elbow. Once diagnosed, the doctor can recommend appropriate treatment, which may include rest, physical therapy, pain management, or, in severe cases, surgical intervention.

Question 6: What are the treatments for tennis elbow?

6th Grade:
Tennis elbow, also known as lateral epicondylitis, is a condition that causes pain and inflammation on the outer part of the elbow. Here are some treatments that might help at a 6th-grade reading level:

1. **Rest and Ice:**
• Give your elbow a break from activities that make it hurt, like gripping or lifting.
• Apply ice to the painful area for about 15 minutes to reduce swelling.
2. **Compression and Elevation:**
• You can use a compression bandage to support your elbow and reduce swelling.
• Elevate your arm by placing it on a pillow to help with blood flow.
3. **Medicine:**
• Your doctor might recommend over-the-counter pain relievers, like ibuprofen, to help with pain and inflammation.
4. **Stretching and Strengthening Exercises:**
• Simple exercises can improve the strength and flexibility of your forearm muscles.
• Your doctor or a physical therapist can show you these exercises.

5. **Brace or Splint:**
• Wearing a brace or splint on your forearm can provide support and reduce strain on the affected muscles.
6. **Modify Activities:**
• Try to avoid activities that worsen the pain, especially repetitive gripping motions.
• If you play sports, consider modifying your technique or using equipment that reduces strain on your elbow.
7. **See a Doctor:**
• If the pain persists or becomes severe, it's important to see a doctor for further evaluation and guidance.

Remember, everyone's body is different, so what works for one person may not work for another. It's essential to follow your doctor's advice and be patient with the healing process.

Standard:
Tennis elbow, or lateral epicondylitis, is a condition characterized by inflammation of the tendons on the outer part of the elbow. Treatment options for tennis elbow aim to reduce pain, promote healing, and prevent further injury. Here are some common treatments:

1. **Rest and Modification of Activities:** Give your elbow adequate rest to allow it to heal. Avoid activities that exacerbate the pain, especially repetitive gripping and lifting.
2. **Ice Application:** Apply ice to the affected area for 15-20 minutes at a time, several times a day, to reduce swelling and pain.
3. **Compression and Elevation:** Use a compression bandage to help control swelling. Elevate the affected arm to reduce swelling.
4. **Anti-Inflammatory Medications:** Nonsteroidal anti-inflammatory drugs (NSAIDs), such as ibuprofen or naproxen, can help reduce pain and inflammation.
5. **Bracing or Splinting:** Wearing a brace or splint can help support the affected forearm and reduce strain on the injured tendons.
6. **Physical Therapy:** A physical therapist can provide specific exercises to strengthen and stretch the muscles and tendons around the elbow. They may also use techniques such as ultrasound or massage.
7. **Corticosteroid Injections:** In some cases, a healthcare provider may recommend corticosteroid injections to reduce inflammation and provide short-term relief.
8. **Platelet-Rich Plasma (PRP) Therapy:** PRP involves injecting a concentrated form of the patient's own blood into the affected area to promote healing.
9. **Extracorporeal Shock Wave Therapy (ESWT):** ESWT uses shock waves to stimulate healing and reduce pain. It's a non-invasive treatment that may be considered if other conservative measures fail.
10. **Surgery:** In severe cases where conservative treatments are ineffective, surgery may be considered to remove damaged tissue or reattach tendons.

It's essential to consult with a healthcare professional for an accurate diagnosis and to determine the most appropriate treatment plan for your specific situation. Additionally, following a gradual return to activities and incorporating proper ergonomic techniques can help prevent future occurrences of tennis elbow.

Question 7: What tests can the doctor do to rule out other problems when evaluating for tennis elbow?

6th Grade:
When a doctor is checking for tennis elbow, they may perform some tests to make sure the pain is not caused by other issues. Here are a few simple tests they might do:

1. **Physical Examination:** The doctor will look at and feel the affected arm, checking for tenderness and swelling around the elbow.
2. **Range of Motion Test:** The doctor may ask you to move your arm in different ways to see if certain movements cause pain or discomfort.

3. **Grip Strength Test:** You might be asked to squeeze something to check your grip strength, as tennis elbow can affect this.
4. **X-rays:** In some cases, the doctor may order X-rays to get a clearer picture of the bones around the elbow. This helps rule out other issues like fractures.

These tests help the doctor understand if the pain is specifically due to tennis elbow or if there might be another problem. Always remember to communicate openly with the doctor about your symptoms and any concerns you may have.

Standard:
When evaluating a patient for tennis elbow (lateral epicondylitis), doctors may perform various tests to rule out other potential causes of elbow pain and to confirm the diagnosis. Some of the tests and examinations that a doctor may conduct include:

1. **Medical History:** The doctor will start by taking a detailed medical history, including information about the onset and duration of symptoms, any recent injuries or activities, and factors that aggravate or alleviate the pain.
2. **Physical Examination:** The doctor will perform a physical examination of the affected arm and elbow, looking for signs of tenderness, swelling, or inflammation around the lateral epicondyle (the bony bump on the outer part of the elbow).
3. **Palpation:** Palpation involves gently pressing on specific areas to assess for tenderness and pain. The doctor may apply pressure to the lateral epicondyle and surrounding structures to identify the source of pain.
4. **Resisted Wrist Extension Test:** The doctor may ask the patient to extend their wrist against resistance to assess pain and weakness. Pain during resisted wrist extension is a common finding in tennis elbow.
5. **Cozen's Test:** This test involves the patient making a fist and extending the wrist while the doctor resists the motion. Pain at the lateral epicondyle during this maneuver is indicative of tennis elbow.
6. **Mill's Test:** The doctor will passively pronate the patient's forearm and then flex the wrist and elbow. This maneuver may reproduce pain at the lateral epicondyle.
7. **Imaging Studies:** X-rays or other imaging studies, such as MRI or ultrasound, may be ordered to rule out other potential causes of elbow pain, such as fractures, arthritis, or ligament injuries.
8. **Nerve Conduction Studies (Electromyography - EMG):** In some cases, nerve conduction studies may be performed to rule out nerve-related issues contributing to elbow pain.
9. **Blood Tests:** In certain situations, blood tests may be ordered to rule out systemic conditions that could be contributing to the symptoms.

It's important to note that tennis elbow is a clinical diagnosis, and the combination of medical history, physical examination, and, if necessary, imaging studies helps in confirming the condition. If there is uncertainty or if symptoms persist, the doctor may refer the patient to a specialist such as an orthopedic surgeon or a physical therapist for further evaluation and management.

Question 8: When is surgery for tennis elbow indicated? What is the surgery?

6th Grade:
Surgery for tennis elbow is considered when other treatments haven't helped. The surgery aims to fix the damaged part of the tendon in your elbow.

In simpler terms, if you have pain in your elbow that doesn't go away with rest or other treatments, the doctor might suggest an operation. During the surgery, the doctor works on the part of your elbow that is causing the pain. It's like fixing a problem inside your elbow to make it feel better.

Remember, surgery is usually a last resort after trying other ways to make your elbow feel better. Always talk to your doctor to understand what's best for your specific situation.

Standard:
Surgery for tennis elbow, also known as lateral epicondylitis, is typically considered when conservative treatments have failed to provide relief, and the symptoms persist or worsen. Conservative treatments may include rest, physical therapy, nonsteroidal anti-inflammatory drugs (NSAIDs), bracing, and corticosteroid injections.

Surgery is generally considered when the following criteria are met:

1. **Persistent and Severe Symptoms:** If the symptoms of tennis elbow persist for at least 6 to 12 months and are severe, surgery may be considered.
2. **Failure of Conservative Treatments:** If conservative treatments have been tried without success, and the pain and functional limitations persist, surgery may be recommended.

The surgical procedure commonly used for tennis elbow is called "lateral epicondyle release" or "lateral epicondylitis surgery." The surgery involves removing damaged or degenerated tissue from the tendon attachment site on the lateral epicondyle of the humerus. This can be done through open surgery or minimally invasive arthroscopic techniques.

During the surgery, the surgeon may:
• **Remove Damaged Tissue:** The surgeon removes the damaged or degenerated tendon tissue from the lateral epicondyle.
• **Release Tension:** The surgeon may release tension on the extensor tendon by cutting a portion of it to reduce strain on the lateral epicondyle.
• **Repair or Reattach Tendons:** In some cases, the surgeon may need to repair or reattach tendons to the lateral epicondyle if they are severely damaged.

Recovery after surgery typically involves a period of rest, physical therapy, and a gradual return to normal activities. It's important to note that while surgery can be effective in relieving symptoms for many individuals, it also involves risks and should be considered after careful evaluation and discussion with a healthcare professional.

As with any medical decision, it's crucial to consult with an orthopedic surgeon or a healthcare provider who can assess your specific condition, discuss treatment options, and help determine whether surgery is the appropriate course of action for your tennis elbow.

PREVALENCE, RISK FACTORS, AND CLINICAL IMPACT OF BONY CYSTS IN THE DYSPLASTIC HIP UNDERGOING PERIACETABULAR OSTEOTOMY: AN EXPLORATORY STUDY

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ABSTRACT

Background: Formation of bone cysts in the acetabulum or femoral head is common in symptomatic acetabular dysplasia, but the prevalence and significance of cysts in hips undergoing PAO is poorly understood. The purposes of this study were (1) to determine the prevalence of cysts in hips undergoing PAO, (2) to identify predictors of the presence of cysts, (3) to determine if the presence or location of cysts was associated with intra-articular damage and (4) to determine if the presence or location of cysts impacted early clinical outcomes after PAO.

Methods: We performed a retrospective review of 270 consecutive hips (249 patients) who were diagnosed with symptomatic acetabular dysplasia and underwent PAO without previous ipsilateral hip surgery. Preoperative low-dose CTs were utilized to identify the presence of cysts, and patient-reported outcome measures (PROs) were recorded at baseline and 1-year minimum follow-up (223 hips, 83%). The prevalence of cysts was reported, and associated factors were determined by univariate analysis (Student's T-test/Mann-Whitney U test for continuous measures, Chi-squared test/ Fischer's exact test for dichotomous measures). PROs and clinical "composite failure", defined as reoperation or failure to reach both the MCID and PASS, were similarly compared.

Results: CT analysis of 270 dysplastic hips undergoing PAO demonstrated 17.0% (n=46) with acetabular (13.7%) or femoral cysts (4.4%). Hips with cysts were older (31.0±9.2 years) than those without cysts (24.1±7.9 years, p<0.001), reported higher Tonnis OA grade (p<0.001), showed higher rates of femoral chondromalacia (p=0.008), and had greater acetabular inclination (16.9° ±6.1) compared to hips without cysts (14.8° ±5.9, p=0.046). At 1-year minimum follow-up (223 hips, 83%), neither the presence nor location of cysts significantly impacted PROs. Cystic hips showed an increased but statistically insignificant difference in reoperations, conversion to THA, or composite failure outcomes.

Conclusion: Seventeen percent of dysplastic hips undergoing PAO had acetabular (13.7%) or femoral (4.4%) cysts on CT. Cysts in dysplastic hips were associated with increased Tonnis grade and acetabular inclination but did not significantly impact early PROs. Greater composite failure rates failed to show statistical significance, suggesting that patients with cystic dysplasia should continue counseling for hip-preserving treatments.

Level of Evidence: III

Keywords: developmental dysplasia, DDH, bony cysts, PAO

INTRODUCTION

Developmental dysplasia of the hip (DDH) encompasses various hip alterations that change the hips biomechanics, increasing propensity for early osteoarthritis and bone cyst formation.[1-4] Formation of bone cysts in the acetabulum or femoral head appears to be common in setting of acetabular dysplasia that has progressed to osteoarthritis with Inui et al. reporting one or more cysts in 94 of 150 such hips.[5] In some cases, these cystic changes represent progression of the acetabular rim disease and may affect the outcomes of surgical intervention. However, in some cases, cysts can be present due to the chronic biomechanical changes present in the joint, without significant articular cartilage damage. Cystic change is also a part of the osteoarthritis (OA) pathway, which makes it particularly challenging to understand their significance in the dysplastic hip.[5-7] In hip OA, cysts often appear first in the acetabulum before spreading to the femoral head as osteoarthritis worsens.[5]

The prevalence and significance of cysts in the dysplastic hip undergoing PAO is not well established. Plain radiographic assessment often underestimates the presence of cysts that are better seen on three-dimensional

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imaging like computed tomography (CT). Low-dose CT is increasing utilized for preoperative assessment and surgical planning of pre-arthritic hip conditions and can be obtained with low radiation exposure comparable to plain radiographic evaluation.[8,9]

Patients with DDH frequently present with bone cysts, but the clinical significance of the presence and the location of these cysts is not completely understood, particularly in young patients who are candidates for hip-preserving treatments. As a result, an exploratory study of this patient population provides valuable, preliminary insight that may prove useful in patient counseling.

The purposes of the current study were (1) to determine the prevalence of cysts in hips undergoing peri-acetabular osteotomy (PAO), as well as (2) to identify predictors of the presence of acetabular and/or femoral cysts, (3) to determine if the presence or location of cysts was associated with intra-articular damage, and (4) to determine if the presence or location of cysts impacts the early clinical outcomes of patients after PAO.

METHODS

A retrospective cohort study of patients undergoing PAO for symptomatic acetabular dysplasia was performed. Institutional review board approval was obtained for the study. PAO was indicated for patients with symptomatic acetabular dysplasia failing at least three months on conservative treatment. Commonly, these patients had a lateral center edge angle (LCEA) less than 20 degrees, or a LCEA between 20 and 25 degrees in the presence of a combined clinical and radiographic picture consistent with instability. The study was performed over a four-year study period. All patients underwent low-dose CT for surgical planning during the study period. Inclusion criteria included primary surgery, PAO surgery for acetabular dysplasia, and a preoperative CT study. Exclusion criteria included previous ipsilateral surgery, neuromuscular disorders, and residual Perthes disease.

Two-hundred-seventy hips (249 patients) were identified and comprised the study cohort (Figure 1). This group had a mean age of 25.3 years ([13.5-53.3]; SD=8.3) and average BMI of 23.6 ([16.3-33.9]; SD=3.4). Preoperative CT scans of the pelvis and proximal femur (Somaton Sensation 64; Siemens Medical Solutions USA, Inc, Malvern, PA, USA; 100 kV, 100 mAs, 0.4 mSv) were performed for preoperative planning with protocols specific to this patient population. We used multiplanar reformatting of axial CT scans to generate radial oblique slices similarly as previously described by Rakhra et al.[10] These three-dimensional CT images was used to evaluate the presence of any communication between the cyst and the joint space, as well as the distribution of the cysts. We divided the hip joint into 3 parts in the coronal (right, middle, left), axial (anterior, middle, and posterior), and oblique (anterior, middle, and posterior) CT images (Figure 2). Figure 3 gives example CT images of both femoral head and acetabular cysts.

Baseline patient and radiographic characteristics were assessed for assessed for potential association with cyst presence. Patient characteristics included patient demographics and pain chronicity (classified as less than 6 months, 6 months to 1 year, 1 to 3 years, 3 to 5 years and greater than 5 years). Preoperative radiographic assessment included a standing anteroposterior (AP) pelvis view, false profile view, and a 45° Dunn view.[11-15] Radiographs were assessed by an experienced reader with established inter– and intra-observer reliability. Radiographic assessment included the Tonnis osteoarthritis grade (OA), lateral center edge angle (LCEA), acetabular inclination, alpha angle.[12,16,17] Acetabular dysplasia severity was classified as borderline (LCEA 20-25), mild (LCEA 15-20), or moderate-severe (LCEA<15). Hip arthroscopy was performed in 57.4% (n=155) of the cohort and allowed for intra-articular damage assessment including the assessment of labral, acetabular cartilage, and femoral head cartilage pathology by the modified Beck classification, as well as the presence of ligamentum teres tears in this subgroup.[18]

Clinical outcomes were measured with validated patient reported outcomes (PROs) collected preoperatively and at a minimum one year postoperatively. PROs included modified Harris Hip score (mHHS), Hip disability and osteoarthritis score (HOOS) subscales, and UCLA activity score.[7,19,20] The mHHS was assessed relative to established thresholds for minimally clinically important difference (MCID 8 points) and patient acceptable symptom state (PASS 74).[21] Reoperation, excluding hardware removal, were assessed including revision surgery and total hip arthroplasty (THA). The rate of clinical "composite failure", defined reoperation/conversion to THA or failure to reach both the MCID and PASS, was also assessed.

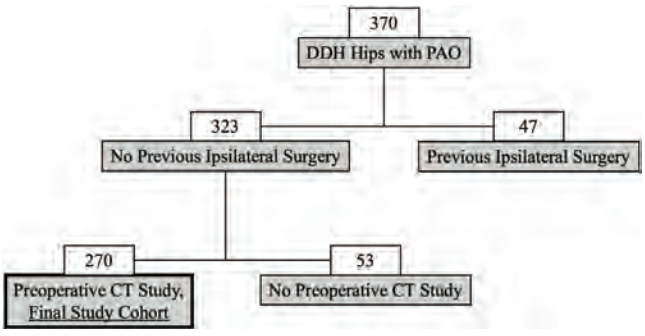

Figure 1. Study Cohort.

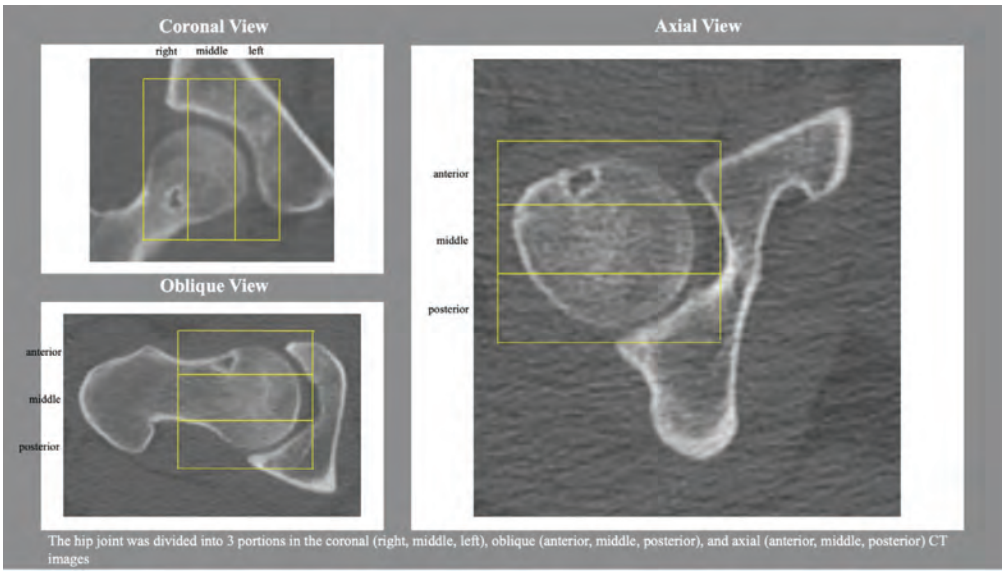

Figure 2. Cyst Location Mapping.

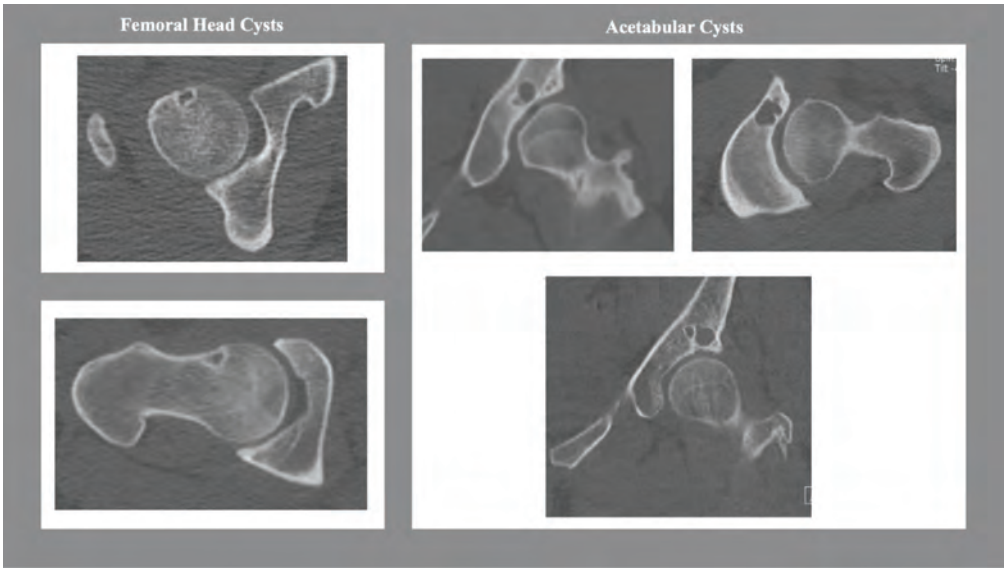

Figure 3. Example Images of Femoral Head and Acetabular Cysts.

Statistical Analysis

The prevalence of cysts in setting of acetabular dysplasia was determined. Factors significantly associated with the presence of cysts were determined by univariate analysis (Student's T-test/Mann-Whitney U test for continuous measures, Chi-squared test/Fischer's exact test for dichotomous measures). PROs and rates of outcome states were similarly compared between patients with and without cysts present.

RESULTS

Prevalence of cysts in hips undergoing periacetabular osteotomy

Among the 270 hips with symptomatic acetabular dysplasia, 17% (n=46) hips were found to have acetabular or femoral cysts (Table 1). 13.7% of hips (n=37) had an acetabular cyst with a total of 40 acetabular cysts. Of the acetabular cysts, 47.5% (n=19) were anterior, 42.5% (n=17) were central, and 10.0% (n=4) posterior (Table 1). 57.5% (n=23) acetabular cysts were greater than 5

mm in size, while 42.5% (n=17) were less than 5 mm in size. Proximal femoral cysts were present in 4.4% (n=12) of hips. Of the femoral cysts, 67.7% (n=8) were femoral head-neck junction cysts, and 33.3% (n=4) were femoral head cysts. Femoral head-neck junction cysts were located on the anteromedial head-neck 50% (n=4), lateral head-neck 25% (n=2), posterior head-neck 12.5% (n=1), central head-neck 12.5% (n=1) with 62.5% large (n=5) and 37.5% small (n=3). Femoral head cysts were located on the anterior superior head 25% (n=1), central head 25% (n=1), medial head 25% (n=1), and antero-lateral head 25% (n=1) with 50% large (n=2) and 50% small (n=2).

Identify predictors of acetabular and femoral cysts

The presence of a cyst (any location) was significantly associated with increased age and Tonnis OA grade. Patients with hip cysts tend to be older 31.0 years ± 9.2 compared to those without cysts 24.1 years ± 7.9 ($p < 0.0001$) and patients who had cysts tended to have a higher Tonnis OA grade than those without ($p < 0.0001$) (Table 2). Significant differences in age and Tonnis OA grade remained significant when comparing the 37 hips that with an acetabular cyst to the 233 hips without an acetabular cyst. Additionally, hips with acetabular cysts had a significantly greater acetabular inclination compared with hips with no acetabular cysts (16.9° ± 6.1 vs. 14.8° ± 5.9, $p = 0.046$). There was not a statistically significant difference ($p=0.098$) in BMI between patients with cystic hips (24.4 ± 3.6) and non-cystic hips (23.5 ± 3.3). There was no significant difference in symptom chronicity between hips with and without cysts ($p=0.408$).

Table 1. Location Breakdown of Cysts

Location	Percentage (N)
Acetabular Cysts (n = 40)	
Anterior	47.5% (19)
Central	42.5% (17)
Posterior	10.0% (4)
Femoral Cysts (n = 12)	
Head-Neck Junction	67.7% (8)
Anteromedial	50.0% (4)
Lateral	25.0% (2)
Posterior	12.5% (1)
Central	12.5% (1)
Head	33.3% (4)
Anterior Superior	25.0% (1)
Central	25.0% (1)
Medial	25.0% (1)
Anterolateral	25.0% (1)

82.6% of patients with cysts were female and this was not significantly different ($p=0.326$) than the 88.0% of patients without cysts being female. Dysplasia severity was not associated with the presence of cysts ($p=0.381$). Table 6 presents a breakdown of follow-up percentages by type of cyst present.

Cysts association with intra-articular damage

Among 155 hips that had an arthroscopy at time of PAO, 27 hips (17.4%) had bone cysts. Femoral head chondromalacia was more common among hips with cysts compared to hips without cysts ($p=0.008$). There was no significant difference in acetabular chondromalacia max grade among this arthroscopy cohort ($p=0.429$), no difference in labral damage ($p=0.999$), nor a significant difference in if the ligament teres was intact ($p=0.322$) (Table 3). In the cohort of hips that have undergone an arthroscopy, there was a greater proportion of hips with intact ligamentum teres among hips without acetabular cysts (Table 3) compared to hips with cysts ($p=0.049$). Among hips that have had an arthroscopy, when specifically analyzing hips with acetabular cysts (n=20) versus femoral cysts (n=9), a significant difference in chondromalacia was observed ($p=0.013$) (Table 3). For femoral cysts, higher grades of cleavage (55.6%) and pitting (22.2%) were noted compared to acetabular cysts (13.3% and 10.0%, respectively) No cases of chondral defects were reported in hips with femoral cysts, compared to 16.7% in acetabular cysts.

Determine if the presence or location of cysts impacts the clinical outcomes of patients after PAO

There were no significant differences in clinical outcomes at baseline or at minimum 1-year follow-up when examining the presence or location of cysts (tables 4 and 5). mHHS improved from 60.6 ± 15.4 to 85.2 ± 18.0 among hips with no cysts while hips with cysts improved from 59.3 ± 12.6 to 84.1 ± 25.7 ($p=0.59$). Similarly, the location of cysts did not significantly change mHHS among hips with acetabular cysts (84.5 ± 25.3, $p=0.64$) or femoral cysts (83.1 ± 24.3, $p=0.86$) at a minimum 1-year follow-up. Reoperation rates were 2.7% overall, with no reoperations reported in the acetabular or femoral cyst subgroups. The rate of total hip arthroplasty (THA) conversion was 0.9% overall, with two cases occurring exclusively in patients with acetabular cysts (6.9%). The composite failure outcome occurred in 12.6% of patients overall. Patients with acetabular cysts did have higher failure rates compared to those without cysts, but this did not reach significance (17.2% vs 9.8%, $p=0.305$). Similarly, femoral cysts were associated with a composite failure of 33.3%, compared to 10.7% in those without femoral cysts ($p=0.130$) (Table 5.2). In the analysis by cyst presence

Table 2. Baseline Characteristics of Patients with DDH

Factors	Hips w cysts N = 46	Hips w/o cysts N = 224	P value	Hips with acetabular cysts N = 37	P value	Hips w femoral cysts N = 12	P value
Dysplasia Severity			0.381		0.157		0.294
Borderline	21.1 (12)	78.9 (45)		17.5 (10)		3(25)	
Mild	13.4 (15)	86.6 (97)		8.9 (10)		7(58.3)	
Moderate to Severe	18.8 (19)	81.2 (82)		16.8 (17)		2(16.7)	
Pain chronicity			0.408		0.115		0.2455
<6 months	7.7 (1)	92.3 (12)		7.7 (1)		0(0)	
6 months-1 year	16.4 (10)	83.6 (51)		9.8 (6)		6(50)	
1-3 years	14.4 (17)	85.6 (101)		11.0(13)		5(41.7)	
3-5 years	26.5 (9)	73.5 (25)		18.6 (8)		1(8.3)	
>5 years	26.5 (9)	73.5 (25)		26.5 (9)		0(0)	
Age (years, mean)	31.0 ±9.2	24.1 ±7.9	<.0001	32.2±9.2	<.0001	28.3±8.2	0.238
Sex (Female)	38(82.6)	197(88.0)	0.326	31(83.8)	0.597	10(83.3)	0.659
BMI	24.4 ±3.6	23.5 ±3.3	0.098	24.4±3.4	0.116	24.0±3.7	0.669
Tonnis grade			<.0001		<.0001		1.0
0	11.8 (26)	88.1 (193)		8.2 (18)		10(83.3)	
1	36.7 (18)	63.3 (31)		34.7 (17)		2(16.7)	
2	100 (2)	0(0)		0(0)		0(0)	
Acetabular inclination	16.4±6.4	14.8±5.9	0.115	16.9±6.1	0.046	13.6	0.920
Max alpha angle	67.6±27.9	60.8±18.4	0.119	68.8±28.2	0.105	66.1	0.048
LCEA	14.1±8.2	15.3±7.1	0.330	13.5±8.7	0.158	18.8	0.160

Results are from t-tests and chi-square analysis with Fisher's exact test being used as appropriate. Outcomes are expressed as mean±SD, N(%).

Table 3. Baseline Characteristics of Acetabular Cysts with Arthroscopes

Factors	Hips w cysts N = 27	Hips w/o cysts N = 128	P value	Hips with acetabular cysts N = 20	P value	Hips w femoral cysts N = 9	P value
Acetabular chondromalacia Max Grade			0.429		0.989		0.013
Malacia	20.0 (2)	80.0 (8)		10.0 (1)		1(11.1)	
Pitting	20.0 (4)	80.0 (16)		10.0 (2)		2(22.2)	
Debonding	12.8 (11)	87.2 (74)		12.9 (11)		1(11.1)	
Cleavage	26.7 (8)	33.3 (22)		13.3 (4)		5(55.6)	
Defect	16.7 (1)	83.3 (5)		16.7 (1)		0(0)	
Femoral chondromalacia Grade			0.0079		0.989		0.069
Malacia	14.6 (20)	85.4 (117)		10.9 (15)		6(66.7)	
Pitting	50.0 (3)	50.0 (3)		33.3 (2)		1(11.1)	
Debonding	0(0)	0(0)		0(0)		0(0)	
Cleavage	50.0 (4)	50.0 (4)		10.9 (3)		2(22.2)	
Defect	0(0)	100 (1)		37.5 (0)		0(0)	
Labral damage	18.1 (27)	81.9 (122)	0.999	13.4 (20)	0.999	9(100)	0.999
Ligamentum Teres intact	15(55.6)	86(69.9)	0.322	9(45)	0.049	7(77.8)	0.999

Results come from Fisher's exact tests and are presented as n(%).

Table 4.1. Baseline PROs of Patients with DDH by Cyst

Outcome Measure	Overall	Cyst (n=37)	No Cyst (n=186)	P-Value
Patient Reported Outcomes				
mHHS	60.4±15.0	59.3±12.6	60.6±15.4	0.92
HOOS Pain	57.1±18.6	55.1±16.9	57.5±19.0	0.58
HOOS Symptoms	55.2±19.8	52.6±19.1	55.7±19.9	0.52
HOOS ADL	65.8±20.2	63.0±20.9	66.3±20.1	0.47
HOOS Sports	41.6±23.4	41.0±20.0	41.7±24.0	0.99
HOOS QoL	31.9±21.3	30.0±18.8	32.3±21.8	0.72
UCLA	6.6±2.7	6.8±2.9	6.6±2.7	0.62

Results are from Wilcoxon Signed-Rank tests. Outcomes are expressed as mean±SD.

Table 4.2. Baseline PROs of Patients with DDH by Acetabular/Femoral Cyst

Outcome Measure	Overall	Acetabular Cyst (n=29)	No Acetabular Cyst (n=194)	P-Value	Femoral Cyst (n=9)	No Femoral Cyst (n=214)	P-Value
Patient Reported Outcomes							
mHHS	60.4±15.0	59.8±19.0	60.5±15.3	0.85	56.7±12.3	60.6±15.1	0.45
HOOS Pain	57.1±18.6	57.8±16.5	57.0±19.0	0.88	42.5±15.9	57.7±18.5	0.08
HOOS Symptoms	55.2±19.8	52.7±19.1	55.6±19.9	0.56	53.9±20.3	55.2±19.8	0.98
HOOS ADL	65.8±20.2	62.2±21.2	66.4±10.0	0.40	64.2±20.0	65.9±20.2	0.80
HOOS Sports	41.6±23.4	40.0±19.4	41.9±24.0	0.74	41.0±23.2	41.6±23.4	0.93
HOOS QoL	31.9±21.3	30.4±18.0	32.2±21.8	0.81	27.1±21.2	32.1±21.3	0.55
UCLA	6.6±2.7	6.9±2.8	6.5±2.7	0.40	5.3±3.0	6.6±2.7	0.16

Results are from Wilcoxon Signed-Rank tests. Outcomes are expressed as mean±SD.

(Table 5.1), similar rates were observed in patients with cysts (21.6%) compared to those without (10.8%; p=0.137). THA occurred exclusively in the cyst subgroup (5.4%), while reoperation rates were low across all groups.

DISCUSSION

Acetabular dysplasia is associated with labral damage, cartilage damage, and eventual osteoarthritis. The increased propensity for bone cysts and cartilage damage associated with the sequelae of DDH have been linked to higher patient reported pain and disability. However, there has not been a large study examining the impact of bone cysts formation and location of cysts in DDH patients. It is possible that the presence of cystic change could be associated with advanced disease that precludes a successful outcome. The current study aimed to examine the prevalence of cysts in hips undergoing periacetabular osteotomy (PAO), identify predictors of acetabular and femoral cysts, determine if the presence or location of cysts was associated with intra-articular damage and if the presence or location of cysts impacted the clinical outcomes of patients after PAO. This study found that DDH with cysts were older than non-cystic hips and that radiographic findings such as Tonnis grade increased with the presence of cysts. There was no significant difference in early outcome PROs based on the presence or location of cysts. Dysplastic hips with cysts showed a greater rate of composite failure but failed to reach significance. This exploratory study suggests that hip-preserving treatment for cystic dysplastic hips results in favorable patient outcomes. Although the composite failure risk is slightly increased, the lack of statistical significance supports continued counseling for patients on the benefits of hip-preserving treatments.

Prevalence of cysts in hips undergoing periacetabular osteotomy (PAO)

The prevalence of bony cysts in hips undergoing periacetabular osteotomy (PAO) reflects a significant aspect of the preoperative evaluation and surgical planning. This study's prevalence of cyst (17%) was slightly below other studies examining dysplastic hips. Recent studies

Table 5.1. PROs by Cyst: Minnimum 1 Year Follow-Up

Outcome Measure	Overall	Cyst (n=37)	No Cyst (n=186)	P-Value
Follow Up (years)	2.78±1.51	2.79±1.53	2.73±1.51	0.79
Patient Reported Outcomes				
mHHS	85.0±19.4	84.1±25.7	85.2±18.0	0.59
HOOS Pain	86.3±15.9	88.8±13.6	85.8±16.2	0.58
HOOS Symptoms	79.0±16.9	80.6±15.8	78.7±17.1	0.59
HOOS ADL	91.8±11.7	93.6±10.4	91.5±11.9	0.80
HOOS Sports	80.0±21.3	83.4±17.5	79.4±21.9	0.63
HOOS QoL	69.5±25.2	73.1±22.1	68.8±25.8	0.50
Reoperation	6 (2.7%)	0	6 (3.2%)	-
THA	2 (0.90%)	2 (5.41%)	0	
Composite Failure Outcome	28 (12.6%)	8 (21.6%)	20 (10.8%)	0.137

Results are from Wilcoxon Signed-Rank tests for continuous variables and McNemar's test being used for categorical. Outcomes are expressed as mean±SD, n(%).

Table 5.2. PROs by Acetabular/Femoral Cyst: Minnimum 1 Year Follow-Up

Outcome Measure	Overall	Acetabular Cyst (n=29)	No Acetabular Cyst (n=194)	P-Value	Femoral Cyst (n=9)	No Femoral Cyst (n=214)	P-Value
Follow Up (years)	2.78±1.51	2.64±1.41	2.80±1.53	0.69	2.70±0.99	2.78±1.50	0.78
Patient Reported Outcomes							
mHHS	85.0±19.4	84.5±25.3	85.1±18.4	0.64	83.1±24.3	85.1±19.3	0.86
HOOS Pain	86.3±15.9	88.7±14.2	85.9±16.1	0.59	88.2±9.65	86.2±16.0	0.78
HOOS Symptoms	79.0±16.9	79.6±15.9	78.9±17.1	0.85	85.0±11.8	78.7±17.1	0.44
HOOS ADL	91.8±11.7	93.6±10.8	91.6±11.9	0.78	91.4±7.11	91.6±11.6	0.40
HOOS Sports	80.0±21.3	82.1±18.3	79.7±21.7	0.89	80.4±20.5	80.0±21.4	0.84
HOOS QoL	69.5±25.2	72.1±22.3	69.1±25.7	0.69	67.7±24.2	69.6±25.3	0.74
Reoperation	6 (2.7%)	0	6 (3.1%)	-	0	6 (2.8%)	-
THA	2 (0.45%)	2 (6.9%)	0	-	0	0	-
Composite Failure Outcome	28 (12.6%)	5 (17.2%)	19 (9.8%)	0.305	3 (33.3%)	23 (10.7%)	0.130

Results are from Wilcoxon Signed-Rank tests for continuous variables and McNemar's test being used for categorical. Outcomes are expressed as mean±SD, n(%).

Table 6. Time To Follow Up

	Number of patients	Patients with Follow Up	Patients With 1+ Year Follow Up	Patients With 2+ Year Follow Up
Total Hips in Study	270	258	223	159
Percent Follow Up		96%	83%	59%
Acetabular Cyst Hips	37	34	29	21
Percent Follow Up		92%	78%	56%
Femoral Cyst Hips	12	11	9	6
		92%	75%	50%

indicate that bony cysts are observed in a notable proportion of dysplastic hips, with prevalence rates varying from 20% to 40% depending on the cohort and imaging modalities used.[3,22,23] These cysts, which are typically detected via advanced imaging techniques such as MRI or CT, can significantly influence the surgical approach and outcomes. The presence of bony cysts may be associated with more advanced stages of hip dysplasia or more severe acetabular deformities. Understanding the prevalence of these cysts is crucial for preoperative planning as they can impact the osteotomy's complexity and the overall prognosis of hip-preservation surgery. Additionally, the presence of cysts might be indicative of underlying bone quality issues, which can affect the healing process and long-term joint stability. Consequently, it is essential for clinicians to carefully assess and address these factors when planning a PAO to optimize surgical outcomes and ensure effective management of the dysplastic hip.

Predictors of acetabular and femoral cysts

The appearance of cysts, specifically on the acetabulum, was shown to be significantly more likely as age increased in DDH. Nakasone et al. noted that in an analysis of 34 hips, there was no significant association between cysts and age.[24] Li et al. similarly found that there was no significant association between age and subchondral bone cysts.[25] However, both of these studies reported on patients with a mean age greater than 60 years compared to this study's mean age of 25.3 years. These results may imply that among younger patients, specifically those with DDH, cyst development occurs with increasing age due to being later in the osteoarthritis disease course. In DDH hips, the presence of cysts tended to be associated with higher Tonnis grades seeming to indicate that cystic DDH have a greater severity of degenerative radiographic changes.[26] However, other radiographic measures of dysplasia that have been validated and shown reliable, such as LCEA, were not shown to be significantly different based on cyst presence or location.[27,28] Additionally, it is important to note that Tonnis grade intraobserver reliability for adults with osteoarthritis is moderate with a κ between 0.76-0.60, but an even lower intraobserver κ of 0.53 occurs when examining a younger cohort similar to the one examined in this study.[29-31] As a result of this, the significant difference in Tonnis OA grade based on the development of cysts should continue to be studied to better understand the role of cysts in hip dysplasia among those with DDH.

Determine if the presence of cysts impacts the clinical outcomes of patients after PAO

It is common for cysts in the hip joint to be asymptomatic, but cyst have been shown to cause pain by compressing nearby structure and by causing perturbations in cellular activity that are likely to affect osteoarthritis progression.[24,32,33] The lack of difference in early clinical outcome measures in this study seem to indicate that cysts in DDH patients are not a driving factor in pain reported in DDH hips. A similar study examining the role of cysts in osteoarthritic knees found that in a comparison of 247 osteoarthritic knees with subchondral cysts to 559 non-cystic osteoarthritic knees, there were no significant differences in clinical outcome measures such as the knee society score.[34] So, while the presence of cysts may be correlated to increased pain compared to a healthy population, this study and others indicate that the presence of cysts in DDH joints may not serve as powerful explanation of a patient's pain. One similar study by Takegami et al. examined the patient reported outcomes of 108 patients with DDH using the Japanese Orthopaedic Association hip disease evaluation questionnaire (JHEQ). Takegami et al. reported that JHEQ movement and mental scores in cystic DDH patients were significantly lower compared to non-cystic DDH patients.[35] However, it is important to note that the JHEQ is designed to reflect the viewpoint of health-care providers rather than that of patients and contains no tool for evaluating quality of life measures.[36] This helps explain how the JHEQ has a strong negative correlation to other patient reported outcomes such as the oxford hip score.[37] The benefit to understanding how cysts impact DDH patients is great, and continued research on this patient population with multiple patient-reported outcomes will help elucidate the clinical outcomes associated with cystic DDH. Multiple researchers reported that acetabular cysts occur first while femoral head cysts develop as osteoarthritis worsens.[5,6,38] This exploratory study noted higher composite failure rates in hips with cysts, but that the association did not reach statistical significance. This appears to indicate that while there may be an increased risk for failure, the risk is not great enough to advise against hip-preserving treatment in patients with cystic dysplastic hips. Future larger cohorts may more precisely quantify the increased risk of failure, and this study may provide preliminary insights into the composite failure rates in this patient population.

Additionally, the radiographic findings of the acetabular cyst hip were significant for increased Tonnis grade and acetabular inclination while femoral cysts were only significant for max alpha angle. Both these clinical and radiographic findings of acetabular and femoral head cysts are consistent with the report from Inui et al. who noted that despite no differences in characteristics between location of the cyst, osteoarthritic changes were more prominent in the acetabulum than in the femoral head.[5]

Limitations

Firstly, when comparing hips with arthroscopy, those with femoral cysts were linked to acetabular chondromalacia max grade, but due to the small sample size (n=9), the results are subject to random error and the direction of the relationship is difficult to interpret. Hips with acetabular or femoral cysts had higher rates of composite failure, but the association was not significant. Future studies with longer follow-up, larger sample sizes and greater statistical power may help clarify whether an association exists between the presence of cysts and composite failure, whether demographic factors contribute to these patients' reported outcomes, and quantify the potential increased risk. Even with limitations around small sample size, this study's strengths are in the large and young cohort of DDH patients. As mentioned earlier, most osteoarthritic subchondral cyst studies have been performed on older patients. In a congenital condition such as DDH, having a young cohort helps better understand their prognosis as they advance through puberty into adulthood. Additionally, this study was able to provide a non-cystic DDH cohort of hundreds of similarly aged hips to serve as a comparison to the cystic DDH patients. This allows any significant findings in this study to be specific to cyst formation and location. It is important to note, however, that many findings border on statistical significance and should be interpreted cautiously. Lastly, this study used a wide breath of clinical outcome measures and radiographic findings that lends the current study's data to have relevance to multiple components of a DDH patient's prognosis and to future studies.

CONCLUSION

Among DDH hips undergoing PAO, 17.0% had a cyst observed on CT with 13.7% having acetabular cysts and 4.4% femoral cysts. Dysplastic hips with cysts were associated with increased Tonnis grade, acetabular inclination, and age. However, this exploratory study found that neither the presence nor the location of cysts demonstrated a significant difference in early follow-up PROs, and that the increased rate of composite failure did not reach statistical significance. This indicates that while there may be a potential for increased composite failure in short term follow-up, the risk is not statistically significant, and patients with cystic dysplastic hips should continue to receive counseling on hip-preserving treatments.

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SURGICAL TRAINING AND DISLOCATION AFTER TOTAL HIP ARTHROPLASTY: EXAMINING A PROFICIENCY-RELATED COMPLICATION

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ABSTRACT

Background: Roughly 500,000 total hip arthroplasties (THAs) are performed each year in the US, often with participation of resident surgeons. Though previous studies have not established a link between resident involvement in orthopedic surgery and complications, these investigations have lacked data such as number of residents involved, year-in-training, involvement of physician extenders, and level of attending involvement.

Methods: A retrospective study examined all patients who underwent THAs at the Veterans Affairs (VA) Puget Sound from 1999-2016 and had a minimum of 90 days of follow-up. Data was collected on patient and treatment factors as well as postoperative dislocation. Logistic regression analysis was employed to determine the characteristics associated with dislocation.

Results: Twenty-three patients (2.5%) experienced a dislocation. Dislocation was associated with increasing age ($p = 0.004$) and THA head diameter ($p < 0.001$), but not with year-in-training of the most senior resident ($p=1.00$) or number of residents involved ($p=1.00$), and did not vary significantly by form of attending involvement ($p = 0.837$). Multivariable analysis demonstrated independent associations of patient age (OR 1.056 per additional year, $p = 0.009$) and THA head diameter (OR 0.806 per additional millimeter, $p = 0.002$) with dislocation.

Conclusion: Dislocation was associated with increasing patient age and smaller THA head diameter, but not factors related to surgical training. THA may be safely performed by residents supervised through graduated autonomy, with the degree of attending supervision varying by case complexity and the resident's experience and skill.

Level of Evidence: III

Keywords: total hip arthroplasty, resident training, graduated autonomy

INTRODUCTION

An estimated 500,000 total hip arthroplasties (THAs) are performed each year in the United States.[1] With an aging population and demand continuing to exceed the supply of trained surgeons, resident training in THA remains a priority for the field.[2] Resident involvement in surgery typically follows a graduated autonomy model, whereby trainees acquire additional responsibility under the supervision of an attending surgeon as they progress in year and skill level.[3] An increase in complications under the graduated autonomy model is a theoretical risk, with 30% of one patient sample endorsing the perception that resident involvement in surgery increases complications.[4] THA complications are estimated to occur in about 7% of patients.[5] Postoperative dislocation, the most common indication for early revision, is generally accepted as a measure of technical proficiency given its association with implant placement and soft tissue management.[6] Multiple studies in both general surgery and orthopedic surgery have shown mixed results regarding whether resident involvement impacts complication rates.[7-11] Furthermore, previous investigations focusing on orthopedic surgery residents have primarily involved database research, lacking data such as year-in-training, number of residents involved, involvement of physician extenders, and form of attending involvement.[12,13] With complex patients often referred to academic centers, teams may be tasked with caring for particularly high-risk populations with multiple comorbidities. Our study examines THA complications within the Veterans Affairs (VA) population, which encompasses patients with generally poorer health status and more medical comorbidities than the population at large.[14] To our knowledge, no study has assessed whether resident involvement in surgery is associated with complications specifically within this complex population.

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We hypothesized that the number of residents involved, year of the most senior resident, and form of attending involvement would not be associated with the dislocation rate among VA patients. A better understanding of whether graduated autonomy in surgical education affects clinical outcomes will help optimize residency training and improve patient education regarding risks and benefits.

METHODS

The Institutional Review Board at the VA Puget Sound Health Care System approved this study. This retrospective cohort study analyzed electronic medical records for all adult patients who underwent THA at a VA hospital over an 18-year period, 1999-2016. Patients who did not have at least 90 days of follow-up were excluded. 923 individuals met inclusion criteria. We acquired data on patient demographics, underlying diagnosis, medical comorbidities (including calculation of Charlson Comorbidity Index), previous hip procedures, medications, length of rehabilitation, implant factors, attending surgeon identity and form of attending involvement (whether scrubbed for entirety of case), resident involvement including number of residents involved and year-in-training of the most senior resident, and involvement of physician extenders. Our population was predominantly male (92.4%) with a mean age of 63. The most common underlying diagnosis was degenerative joint disease (83%), followed by avascular necrosis (12.9%). The median Charlson Comorbidity Index (CCI) was 1 with an interquartile range of 1 to 3. A CCI ≥2 was present for 438 patients (47.4%), and a CCI ≥3 was present for 230 patients (24.9%).

Univariable analyses were performed to determine characteristics associated with the incidence of dislocation. One patient with a traumatic dislocation following a high-speed motor vehicle accident was excluded from this analysis. Multivariable logistic regression analysis was then performed using variables that had significant univariable associations. Associations were deemed statistically significant for $p < 0.05$. Finally, receiver operating characteristic (ROC) analyses were performed for significantly associated variables to estimate optimal thresholds for dislocation.

Table 1. Univariable Associations with Dislocation

Parameters	P value	Odds Ratio (95% CI)
Treatment Factors		
Increasing THA head diameter	< 0.001	0.804 (0.707 - 0.914)
Stem offset	0.769	0.837 (0.255 - 2.747)
Year-in-training of most senior resident	0.908	1.044 (0.504 – 2.162)
Number of residents involved	0.567	0.823 (0.422 – 1.604)
Physician extender involvement	0.442	0.701 (0.283 – 1.735)
Attending	0.647	1.069 (0.804 – 1.421)
Attending Scrubbed for Entirety	0.837	0.917 (0.400 – 2.100)
Patient Factors		
Increasing Age	0.005	1.064 (1.019 – 1.112)
CCI	0.985	1.003 (0.740 – 1.360)
Sex	0.559	1.827 (0.243 – 13.757)
BMI	0.636	1.021 (0.935 – 1.115)
Previous ipsilateral hip surgery	0.631	1.435 (0.328 – 6.277)

RESULTS

Residents were involved in 99.8% of cases, with an average of 2 residents involved per case. Physician extenders were involved in 75.0% of cases. The most senior resident was a 5th year resident in 56.6% of cases, and a 4th year in 40.5% of cases. The most senior resident involved was a 2nd or 3rd year in only 2.5% of cases. An attending was documented to be scrubbed for the entirety of 54.3% of cases. In 19.2% of cases the THA head diameter was ≤28mm, 37.0% were 32mm, 28.0% were 36mm, and 15.5% were ≥38mm. 21 patients (2.3%) experienced a dislocation. Univariable associations with dislocation included increasing patient age (OR 1.064 per year, 1.019-1.112, $p = 0.005$) and increasing THA head diameter (OR 0.804 per millimeter, CI 0.707-0.914, $p < 0.001$). Number of residents involved, year-in-training of the most senior resident, physician extender involvement, specific attending, form of attending involvement (whether scrubbed for entirety of case), Charlson Comorbidity Index (CCI), sex, BMI, previous ipsilateral hip surgery, and femoral stem offset were not significantly associated with dislocation (Table 1). Multivariable analysis demonstrated independent associations of patient age (OR 1.056 per additional year, $p = 0.009$) and THA head diameter (OR 0.806 per additional millimeter, $p = 0.002$) with dislocation (Table 2). ROC analyses suggested optimal binary thresholds of age ≥62 and THA head diameter ≤32mm as predictive of dislocation, though risk

Table 2. Multivariable Associations with Dislocation

Parameters	P value	Odds Ratio (95% CI)
Increasing THA head diameter (1 mm increments)	0.002	0.806 (0.706 – 0.921)
Increasing age (1 year increments)	0.009	1.056 (1.014 – 1.101)

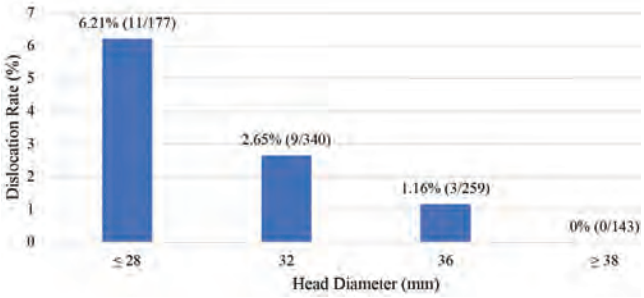

Figure 1. The dislocation rate was greater for smaller femoral head diameters. The most optimal threshold for increased risk was head diameter ≤ 32mm, although risk generally changed incrementally with THA head diameter.

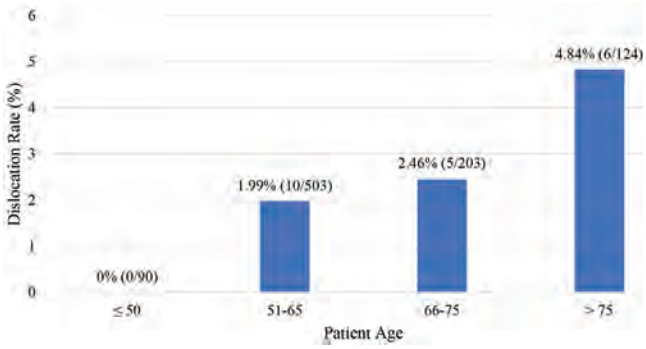

Figure 2. The dislocation rate was greater for older patients. The most optimal threshold for increased risk was age ≥ 62, although risk generally increased incrementally with age.

of dislocation increased incrementally for both variables as demonstrated in Figure 1 and Figure 2. The odds of dislocation increased by 5.6% for each additional year of patient age and decreased by 19.4% for each additional millimeter of THA head diameter.

DISCUSSION

We report a 2.3% dislocation rate among veterans who underwent THA, consistent with rates from 1-3% reported in the literature.[5,15] In the setting of graduated resident autonomy, the dislocation rate for veterans undergoing THA was not influenced by resident year-in-training or form of attending involvement. The most senior resident was in their 4th or 5th year of training in 97.5% of cases, suggesting a close attention to readiness for resident autonomy in this training program. This adds to a growing body of evidence that residents with adequate experience can safely participate in THA, given dislocation is generally accepted as a measure of technical proficiency. Our study is unique in that it assesses the impact of resident year-in-training and form of attending involvement, while also assessing patients with a minimum of 90 days of follow-up, whereas previous studies have examined 30-day risk of dislocation.[12]

We found patient age and THA head diameter were independently associated with dislocation. Prior studies have demonstrated that increasing age is associated with a greater risk of dislocation and other complications.[12,16] Similarly, previous research has demonstrated that increased THA head diameter is associated with reduced dislocation rates, thought to be the result of increasing the impingement-free range-of-motion and the "jump" distance needed for the head to exit the acetabulum.[17]

While a CCI ≥2 has been reported to be present for only 10% of elective arthroplasty patients, this accounted for 438 of 923 patients (47.5%) of our veteran population.[18] Understanding the risks of THA and how this might relate to surgical training is particularly important in this population. Our data showing that resident involvement is not associated with dislocation even within a relatively high-risk population provides further reassurance that in a surgical training program employing graduated responsibility with close supervision, trainees can gain necessary experience while safely caring for complex patients.

Limitations of the study include that resident autonomy in THA was primarily confined to the last two years of training, with no robust data indicating whether autonomy at earlier points in residency is associated with complications. Additionally, this work has limitations typical of retrospective research, including that we are unable to determine causation or to acquire data that was not recorded in the patient's chart.

CONCLUSION

The dislocation rate for veterans undergoing THA was not associated with factors related to surgical training including the form of attending involvement. Dislocation was associated with increasing patient age and smaller THA head diameter, reinforcing the need for specific risk counseling for elderly patients and careful consideration of implant selection. Total hip arthroplasty may be safely performed by residents supervised through graduated autonomy, with the degree of attending supervision varying by case complexity and the resident's experience and skill.

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OBJECTIVE FLUOROSCOPIC IMAGE-BASED ASSESSMENT OF INTRAOPERATIVE WIRE NAVIGATION SKILL AGREES WITH SUBJECTIVE EXPERT OPINION

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ABSTRACT

Background: The current standard for assessing orthopedic technical skill demonstrated in operating room performance relies primarily on subjective evaluations administered by an expert mentor. This study demonstrates the utility of fluoroscopic image-based analysis as an objective mechanism for assessing technical proficiency for a common wire navigation procedure by comparing it for the first time to the gold standard in orthopedic skills assessment: subjective expert opinion.

Methods: The final pin construct achieved during the closed reduction and percutaneous pinning of pediatric supracondylar humerus fractures was assessed for 23 operating room performances from fluoroscopic imaging to produce an objective ranking. Individual rank-orderings from six experts were independently aggregated into a consensus ranking for the same 23 performances. Inter-rater reliability of expert assessments was measured as Cronbach's α for individual rankings. Spearman correlation coefficients were used to evaluate relationships between individual expert rankings, a consensus ranking, and an algorithm ranking derived from objective scores.

Results: The inter-rater reliability of the experts' individual rankings yielded an α of 0.78, exceeding the 0.70 threshold for acceptable reliability. There was strong agreement between the objective ranking and the expert consensus (R^2 = 0.59), with the objective ranking agreement with consensus being superior to all but one individual expert.

Conclusion: These findings suggest that objective fluoroscopic image-based analysis is an effective tool for assessing technical operating room performance and highlight its potential role as a complementary tool to expert assessment in orthopedic skills training.

Clinical Relevance: While traditional assessments of intraoperative skill performance based on expert opinion remain important, they can be limited by cognitive biases and variability in feedback. The integration of objective metrics with expert consensus offers a more robust and scalable approach to skill assessment. This hybrid method has potential to complement subjective evaluations by facilitating more consistent and data-driven feedback, which can be particularly useful for training programs with limited mentor availability.

Keywords: surgical data science, skills assessment, expert opinion, rank ordering, fluoroscopic wire navigation

INTRODUCTION

Expert opinion has traditionally served as the foundation of orthopedic technical skills assessment in the operating room (OR).[1,2] This approach, rooted in the apprenticeship model, relies on mentors' insights and iterative feedback to help trainees close the gap between observed performance and desired proficiency.[3,4] Structured tools such as behavioral descriptors and Likert-scale ratings are commonly used and have proven utility in this context.[5-7] However, even these well-established methods are susceptible to inter-rater variability and cognitive bias, limiting their reliability and consistency in practice.[8,9]

A representative example of this challenge is fluoroscopic wire navigation, a core psychomotor task in which surgeons use intraoperative fluoroscopy to guide wires through bone during fracture repair.[10,11] Mastery of this skill requires repeated practice to ensure accurate wire placement and stable implant constructs.[12] Performance is often evaluated postoperatively through expert review of fluoroscopic images, but such assessments

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are constrained by image quality, visual obstructions (e.g., soft tissue, hands, instruments), and subjective interpretation.[13,14]

To improve reliability, some training programs involve multiple expert raters per case. While this can reduce individual bias, it introduces compliance burdens and still leaves room for variation across assessors.[15-17] In contrast, high-fidelity surgical simulators provide controlled environments for practice and offer repeatable assessments independent of mentor involvement.[18-24] In wire navigation tasks specifically, structured evaluations of postoperative fluoroscopic imaging have been proposed as objective proxies for surgical competence,[25-28] based on the assumption that optimal implant placement is associated with better outcomes and reflects underlying technical skill.[29,30]

Building on this rationale, fluoroscopic image-based analysis has emerged as a formalized assessment method that quantifies technical proficiency from full image sequences using predefined criteria.[31-34] However, these methods have not been systematically validated against expert opinion, which remains the current reference standard for intraoperative performance evaluation. Expert judgment remains essential for interpreting technical actions within the broader context of operative care.

Recent work has shown that residents trained using fluoroscopic image-based simulators can outperform their traditionally trained peers in the OR.[12] Yet, the objective criteria used in these assessments have not been directly compared with expert evaluations. To facilitate broader adoption, it is necessary to demonstrate that image-based scoring aligns with expert judgment and can meaningfully enhance it.[13]

This study evaluates whether objective criteria derived from fluoroscopic images can explain and agree with expert assessments of technical skill during closed reduction and percutaneous pinning of pediatric supracondylar humerus fractures. Because individual expert judgments often vary, we hypothesized that a consensus ranking would reveal a consistent signal within the individual noise, and that this consensus would correlate with objective criteria.[35] The study pursued two primary aims: (1) to determine whether a composite set of objective scoring criteria agrees with expert consensus,[25] and (2) to compare individual expert assessments and their consensus with the objective rankings.

METHODS

Study Design and Participants

Fluoroscopic images from 55 resident-performed closed reduction and percutaneous pinning of pediatric supracondylar humerus fractures were collected from a high-volume university hospital in the United States between June 2018 and July 2019. Inclusion criteria required that three lateral pins were used, as well as final anterior-posterior (AP) and lateral images that depicted the same construct without significant pixel blurring be available. Of the 55 performances, 23 met inclusion criteria. To maximize diversity and minimize bias in performance quality, all 23 qualifying cases were included in the analysis. No clinical outcome data were collected for any of these performances. All participants provided informed consent to participate in this research, in accordance with an approval by the Institutional Review Board of the University of Iowa (ID# 201409755).

A rank-ordering approach—a proven method for clarifying preferences among imaged clinical outcomes[1,36,37]—was employed to procure expert evaluations of the selected performances. A PowerPoint presentation was created, with each slide containing a high-quality digital copy of the final AP and lateral fluoroscopic images for each of the 23 performances (i.e., 23 total slides). All identifying information was removed from the images, and each slide was given a random four-digit title to discourage bias from chronological naming conventions. A screen capture of the user interface is shown in Figure 1. Each slide also included the following note to remind participants of the evaluation goal:

Use the slide sorter to rank order these cases from best (1) to worst (23) according to the final pin construct. Please attempt to ignore the fracture reduction.

This presentation format offers users three key benefits: (1) the ability to view multiple performances at once with the slide overview tab; (2) a built-in functionality to insert comments and annotations at the user's discretion; and (3) an intuitive mechanism for sorting, i.e., declaring a preference. This third point is a major distinction between rank-ordering and Likert scales. The PowerPoint format does not allow for a user to declare a tie; (de)merits of each performance must be weighed against each other.

The authors met with several attending surgeons in their university hospital's Orthopedics and Rehabilitation Department to identify the desirable characteristics of high-quality implant constructs for the performances and to develop the objective scoring criteria. Five metrics were explored as potential predictors of expert opinions for the 23 performances (Figure 2). The first metric was derived directly from Pennock et al.,[30] while the others were developed over time in consultation with subject matter experts from the authors' institution: (1) AP ratio, the distance between the most medial and most lateral pins relative to the width of the humerus at the level of the fracture in the AP fluoroscopic image; (2) lateral ('lat.') ratio, the spread of the pins relative to the width of the humerus at the level of the fracture in the lateral

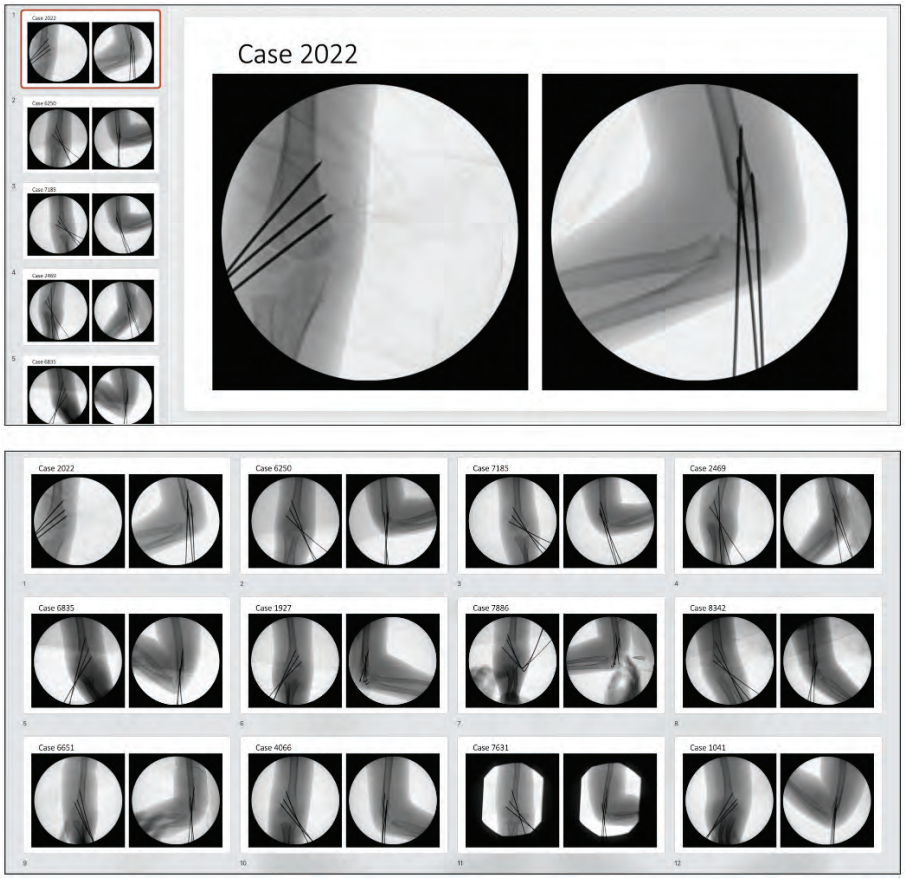

Figure 1. Screen captures of the PowerPoint interface provided to experts. (Top) Each of 23 slides illustrates the final AP and lateral images for a given performance, an encoded titular identifier, and an instructive reminder of the rank order task. (Bottom) In slide sorter view, all of the cases can be quickly sorted.

fluoroscopic image; (3) middle ('mid.') ratio, the relative separation of the three pins along the fracture in the AP view; (4) lateral-center angle, the angle between the lateral and center pins in the AP view; (5) lateral-medial angle, the angle between the lateral and medial pins in the AP view; and (6) center-medial angle, the angle between the center and medial pins in the AP view.

Of more than 20 criteria examined by Pennock et al., only the AP ratio significantly correlated with clinical outcomes; constructs spanning one-third of the humerus width at the fracture were significantly less likely to fail. While not examined directly, Pennock et al. postulated that pin spread is the single most important attribute of a biomechanically stable implant construct. It is for this reason that this study includes the lateral ratio and middle ratio in its tested objective criteria. The angle-based metrics (4-6) are unique to this study and were included because they are easily derived from the annotations required for the first three metrics (as is the middle ratio).

Six board-certified, fellowship-trained orthopedic surgeons from four institutions across the United States participated as expert raters in this survey. All experts hold active orthopedic faculty positions and contribute regularly to scholarly research. The experts were recruited via email invitations sent to members of professional pediatric orthopedic societies. No exclusion criteria were applied in the recruitment of the experts. The experts had no prior knowledge of the study design, nor of the metrics used for the objective analysis.

Procedures

Objective parameters were measured using custom software designed to assist non-experts with fluoroscopic image analysis.[38] The software allowed users to annotate the fracture line and the three pins in the final AP and lateral images, then it automatically calculated the values for the objective criteria. An analyst initially identified the fracture lines, and an attending orthopedic surgeon at the university hospital verified them. The analyst was

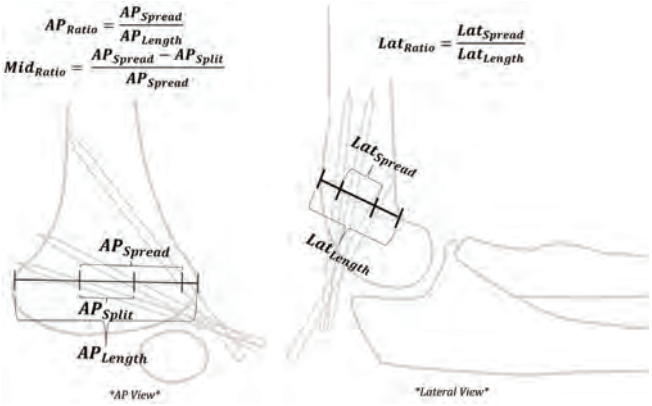

Figure 2. An illustration of the AP ratio, middle ('Mid') ratio, and the lateral ('Lat') ratio metrics, shown in their respective 2D views with a graphic depicting the anatomy of a supracondylar humerus fracture. Equations for calculating the latter two ratios are included. AP spread and Lat spread quantify the distance between the outermost pins along the fracture in their respective views, while AP length and Lat length quantify the width of the bone at the fracture site, and AP split is the smallest distance between the center wire and its nearest wire at the fracture site.

an engineering graduate student who participated in discussions to determine which parameters would be measured. The supervising surgeon, however, did not take part as an expert in the subsequent rank-ordering task.

Randomly shuffled versions of the original 23-slide PowerPoint presentation were distributed to the six experts. Each expert independently reviewed the performances depicted in the slides, sorted them by the most skilfully demonstrated construct, and then returned their sorted document via email. All identifying information was removed from the ranked results before synthesizing the data. Expert assessments were aggregated to form a consensus by (1) calculating the within-performance arithmetic mean of the six expert rankings and then (2) ranking those mean values across the 23 performances. In the cases of a tie, tie-breaking preference was given to the performance with the smaller within-performance variance. While other methods exist,[39-41] a simple mean aggregation was chosen to approximate the signal within the experts' data and prevent overfitting to a small sample.

A forward-selection iterative technique was used to build a simple and explainable model for identifying a combination of objective measurements that best correlated with the expert consensus. This method evaluated models based on explanation of variance (R^2) and statistical significance (p-value). In each iteration, a candidate model was compared to a reference model; if the candidate model improved upon the reference, it became the new reference for the following iteration. Models that did not improve performance were discarded. A y-intercept term was included in every tested model to

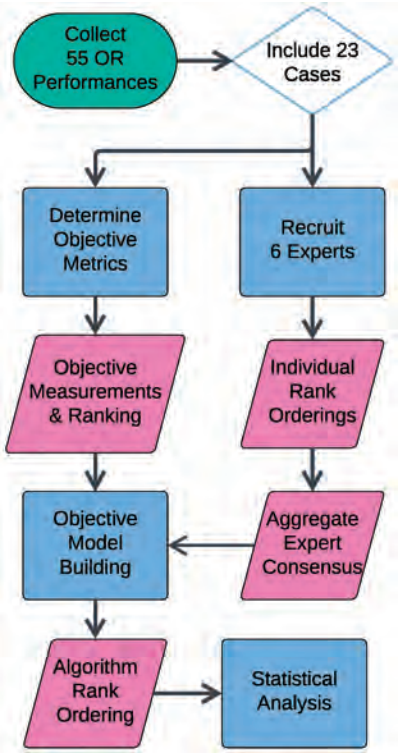

Figure 3. A flowchart of the experimental procedure illustrating the steps involved in collecting the OR performance image data, applying inclusion/exclusion criteria, and performing expert and objective rank-ordering data collection. Parallel paths represent the expert evaluation process and the development of objective rankings, and converge in the statistical analysis phase, which includes inter-rater reliability, Spearman correlation, MRSE, and R^2 calculations.

avoid assuming that the best expert consensus ranking in the sample represents the best possible outcome in the population. No data transformations were applied, and only linear models were considered. The model from the final iteration—the one that agreed best with the expert consensus—was selected for generating an objective score[25] for each of the 23 performances. The sorting of these scores determined the algorithm's final ranking. Classic regression assumptions like linearity, homoscedasticity, and normality of residuals, are not applicable given the ordinal nature of the ranking data, which do not have equal intervals and does not follow a continuous distribution. Figure 3 details a flowchart of the experimental procedure.

Statistical Analysis

Inter-rater reliability of the expert assessments was measured as Cronbach's α for their individual rankings.[42] This metric was evaluated against a threshold value of $\alpha \geq 0.70$ to discriminate sufficiently acceptable reliability.[43] A table of Spearman correlation coefficients were calculated to evaluate the relationships between each of

Table 1. Iterations of the Forward-Selection Model Building Technique for the Algorithm Ranking

Model	Explanatory Variable(s)	Intercept	Slope	Residual Error	R^2	Models Compared	P-Value
1	AP	5.940	0.051	6.032	0.248	-	0.016
2a	AP + L	3.823	0.677	5.157	0.450	1 - 2a	0.001
2b	AP + M	4.051	0.655	5.262	0.428	1 - 2b	0.001
*2c	AP + L + M	2.522	0.783	4.342	0.594	1 - 2c	< 0.001
3a	AP + L + M + LCθ	5.700	0.518	5.954	0.267	2c – 3a	0.012
3b	AP + L + M + LMθ	4.787	0.594	5.601	0.351	2c – 3b	0.003
3c	AP + L + M + CMθ	4.680	0.603	5.556	0.362	2c – 3c	0.002

*AP: AP Ratio; L: Lateral Ratio; M: Mid-Ratio; LCθ: Lateral-Center pin angle; LMθ: Lateral-Medial pin angle; CMθ: Center-Medial pin angle.
*Model 2c selected as the best model.

the individual expert rankings, their consensus ranking, and an algorithm ranking derived from objective scores for each of the 23 performances. The root-mean-squared error (RMSE) was used to measure the error of the individual experts' rankings and the algorithm's ranking relative to the expert consensus.

The individual expert rankings, the expert consensus, and the algorithm scores were plotted against the algorithm ranking. A coefficient of determination (R^2) was calculated to assess the relationship between the algorithm ranking and the expert consensus. All statistical analyses were conducted and plots created using MATLAB (Mathworks, Natick, MA).

RESULTS

The inter-rater reliability of the experts' individual rankings yielded an α of 0.78, exceeding the preset threshold for acceptable reliability. Table 1 outlines the three iterations used to select the objective criteria for the scoring algorithm. Of the six objective metrics considered, the model (2c), consisting of the AP ratio, lateral ratio, and middle ratio produced algorithm scores for the 23 performances and a ranking that had the best agreement with expert consensus. The remaining three metrics, lateral-center pin angle, lateral-medial pin angle, and center-medial pin angle, did not sufficiently improve the agreement, leading to their exclusion from the model.

Equation 1 below presents the composite model for the algorithm's scoring criteria. Table 2 shows the Spearman correlation coefficients computed for all rankings. Notably, the algorithm demonstrated the second-highest correlation with the expert consensus (ρ = 0.78), with only one individual expert (Expert 1, ρ = 0.83) achieving a higher correlation. Two inter-expert correlations were near zero, indicating minimal agreement between those experts. The errors of the six experts and of the algorithm are reported in Table 3. Only one of the experts (Expert 1, RMSE = 3.12) outperformed the algorithm (RMSE = 4.26). The highest recorded error was an RMSE of 5.9 (Expert 5).

$$\textit{Algorithm performance score} = (AP_{ratio} + lat_{ratio} + mid_{ratio}) / 3 \quad \text{Equation 1}$$

The raw rankings of individual experts, their consensus, and the algorithm score-based ranking are indicated in Figure 4. Rankings are plotted as a function of the algorithm ranking, with the x-axis indicating the algorithm's ranking from worst (at the origin) to best. The second y-axis presents the normalized algorithm scores for each performance. The algorithm accounted for 59% of the variance in the expert consensus. Notably, disagreements between experts for the same performance spanned from zero to 22 ranking positions.

DISCUSSION

A consistent and fair dialogue between expert mentors and surgical trainees is crucial for developing technical skills.[44,45] For common technical skills like fluoroscopic wire navigation, there are well-documented metrics linked to favorable patient outcomes and technical proficiency.[30] In pediatric supracondylar humerus fractures, mentors assessing a trainee's performance typically consider the AP ratio, which indicates the pin spread relative to the fracture width, as a critical measure of technical skill. Generally, a higher AP ratio can suggest a lack of precise psychomotor control. However, this metric alone is not the sole determinant of a mentor's evaluation. The inherent complexity of these procedures provides room for evaluators to emphasize some factors over others, leading to differential bias.

When evaluating a performance using the final AP and lateral images, a mentor might (1) imprecisely or

Table 2. Spearman Correlation Coefficients Representing Agreement Between Expert Rankings, Their Aggregated Consensus, and the Ranking of Objective Algorithm-Generated Scores

Spearman Correlation ρ	Subjective Expert Rankings						Algorithm Ranking
	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Consensus	
Expert 1	0.55	0.69	0.56	0.34	0.60	0.93	0.69
Expert 2		0.27	0.37	0.43	0.36	0.70	0.67
Expert 3			0.55	-0.01	0.34	0.70	0.36
Expert 4				-0.13	0.19	0.60	0.20
Expert 5					0.37	0.45	0.58
Expert 6						0.66	0.67
Consensus							0.78

Darker-shaded cells correspond to stronger associations between variables.

Table 3. Root-Mean-Square Error (RMSE) as a Function of the Expert Consensus for the Six Individual Expert Rankings and for the Algorithm-Generated Rankings

RMSE	Subjective Expert Rankings						Algorithm Ranking
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	
Expert Consensus	3.1	4.6	4.8	5.2	5.9	4.8	4.3

Darker-shaded cells correspond to lower error.

inaccurately estimate the AP ratio, (2) apply different weights to the importance of the AP and lateral views in assessing the pin construct, or (3) introduce other cognitive biases into the evaluation. An expert may not agree with their own opinion a month later, let alone with a peer's perspective. Such inconsistencies are unsurprising given the inherent limitations of individual expert opinion, but they can impede the skill training process by distorting feedback with bias.

To overcome these limitations, residency programs often face the classic trade-off between resource allocation and assessment accuracy: they can either increase the number of raters to reduce bias or focus on making individual experts more reliable judges of skill. In this discussion, we explore how combining objective data with the wisdom of crowds can improve assessments without encountering this trade-off.

A simple aggregation method was intentionally chosen to avoid overfitting and to highlight the underlying signal within the noisy data, ensuring interpretable results and emphasizing expert consensus. This approach successfully demonstrates the wisdom of crowds at play in this work, as six independent, decentralized, and diverse experts[35] produced rank orderings with a measured inter-rater reliability ($\alpha = 0.78$) that indicates acceptable internal consistency. This threshold aligns with typical standards in the field,[46,47] and it is notable for subjective ratings in complex domains like orthopedic skills assessment, which can widely vary. Despite some variability among individual opinions, the data suggest a shared understanding of the task, as evidenced by the generally moderate-to-strong correlations between experts and the consensus. Although Expert 5 exhibited weaker correlations, their inclusion did not significantly detract from the overall consistency, demonstrating that all raters contributed meaningfully to the scale without any individual disproportionately affecting reliability.

Despite the cognitive demands and complexity of the rank-ordering task, there are occasions where expert opinions showed exact or near-exact agreement across the 23 performances (Figure 4). This is supported by strong correlations between individual experts and the expert consensus. Only two inter-expert relationships were weak, both involving Expert 5, with Spearman correlation coefficients with other experts being near-zero (Table 2, $\rho \leq |0.1|$).[48] The relationship between the individual experts and their aggregated consensus ranges from moderate (Expert 5, $\rho = 0.45$) to near-perfect (Expert 1, $\rho = 0.93$), further supporting the robustness of the survey design and methods for aggregating expert opinions.

The ability of expert surgeons to reliably rank order the quality of wire pinning constructs lends credibility to the model selected for the algorithm scoring, and more broadly, to the fluoroscopic image-based analysis approach (Table 1, Model 2c). In addition to the well-

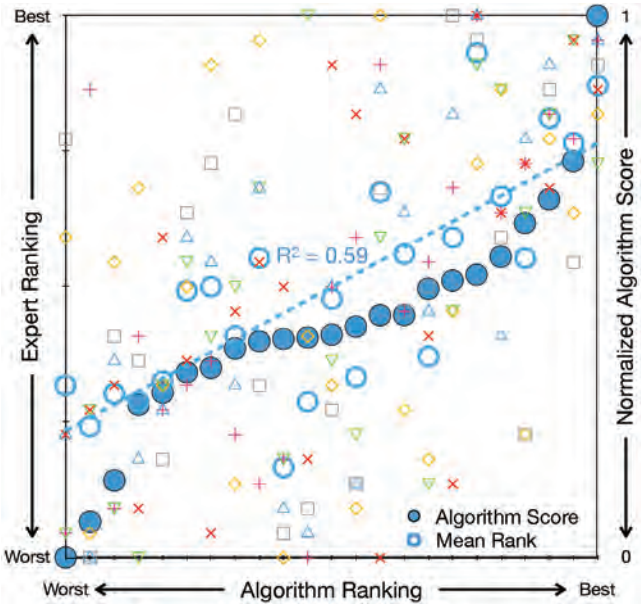

Figure 4. A graphical representation of the ranking values for each of the 23 performances. Individual expert rankings are shown as small and individualized icons, the intra-performance arithmetic mean rank values representing expert consensus are shown as larger and open circles, and the algorithm scores are shown as larger shaded circles. All variables are plotted as a function of the algorithm ranking.

validated AP ratio,[30,49] two additional novel metrics, lateral ratio and middle ratio, played a significant role ($p < 0.001$) in explaining the aggregated expert opinion. This development process supports face validity, as the objective criteria were designed in collaboration with orthopedic surgeons to ensure clinical relevance. Although informed by only a simple linear model with uniform weights, the algorithm ranking strongly correlated with expert consensus ranking (Table 2, $\rho = 0.78$; Figure 4, $R^2 = 0.59$). The algorithm, while explicitly calibrated to a collective wisdom, outperforms the individuals from whom that wisdom was derived. That only one expert (Table 3, Expert 1, RMSE = 3.1) outperformed the algorithm (RMSE = 4.3) further supports the convergent validity between the objective and subjective methods.

Although assumptions of linear regression (e.g., linearity, homoscedasticity, and normality of residuals) are not considered here due to the ordinal nature of the data, the forward-selection model building technique proved useful in identifying the combination of pin spread related metrics that reasonably explain, or describe, the expert consensus. This aligns with existing knowledge that aggregated opinions typically yield better results than individual judgments, including in surgical skills assessment,[35,50-52] as the algorithm aims to detect a consistent signal amid idiosyncratic noise.[53] Although diverging expert opinions may enhance the utility of the aggregated consensus, they also highlight the inherent fallibility of human judgment.

Despite reliable agreement and a demonstrated shared understanding of technical proficiency, significant discrepancies still highlight the challenges of subjective skills assessment. Even with the universal acceptance of the AP ratio as a gold-standard measure, individual expert opinions varied widely in this study. Ranking disagreements ranged up to 22 positions for the same performance (Figure 4), showing how two experts can apply fundamentally different assessment criteria. On average, the range of expert opinions spanned 12 ranking positions—more than half of the total measurement scale.

The variability in expert opinions reveals a broader issue of bias inherent in subjective skills assessments. Literature acknowledges that non-standardized factors can influence these assessments, resulting in inconsistencies.[16,54] Experts may rely on personal heuristics or idiosyncratic factors, such as focusing on specific details like "the lateral-most pin is outside the ideal start point inside the hourglass," despite broader objective criteria. Increasing the number of assessors can mitigate this variability, as relying on a single expert may amplify subjective bias. If left unchecked, this variability can disrupt the "see one, do one, teach one" methodology and hinder the feedback process essential for skill development.[2,44,45,55]

Recent assessment strategies aim to address these limitations by incorporating input from multiple assessors to reduce bias.[16,54,56,57] Even within these efforts, residents have expressed concerns about receiving insufficient assessments from their busy mentors.[16] Additionally, residents continued to perceive bias in evaluations, even when using post-operative and consensus-driven protocols. The findings from this study, along with insights from the literature, emphasize the need for more objective and standardized approaches to reduce the impact of individual variability in surgical skill assessment. The findings of this study suggest that fluoroscopic image-based analysis provides a reliable framework for assessment that provides objective measures with which a larger group of experts can agree with.

Implications for Orthopedic Technical Skill Assessment

Rather than relying solely on traditional subjective methods or attempting to eliminate individual biases,[53] future assessments could benefit from incorporating techniques like fluoroscopic image-based analysis to achieve several goals. First, this approach promotes

systematic introspection to identify objective criteria that are crucial for evaluation and feedback. Second, it champions crowd source science that captures signals that these criteria effectively model. Third, it can improve compliance and scalability by minimizing privacy and logistical obstacles.[57,58]

From an institutional perspective, this hybrid methodology offers significant advantages over traditional approaches. It is less prone to the limitations of traditional methods; more robust than individual subjective assessments by being grounded in agreement with a greater number of experts. Additionally, it has potential to be more cost-effective by offering analogous efficiencies to simulated performance assessments. Thomas et al.,[59] envision mentors post-operatively reviewing intraoperative fluoroscopic images alongside objective metrics that evaluate decision-making and construct quality, a framework that increases repetitions of assessments without increasing burden on expert mentors. Rather than relying solely on visual approximations from manual inspection of images or intraoperative videos,[56,57] mentors also could use discrete measurements to inform, complement, or validate their judgments and provide more precise feedback to trainees.

For trainees, this hybrid approach offers objective feedback backed by a broader consensus, fostering greater trust and confidence in the evaluations. Furthermore, it could facilitate objective self-evaluation for performances when mentors are unavailable. Since these criteria are derived from straightforward annotations, automated fluoroscopic image-based analysis will likely be feasible in the future. Automation, like that seen in surgical simulator skills evaluations, could significantly improve trainee access to actionable feedback, thereby, enhancing technical proficiency and development of better-prepared surgeons.

Moreover, experts may find rich value in combining quantitative, objective data with their traditional subjective evaluations.[13,60] Such integration could ensure that assessment, and skills training more broadly, become more comprehensive and less vulnerable to subjective bias and individual variability. This approach reinforces the notion that a combination of different assessments is essential for a thorough evaluation of intraoperative performance,[55] making fluoroscopic image-based analysis an important tool for the future of orthopedic surgical training.

Limitations

In designing the algorithm, we prioritized interpretability and parsimony over complexity and robustness, intentionally avoiding complex data transformations and non-linear relationships. While this approach provided a reasonably strong goodness-of-fit, it may have been compromised by unenforced assumptions regarding independence, normality of residuals, and collinearity among predictors. These factors, along with the distributional properties of the data, were not deeply examined. Nonetheless, the forward-selection model-building procedure remains a suitable approach for identifying objective metrics that strongly correlate with the expert consensus. It is important to emphasize that the goal of this study was not to validate a specific mathematical model for assessing skill but to demonstrate the utility of fluoroscopic image-based analysis as a framework for explaining how objective metrics can align with a group of experts' consensus opinion. Future research should explore more rigorous model-building techniques to ensure expert mentors can fully understand and apply the results.

Additionally, expert feedback indicated that the rank-ordering task was cognitively challenging, likely due to the requirement to compare 23 performances simultaneously. This cognitive challenge may have contributed to the observed variability in individual rankings (Figure 4). The small sample size of experts (6) and the absence of validation using unseen data further limit the model's generalizability. Future studies should focus on more robust designs, such as reducing the cognitive load of assessments or increasing the number of participating experts.[15,37,61] Alternative approaches, such as paired comparison surveys,[62] may also address these issues.

Finally, the practical constraints and inclusion/exclusion criteria for the 23 selected performances may have introduced bias. While the data were collected from a high-volume hospital, multi-institutional studies are necessary to confirm the generalizability of these findings to other settings and populations.

CONCLUSION

This study examines the utility of fluoroscopic image-based analysis as an objective method for evaluating technical skills in percutaneous wire pinning for pediatric supracondylar humerus fractures. By comparing objective metrics with aggregated expert opinions, we observed significant alignment ($R^2 = 0.59$), reinforcing the face validity and convergence validity of this approach in orthopedic performance evaluation. In another example of the wisdom and objectivity of crowds, the objective ranking better reflected the expert consensus than individual experts themselves, demonstrating that aggregating expert opinions can reduce variability and improve reliability.

While traditional assessments based on expert opinion remain important, they are often limited by cognitive biases and variability in feedback. The integration of

objective metrics with expert consensus offers a more robust and scalable approach to skill assessment. This hybrid method has potential to complement subjective evaluations by facilitating more consistent and data-driven feedback, which can be particularly useful for training programs with limited mentor availability.

Future research should aim to expand the use of fluoroscopic image-based analysis across broader surgical contexts. Ultimately, combining objective data with expert assessments holds the potential to create a standardized, scalable framework for evaluating technical proficiency, enhancing surgical training, and improving patient outcomes.

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DOES RESILIENCE CORRELATE WITH PATIENT-REPORTED OUTCOMES FOLLOWING ISOLATED GASTROCNEMIUS RECESSION

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ABSTRACT

Background: Patients' characteristics, both physical and mental, are proven to have relationships to patient-reported outcomes following orthopaedic surgeries. This study aims to elucidate the impact of resilience, using the Brief Resilience Scale, on patient-reported outcomes following isolated gastrocnemius recession for patients with plantar fasciitis or Achilles tendinopathy with secondary exploratory analysis on factors influencing these outcomes.

Methods: Patients were selected utilizing the current procedural terminology code 27687 between 2013-2020. The electronic medical record was reviewed for basic demographics. Patients were contacted for patient-reported outcome measurement information system (PROMIS) scores, foot function index (FFI) scores, and brief resilience scale survey questionnaires. Pearson correlations were used to assess the association of FFI and PROMIS domains. A linear regression model was constructed to evaluate the independent effect of resilience on each FFI and PROMIS outcome instrument. A significance threshold of $P < 0.05$ was used to determine significance in the regression model.

Results: Increased resiliency showed a significant correlation with increased PROMIS physical function ($r = 0.46$, $p<0.0001$), decreased PROMIS pain interference ($r = -0.043$, $p < 0.0001$), and decreased PROMIS depression ($r= -0.04$, $p < 0.0001$). Increased resiliency showed a significant correlation with decreased FFI activity limitation ($r= -0.047$, $p < 0.0001$), decreased FFI disability ($r = -0.53$, $p < 0.0001$), decreased FFI pain ($r = -0.36$, $p < 0.0001$), and decreased FFI total ($r= -0.52$, $p < 0.0001$).

Conclusion: This study demonstrates the positive impact resilience has on patient-reported outcomes following isolated gastrocnemius recession for patients with a clinical diagnosis of either Achilles tendinopathy or plantar fasciitis. We were able to show a moderate correlation between higher resiliency and improved PROMIS and FFI scores for all domains. Optimizing resiliency preoperatively may help to optimize an individual's own surgical outcomes and aid physicians in managing patient expectations following surgery.

Level of Evidence: IV

Keywords: gastrocnemius, resilience, PROMIS, patient-reported outcomese

INTRODUCTION

Gastrocnemius recession (GR) is an effective treatment for equinus deformities of the foot secondary to a multitude of pathologies, most commonly gastrocnemius contracture.[1-4] In a study on the prevalence of isolated gastrocnemius contractures in patients suffering from midfoot or forefoot pathology, the presence of isolated gastrocnemius contracture was 65-88%.[2] Historically, GR was reserved for pediatric neurological contractures, but, as the link between isolated gastrocnemius contracture and foot pathologies has developed, the indications for performing a GR have increased both in isolation and with other procedures.[3,4] With the expanded indications, the utilization of GR is becoming more frequent in the treatment of forefoot and midfoot pathologies.[3-5]

Patient-reported outcomes have long been used to assess the efficacy of various treatments. Commonly reported outcomes include the patient-reported outcome measurement information system (PROMIS) and the foot functional index (FFI).[6-9] PROMIS was created with funding from the NIH to collect patient-reported outcomes on quality of life regarding a variety of conditions. Since its creation in 2004, many studies have found this scoring system to be a reliable tool for assessing the health burden of injuries and illnesses.[10] Several studies have been conducted on the association between PROMIS scores and surgical outcomes in orthopaedics.[11-13]

An additional patient measurement being studied for correlations with operative outcomes is resilience. Per Smith et al., resilience is defined as the ability to

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bounce back or recover from a stressful event.[14] This trait is considered to be stable, aiding in its ability to predict patient outcomes.[15] The Brief Resilience Scale (BRS) is the current gold standard method for determining patient resilience.[14,16] The BRS has shown excellent psychometric properties and has been used in multiple populations.[14]

There has been recent interest in using resiliency scores as a predictive model for determining patient outcomes following surgery. Past papers have studied the use of resiliency as a predictive model for outcomes following Orthopedic procedures.[17-19] To our knowledge, no papers have studied the effect of resiliency on outcomes of isolated GR. The aim of this paper is to expand the knowledge of resiliency by assessing correlations between resilience and postoperative outcomes following isolated GR.

METHODS

Following approval from our institution's institutional review board (IRB), the electronic medical record was queried for the current procedural terminology code 27687 (Gastrocnemius Recession) for a single surgeon from Jan 2013 to June 2020 which yielded 479 patients. Patients were included if they underwent isolated GR and had a preoperative diagnosis of plantar fasciitis or Achilles tendinopathy. This surgeon utilized the Silfverskiold test to measure the degree of contracture of the ankle joint while isolating the gastrocnemius. A positive test for this surgeon is a loss of an estimated 8 degrees of flexion or more of dorsiflexion upon knee extension.

Patients were excluded if they had undergone concomitant surgery, had less than one year of follow-up, were under the age of 18, or declined to answer all three surveys. Patients were contacted retrospectively via phone interviews to complete outcome questionnaires. A total of 189 patients met the inclusion criteria. Utilizing the EMR, patient charts were reviewed to obtain basic patient demographic information. Clinical measures included patient American Society of Anesthesiology (ASA) scores and body mass index (BMI). Comorbidities such as tobacco and alcohol use, diabetes, hypertension, peripheral neuropathy, chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), coronary artery disease (CAD), chronic kidney disease (CKD), rheumatoid arthritis (RA), and osteoporosis/osteopenia were collected. Additional variables included any history of chronic NSAID use, duration of symptoms, and a history of previous foot and ankle procedures.

Gastrocnemius Recession Surgery

This surgeon's technique for GR is performed under general anesthesia. A posteromedial incision is made on the posterior aspect of the musculotendinous junction of the Achilles tendon. After sharp dissection through the skin and blunt dissection through the subcutaneous tissue, the paratenon is exposed with a vertical cut. Army-Navy retractors are used to keep the paratenon exposed. Complete recession of the gastrocnemius musculotendinous junction is carried out using a beaver blade. Thorough irrigation of the wound is performed. The subcutaneous tissues are closed using 4-0 Monocryl and skin closure is performed using skin staples.

Patient Reported Outcomes

The BRS, PROMIS, and Foot Function Index (FFI) scores were obtained through a combination of follow up clinic visits and phone interviews. The PROMIS pain interference (PI) version 1.1, physical function (PF) version 1.2, and depression (D) version 1.0 computer adaptive test (CATs) were collected. CATs reduce the total number of answered questions through an algorithm that selects the most relevant question based on the patient's previous answers. Each PROMIS domain has a mean T-score of 50, representing the general population, and a standard deviation of 10. A higher score correlates with more association with the category. For example, a patient with a pain interference score of 60 has a pain score one standard deviation above that of the general population.

FFI domains of pain, disability, and activity limitation were collected and scored. Each patient's total FFI score was calculated as an average of the three domain scores. Higher scores correlate with increased pain, disability, or activity limitation.

The BRS was used to assess patient resiliency. The BRS is based on a series of six questions scored on a 5-point Likert scale. A higher score correlates with a higher level of resilience.

Statistical Analysis

Data was aggregated in Microsoft Excel and entered in R (version 4.2.0) for statistical analysis. All continuous variables were first evaluated for normality via the use of a Shapiro-Wilk test. After checking for normality, Pearson correlations were used to assess the association of variables on FFI and PROMIS domains. A linear regression model was constructed to evaluate the association of resilience with each FFI and PROMIS outcome scores, while accounting for the effects of demographic and prognostic variables (age, BMI, diabetes, history of previous operation). BRS was included in all regression models. Other variables were included in the regression models based on an a priori significance threshold of $P < 0.05$ in bivariate analysis.

RESULTS

Patient demographics, comorbidities, and complications can be seen in Table 1.

Patient Reported Outcomes

Patient reported PROMIS, FFI and BRS scores, which were collected a median of 4.17 years postoperatively with an IQR of 3.86 (2.16 - 6.02), can be seen in Table 2.

Increased resiliency, as assessed by BRS, showed a significant correlation with increased PROMIS PF ($r = 0.46$, $p < 0.0001$), decreased PROMIS PI ($r= -0.043$, $p < 0.0001$), and decreased PROMIS D ($r= -0.04$, $p < 0.0001$). Increased resiliency showed a correlation with decreased FFI activity limitation ($r= -0.047$, $p < 0.0001$), decreased FFI disability ($r= -0.53$, $p < 0.0001$), decreased FFI pain ($r= -0.36$, $p < 0.0001$), and decreased FFI total ($r= -0.52$, $p < 0.0001$).

Bivariate analysis

The results of the exploratory bivariate analysis for the factors affecting patient-reported outcomes are shown in Table 3.

Figure 1 demonstrates the different beta values for BRS with bivariate analysis between the different sections of the patient-reported outcome tools used. The closer the beta value is to 1 suggests significance of these correlations. This graph does not stratify the population based on comorbidities.

Regression Analysis

Resilience was found to have statistically significant effects ($p < 0.001$) on all PROMIS and FFI measures when controlling for the effect of confounding variables (Table 4). However, beta values suggest a wider range of deviation for several PROMIS categories. In addition to resilience, a history of previous ankle procedure, diabetes, duration of symptoms, tobacco use, peripheral neuropathy, and wound complications were found to have statistically significant ($p < 0.05$) effects on PROMIS and FFI scores in multivariate analysis (Table 4).

DISCUSSION

In this study, we investigated the relationship between resilience and patient-reported outcomes following isolated GR in patients with plantar fasciitis or Achilles tendinopathy. GR is a commonly performed procedure, with a past study by Sankey et al. proving its effectiveness through improvements in PROMIS and pain VAS scores.[1] Adding to prior knowledge, our results demonstrate that increased patient resilience is correlated with improvements in patient-reported outcome measures. Few papers have been published on the topic of resilience and its effect on surgical outcomes in foot and ankle surgery.[20,21] To our knowledge, this is one of the largest studies on the association between resilience and its impact on post operative recovery, pain tolerance, and function following foot and ankle surgery, and the first to do so following GR.

Indications for GR include most pathologies that lead to equinus contractures such as plantar fasciitis and Achilles tendonitis.[4,5,22] The purpose of the surgery is to lengthen the calf muscles and tendons at the back of the leg, relieving tightness in the calf, and subsequently de-

Table 1. Cohort Demographics, Procedural Characteristics, and Clinical Outcomes

Variable	Median (range) or N (%)
Age	49.97 (18-78)
Sex (F)	138 (73.05)
BMI	35.38 (18-67)
ASA	2.58 (1-4)
Tobacco use	54 (28.57)
DM	32 (16.93)
PN	31 (16.40)
HTN	97 (51.32)
RA	3 (1.58)
Equinus contracture	131 (69.31)
Plantar Fasciitis	132 (69.84)
Achilles Tendinopathy	59 (31.22)
Chronic NSAID use	78 (41.27)
Duration of Symptoms (months)	25.67 (6-240)
History of Previous F/A procedures	41 (21.69)
Sural Neuropathy	20 (10.58)
Wound Complication	7 (3.70)
Revision Surgeries	10 (5.29)
Time from surgery to survey (yr)	4.17 (1.12-9.10)

Table 2. Patient-Reported Outcomes Following GR

Patient Reported Outcome	Median Scores (IQR)
PROMIS PF	44.5 (38.6-52.7)
PROMIS PI	53.9 (38.7-62.7)
PROMIS D	38.9 (34.2-48.6)
FFI Pain	28.00 (2-62)
FFI Disability	32.22 (7.78-65.56)
FFI Activity Limitation	3.00 (0-30)
FFI Total	28.24 (7.65-54.12)
BRS	19.00 (15.04-22.20)

Table 3. Bivariate Analysis for the Factors Affecting Patient-Reported Outcomes

Categorical Variable (p)	PROMIS PF (p)	PROMIS PI (p)	PROMIS D (p)	FFI Pain (p)	FFI Disability (p)	FFI Activity Limitation (p)	FFI Total (p)
BRS	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*
Previous F/A procedure	0.12	0.02*	0.02*	<0.001*	0.01*	0.04*	<0.0001*
Equinus Contracture	0.61	0.54	0.98	0.48	0.7	0.94	0.59
Plantar Fasciitis	0.84	0.53	0.61	0.75	0.87	0.23	0.8
Achilles Tendinopathy	0.7	0.47	0.85	0.87	0.64	0.3	0.98
Female Sex	0.98	0.82	0.44	0.49	0.67	0.69	0.59
Age >45	0.25	0.9	0.05	0.48	0.89	0.37	1
BMI >30	0.78	0.23	0.31	0.09	0.35	0.48	0.18
Tobacco Use	0.13	0.04*	0.96	<0.0001*	<0.0001*	0.03*	<0.0001*
DM	0.62	0.78	0.02*	0.9	0.83	0.61	1
HTN	0.54	0.09	0.43	0.05	0.15	0.18	0.07
PN	0.29	0.1	0.88	0.8	0.76	0.03*	0.63
RA	0.46	0.15	0.01*	0.15	0.74	0.06	0.96
Chronic NSAID use	0.16	0.22	0.59	0.49	0.76	0.81	0.64
Symptoms longer than 2 years	0.64	0.75	0.4	0.02*	0.05	0.24	0.02*
Wound Complication	0.54	0.46	0.88	0.43	0.72	0.09	0.68
Revision Surgery	0.04*	0.06	0.16	0.04*	0.12	0.06	0.04*
Follow up >3 years	0.34	0.74	0.45	0.79	0.42	0.3	0.57

creasing pain. This procedure has a good patient satisfaction rate with one paper reporting 93% of patients saying they would recommend it to a friend.[4] Previous studies have demonstrated this procedure's ability to increase patient ankle function and decrease pain levels.[4,5,22-25] The relationship between resilience and outcomes analyzed in this study can aid physicians in managing patient expectations following GR.

The interaction of biological, psychological, and social factors, termed the biopsychosocial model of disease, has typically been associated with non-surgical disease.[26] More recently, however, studies have been conducted to emphasize the importance of identifying and addressing the psychosocial factors that may impact postoperative patient outcomes.[26,27] Ayers et al. found that preoperative psychological factors including emotional health, social support, and coping skills correlated with functional impairment following orthopaedic surgery.[27] The results of this study were in line with our own. We found that resiliency, an intrinsic psychological attribute, correlates with improvements in patient-reported outcomes. While there are limitations in how to effectively treat and/or minimize underlying psychosocial issues in a patient, they are important factors to identify and discuss when creating patient-specific guidelines for post-surgical care and framing expectations of outcomes. This paper serves to add to the growing literature on the impact of psychosocial factors on outcomes following orthopaedic procedures.

In this study, we used BRS to test for resiliency in patients who underwent GR. The BRS is the current gold standard for assessing resiliency and serves as a reliable method for measurement. Several papers have been published on using resiliency as a predictor of post-operative outcomes in orthopaedic patients.[17,18,20,27-29] Similar to the findings of our study, Otlans et al., a review of the literature investigating outcomes in patients undergoing orthopaedic surgery procedures, found that various subspecialties have demonstrated positive correlations between resilience, favorable mental health, and improved physical function.[20] Considering the limited amount of evidence on the relationship between mental health and post-operative outcomes following foot and ankle surgeries, we suggest that further research is required to identify other key factors influencing recovery. A thorough analysis of contributing factors enables physicians to more accurately predict patient prognosis and optimize therapies to improve physical function. This paper serves to describe the association between an intrinsic patient characteristic and surgical outcomes.

Table 4. Linear Regression Model for Factors Affecting Patient-Reported Outcomes

PROMIS D	Beta p value
BRS	-0.81 0
Previous F/A procedure	-4.29 0.02
Age > 40	-0.11 0.08
DM	4.04 0.05
RA	11.52 0.13
PROMIS PI	Beta p value
BRS	-0.95 0
Previous F/A procedure	-4.16 0.03
Tobacco Use	3.49 0.05
PROMIS PF	Beta p value
BRS	0.97 <0.0001
Revision surgery	-3.84 0.25
FFI pain	Beta p value
BRS	-2.33 0
Previous F/A procedure	-18.57 0
BMI > 30	-0.34 0.21
Tobacco Use	18.7 0
HTN	5.27 0.22
Symptoms more than 2 years	-0.15 0.01
Revision Surgery	18.54 0.05
FFI Disability	Beta p value
BRS	-3.08 0
Previous F/A procedure	-12.81 0.01
Tobacco Use	15.61 0
Symptoms more than 2 years	-0.12 0.02
FFI activity limitation	Beta p value
BRS	-2.38 0
Previous F/A procedure	-3.46 0.45
PN	14.09 0
RA	15.5 0.39
Wound complication	-14.05 0.05
Revision Surgery	9.4 0.26
FFI total	Beta p value
BRS	-2.63 0
Previous F/A procedure	-13.04 0
Tobacco Use	14.22 0
HTN	5 0.14
Symptoms more than 2 years	-0.11 0.02
Revision Surgery	13.8 0.07

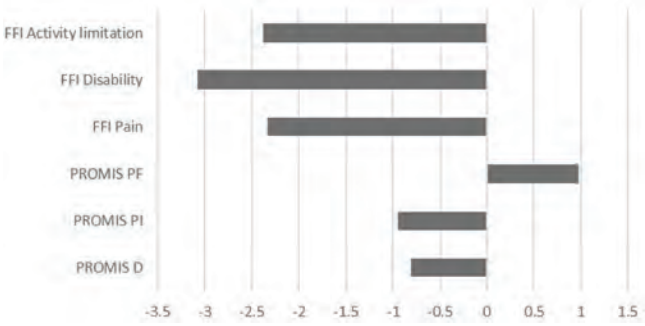

Figure 1. Beta Value of BRS with different PROM sections following GR.

Two previous papers have described the impact of resilience on PROMIS scores following foot and ankle procedures.[11,12] These previous studies both concluded that resiliency has a moderately positive impact on physical function and pain postoperatively. Our study supports and contributes to the generalization of the literature by demonstrating the positive impact resiliency plays in orthopedic outcomes. We found that increased resiliency is an independent positive factor with a moderate correlation when predicting PROMIS PF. Additionally, resiliency was found as a positive predictor for improved FFI pain, activity limitation, disability, and FFI total. While this study did find resilience to be associated with improved patient-reported outcomes, further research on the topic is warranted to expand on the mechanism of the relationship, its association with patient-reported satisfaction, and the potential development of new therapeutic and motivational techniques.

Given its retrospective design, this paper was limited in its ability to assess resilience scores in patients preoperatively. While previous literature has shown that resiliency is unchanged by surgery and other stressors, it is critical for future studies to assess BRS scores both pre- and postoperatively in the same patient.[1,2,5] If a significant change in BRS scores is appreciated, this would challenge the current literature's stance on viewing resiliency as an intrinsic patient characteristic. This study also included patients undergoing GR for a variety of pathologies. While this allows for increased generalizability of our study, we are unable to determine the effect of the different surgical indications on outcomes. Lastly, we recognize that the utilization of a phone survey to collect resiliency measures introduces potential selection and response bias.

CONCLUSION

This study demonstrates the positive impact of resilience on patient-reported outcomes following isolated GR in patients with Achilles tendinopathy or plantar fasciitis. While not the primary factor, resilience can be useful to physicians in estimating aspects of surgical outcomes.

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ANATOMICAL STRUCTURES AT RISK AND JOINT PREPARATION EFFECTIVENESS IN PERCUTANEOUS FIRST METATARSOPHALANGEAL FUSION WITH THE SHANNON BURR: A CADAVERIC STUDY

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ABSTRACT

Background: This cadaveric study aims to evaluate the anatomical structures at risk and the amount of joint preparation achieved during percutaneous first metatarsophalangeal joint preparation with a Shannon burr using a direct medial and dorsal-lateral approach.

Methods: Eleven fresh-frozen cadaver foot and ankle specimens underwent first metatarsophalangeal joint preparation with a Shannon burr under fluoroscopy. Following joint preparation, dissection was carried out to locate and evaluate critical soft tissue structures in the vicinity of the first metatarsophalangeal joint, including the extensor hallucis longus tendon, medial dorsal cutaneous nerve, and lateral dorsal digital artery. Measurements from the surgical site to these critical structures were recorded. Image analysis using ImageJ software was conducted to measure the joint surface area prepared on both the distal metatarsal and proximal phalanx articular surfaces.

Results: Contact with the lateral dorsal digital artery and extensor hallucis longus tendon occurred three times each out of the 11 procedures (27%) through the dorsal-lateral approach without macroscopic laceration. The medial dorsal cutaneous nerve was contacted three times (27%) via the medial approach without macroscopic laceration and transected once (9%). The average percentage of joint preparation for the distal first metatarsal was 71.8% (+/- 24.0%), and for the proximal first phalanx was 78.2% (+/- 19.8%). There was no statistically significant difference in joint preparation percentage between both surfaces (p = 0.507). The raw joint surface area prepared on the metatarsal and phalangeal surfaces was 215.24 mm^3 and 187.98 mm^3, respectively.

Conclusion: This study emphasizes the importance of understanding local anatomy and maintaining surgical precision during percutaneous first metatarsophalangeal joint fusion using a Shannon burr. Additionally, this technique offers comparable joint surface preparation to other minimally invasive techniques, however, inferior joint preparation compared to open techniques. Future studies with larger in vivo sample sizes are warranted to further refine the percutaneous approach and enhance patient outcomes.

Level of Evidence: V

Keywords: minimally invasive surgery, foot and ankle surgery, hallux rigidus, hallux valgus

INTRODUCTION

Hallux valgus (HV) and hallux rigidus (HR) are two of the most common pathologies of the first metatarsophalangeal joint (1-MTPJ), with HV affecting up to 23% of adults 18-65 years old and HR affecting 2.5% of the general population.[1,2] HV, also known as a bunion, is characterized by the deviation of the big toe towards the other toes, typically caused by a combination of genetic predisposition, tight footwear, and foot mechanics, leading to symptoms such as a visible bump, pain, limited range of motion, and toe misalignment.[3] HR involves the progressive degeneration of the cartilage in the 1-MTPJ, leading to stiffness, limited range of motion, and pain.[4] Surgical intervention for both of these conditions is often considered when conservative treatments fail to provide relief or when the deformity is severe.[3,4]

The surgical interventions for the treatment of these pathologies have witnessed significant advancements over time. These advancements have aimed to optimize surgical outcomes and improve patient satisfaction. One surgical intervention in particular, 1-MTPJ arthrodesis, has become the gold standard for severe HR and may be used in HV management when associated with painful arthritis and the joint is not salvageable.[3,4] Among the evolving arthrodesis techniques, percutaneous ap-

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proaches have gained substantial popularity due to their minimally invasive nature and potential benefits over traditional open procedures.[5-7]

Percutaneous techniques in foot surgery offer several advantages, including a smaller surgical incision - which reduces the risk of surgical wound dehiscence and superficial infections - and less postoperative pain.[8-10] These benefits have led to increased interest in percutaneous approaches for 1-MTPJ pathology treatment. Among these techniques, percutaneous 1-MTPJ fusion with a burr has demonstrated promising outcomes in various studies.[5,7] The technique involves the use of a specialized burr to prepare the "ball-and-socket" joint surfaces and facilitate fusion, providing an effective and less invasive alternative to traditional open fusion procedures.[5,11]

However, despite the encouraging results reported in the literature, it is crucial to acknowledge that the percutaneous approach is not without its risks. The close proximity of vital neurovascular and tendinous structures within the 1-MTPJ region poses a potential hazard during the surgical procedure. Accidental damage to these structures can result in significant complications, highlighting the need for a comprehensive understanding of the anatomical structures at risk to ensure patient safety and improve surgical techniques.

To address this critical aspect, the primary objective of this cadaveric study is to evaluate the anatomical structures at risk during percutaneous 1-MTPJ fusion with a Shannon burr. This detailed anatomical analysis aims to enhance surgeon awareness and provide valuable guidance for surgical decision-making, ideally resulting in minimal complications associated with the procedure.

METHODS

This study used 11 fresh-frozen cadaveric foot and ankle specimens that had been amputated at the mid-tibia level (Table 1). The specimens were thawed for 12 hours prior to any dissection or procedural manipulation and each were examined both grossly and under fluoroscopy for any pre-existing pathology of the first ray. Specimens with pre-existing pathology were excluded from the study. 1-MTPJ preparation procedures were performed by a single fellowship trained foot and ankle surgeon on all 11 specimens.

Joint Preparation of the 1-MTPJ

The surface anatomy of each specimen was identified and the 1-MTPJ was localized using an 18 gauge needle under fluoroscopy. The primary portal was located over the joint line on the medial aspect of the 1-MTPJ mid-axis dorso-plantarly (Figure 2). An additional portal was made on the dorsal-lateral aspect approximately 5 mm lateral to the EHL tendon over the joint line (Figure 1). Both portal sites were marked with a skin marker. The portal incisions were made with a 15 blade followed by blunt dissection of the subcutaneous tissue with a straight hemostat. At this point, the straight hemostat was also used to enter the joint and widen the joint capsule. Next, a curved periosteal elevator was used to elevate the joint capsule surrounding the 1-MTPJ. Joint preparation was then performed using a Shannon burr, which was advanced through the joint capsule under fluoroscopy to ensure proper positioning. Traction was applied to the first digit using a towel clip and joint surfaces were debrided using both a 2 mm x 8 mm and 2 mm x 19 mm Shannon burr at 15,000 rpm. The shorter burr was initially used to prepare the joint, but if more depth was needed, the longer burr was substituted. This was done first from the medial portal, burring the closest aspects of the joint surface first and then progressing to the farther aspects of the joint. This process was subsequently repeated using the dorsal-lateral portal. Debris was removed by using copious saline irrigation through both portal sites. -MTPJ fusion was not completed in any specimens since this study was focused on soft tissue damage and critical structure proximity during the joint preparation stage while using the Shannon burr.

Table 1. Distance Between Dorsal Percutaneous Entry and Structures Potentially at Risk

Structure by Portal	Mean	Minimum Value	Maximum Value	Confidence interval	Instances of contact[a]
Dorso-Lateral					
LDA	3.55	0	7	2.69-4.41	3 (0)
MDCN	18.27	4	30	16.05-20.49	0
EHL	4.45	0	12	3.30-5.60	3 (0)
Medial					
LDA	23.27	11	36	20.71-25.83	0
MDCN	3.91	0	10	2.91-4.91	3 (1)
EHL	17.91	9	24	16.46-19.37	0

[a]Number of instances of damage denoted in parentheses.
LDA - lateral dorsal digital artery of the great toe; MDCN - medial dorsal cutaneous nerve; EHL - extensor hallucis longus.

Table 2. Comparison of Sstructures at Risk from Dorsal and Medial Approach

Structure	Dorsal (mean)	Medial (mean)	p - Value
LDA	3.55	23.27	< 0.001
MDCN	18.27	3.91	< 0.001
EHL	4.45	17.91	< 0.001

LDA - lateral dorsal digital artery of the great toe; MDCN - medial dorsal cutaneous nerve; EHL - extensor hallucis longus.

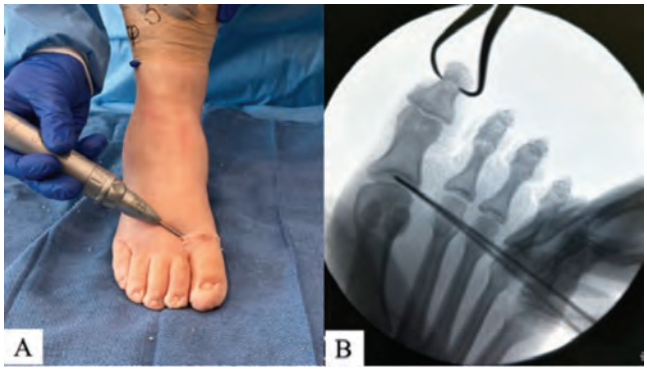

Figure 1A to 1B. Landmarks (1A) and radiographs (1B) for dorsal-lateral approach.

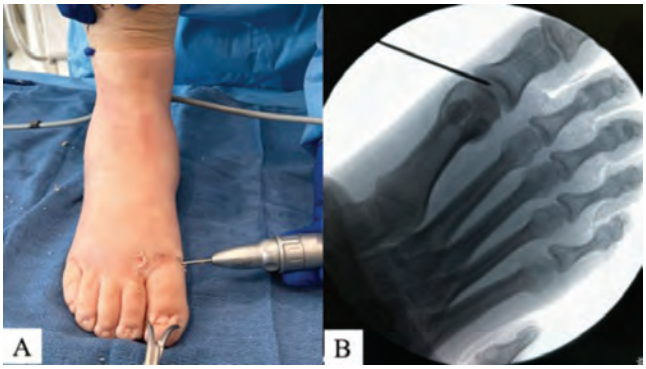

Figure 2A to 2B. Landmarks (2A) and radiographs (2B) for medial approach.

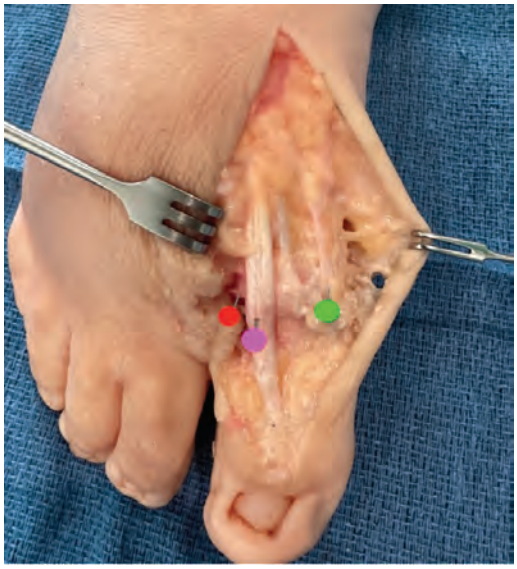

Figure 3. Dissection of the dorsal aspect of the foot. Lateral dorsal digital artery (red), medial dorsal cutaneous nerve (green), and extensor hallicus longus (pink).

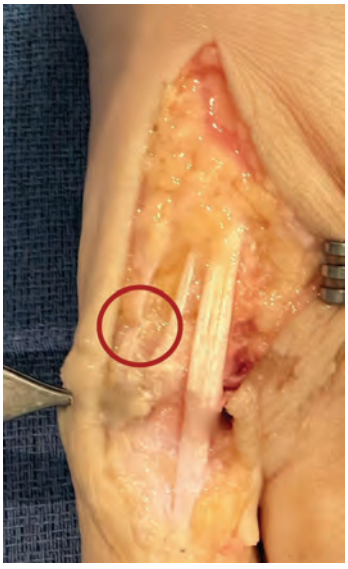

Figure 4. Transected medial dorsal cutaneous nerve.

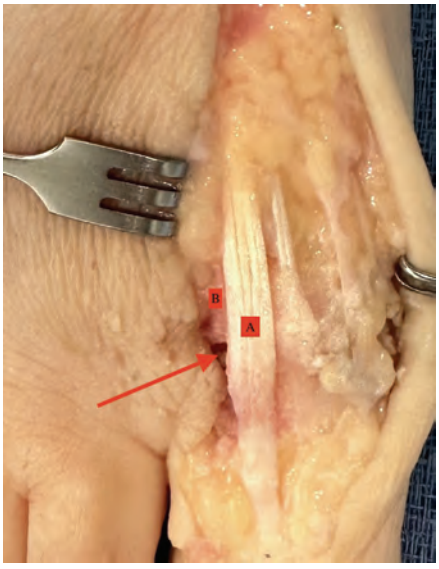

Figure 5. Instance of contact of the lateral dorsal digital artery (B) Instance of contact of extensor hallucis longus (A) (arrow indicates medial portal). Instances of contact did not reveal any macroscopic damage to the structure of interest.

Dissection

Following the above procedure, dissection was carried out to locate and evaluate critical soft tissue structures in the vicinity of the 1-MTPJ. Skin was incised with a 15 blade over the dorsal aspect of the first ray. Blunt dissection was performed and local structures were identified. The structures examined in this study were the extensor hallucis longus (EHL) tendon, medial dorsal cutaneous nerve (MDCN), and the lateral dorsal digital artery (LDA) (Figure 3). Measurements were taken from where each portal site pierced the joint capsule to the nearest point on each critical structure. Measurements were taken with a flexible 15 cm ruler and were recorded in millimeters (mm). Injury to a structure was classified as "contacted" or "damaged" on the macroscopic scale (Figure 4 and 5).

Image Analysis

The surface area prepared by the Shannon burr was measured by photographing the joint surface and uploading the image to ImageJ software.[12] This software was developed at the NIH and is a Java-based open-source software used by numerous researchers to visualize and interpret imaging data. Furthermore, ImageJ software has been used similar studies to analyze surface areas. The area of the prepared joint was compared to the total joint surface, and a percentage was calculated.

Data Analysis

Descriptive statistics (mean and frequency) were performed to describe the population characteristics (age, sex, and laterality) as well as the distance from the surgical site to critical structures. IBM SPSS Statistics v29.0 (Armonk, NY) was utilized for statistical analysis.

RESULTS

Eleven cadavers met the inclusion criteria for this study. The average age of the cadavers was 66.6 +/- 20.1 years. There were five female feet and six male feet. There were seven right feet and four left feet. The distance from the joint capsule access site was measured to the structures at potential risk.

From the dorsal-lateral portal site, the mean distances to the LDA, MDCN, and EHL were 3.55 (0-7), 18.27 (4-30), and 4.45 (0-12) mm, respectively (Table 1). The LDA and EHL were contacted 3/11 (27%) times through this portal, but were not transected or macroscopically lacerated. The MDCN was not contacted.

From the medial portal site, the mean distances to the LDA, MDCN, and EHL were 23.27 (11-36), 3.91 (0-10), and 17.91 (9-24) mm, respectively (Table 1). The MDCN was contacted (but not macroscopically lacerated) 3/11 (27%) times and transected once (9.1%). No other structures were contacted or transected through the medial portal.

The dorsal-lateral approach was significantly closer to the LDA (3.55 vs 23.27, $p < 0.001$) and EHL (4.45 vs 17.91, $p < 0.001$) when compared to the medial approach (Table 2). The Shannon burr through the dorsal-lateral approach made contact with the LDA and EHL three times without damage (Table 1). The only structure at higher risk from the medial approach compared to the dorsal-lateral approach was the MDCN (3.91 vs 18.27, $p < 0.001$), where the burr through the medial approach contacted the MDCN three times and transected it once (Tables 1&2).

DISCUSSION

In the present study, we analyzed the proximity and any associated damage to the LDA, MDCN, and EHL tendon during the joint preparation stage of a percutaneous 1-MTPJ fusion using a Shannon burr. These structures were chosen based on their proximity to the portal sites and the outcome-altering complications associated with their respective damage. To our knowledge, this is the first study analyzing the injury to surrounding structures during the joint preparation stage of the percutaneous 1-MTPJ fusion utilizing a medial and dorsal-lateral approach.

Historically, 1-MTPJ fusion has largely been achieved via an open surgical approach, however, more recently arthroscopy and minimally invasive techniques have garnered attention.[5,12,13] Advantages of open surgery in general include direct visualization of the joint, greater flexibility to address complex deformities and associated pathologies, and excellent stability with rigid fixation.[14] However, it involves larger incisions, more tissue trauma, longer recovery time, and potential complications.[14]

Arthroscopic approaches have been shown to have a higher union rate compared to open techniques while achieving satisfactory articular surface preparation and minimal damage to surrounding structures.[13,15,16] Downsides of the procedure include increased operating room setup time and that the EHL tendon might be at risk with the dorsal-lateral portal.[13]

Lastly, minimally invasive percutaneous techniques - which were utilized in this study - involve smaller incisions or poke holes, reduced soft tissue disruption, reduced surgical time, a higher union rate, and less scarring.[14,17] They may also allow for faster recovery and earlier return to normal activities with a reduction of postoperative pain.[15] However, these techniques have limitations in addressing severe deformities or complex pathologies, they offer limited visualization, require

specialized instruments, and may have technical complexities.[14] Furthermore, severe osteoporosis should be considered a contraindication.[17]

The limited visualization has been thought to be a risk for inadvertent structure injury, which was demonstrated in a study on arthroscopic MTP fusion by Angthong et al.[12] In their study, the EHL was injured in 37.5% of the cadavers.[12] This is compared to our study, where we used a direct medial approach instead of their dorsal-medial approach. In our study, we saw that while the EHL was contacted in 27% of the cadavers during the approach, there was no macroscopic evidence of laceration or transection. Conversely, the present study revealed that the MDCN was transected once (9% of the cadavers) and contacted without laceration three times (27%). The Angthong et al. study had no reported instances of transection or contact to the MDCN.[12] The difference in risk profiles between their study and the present one is most likely due to the position of the medial approach. Ultimately, threats to and damage of nearby structures was seen in this study although these instances were minimal. In a study on the arthroscopic soft tissue release for hallux valgus, it was also reported that the EHL had a higher risk of injury due to proximity when utilizing the dorsal-lateral approach to the 1-MTPJ. Because of this risk, they recommended using a "nick-and-spread" technique to create the arthroscopic portal.[13] In the present study, the EHL was contacted in 27% of the cadavers when using this approach, however, it was not macroscopically damaged. These findings support the idea that as technology and surgical techniques continue to evolve and more surgeries are done percutaneously, it is essential to understand the associated intraoperative risks with such procedures.

Several limitations should be acknowledged. First, the study utilized a single type of burr, the Shannon burr, which may not fully represent the wide range of instruments and techniques employed in clinical practice. Secondly, a single surgeon performed all of the procedures. Lastly, the small number of cadaveric samples used in this study restricts the generalizability of our findings to a larger population.

While supporting general safety notions from previous studies, this research also contributes to the limited literature on the procedure. Future studies with larger, in vivo sample sizes in a standard operating room are warranted to further refine the surgical technique and enhance patient outcomes. Furthermore, future studies should analyze the amount of joint surface preparation necessary to achieve fusion through the percutaneous approach.

CONCLUSION

This cadaveric research study provides insights into the anatomic and neurovascular structures at risk during minimally invasive percutaneous 1-MTPJ fusion surgery. The identification of neurovascular transection as a potential complication highlights the importance of surgical precision and awareness of anatomic variation. Ultimately, the findings of this study reveal that the structural risks of a percutaneous approach during a 1-MTPJ fusion surgery are minimal.

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POSTOPERATIVE ALIGNMENT IN HINGE TOTAL KNEE ARTHROPLASTY – "ARE HINGE KNEES TOO VALGUS?"

Ryan S. Bailey, MD[1]; Christopher Halbur, MD[1]; Trevor R. Gulbrandsen, MD[1]; Timothy S. Brown, MD[1]; Nicolas O. Noiseux, MD, MS, FRCSC[1]

ABSTRACT

Background: Hinged knee prostheses are a potentially beneficial treatment approach in complex primary and revision total knee arthroplasty (TKA). Previous reports have demonstrated good long-term outcomes and survivorship with appropriate indications. However, adequate restoration of joint line and limb alignment remain challenging, with the implant design playing a significant role. Optimal limb alignment is generally within 0° to 3° of the mechanical axis. However, little data exists on limb alignment results following hinged knee procedures. The aim of this study was to evaluate the limb alignment of patients following hinged TKA.

Methods: A retrospective review was performed of 117 operations in 114 patients who received a TKA with hinged prosthesis at one academic institution between 2008 and 2021. Ten were excluded due to inadequate follow-up or imaging, leaving 107 procedures in 104 patients for analysis. Demographics, indications, and postoperative weight-bearing radiographs were analyzed. Alignment measurements included the mechanical axis (hip-knee-ankle angle) and anatomic tibiofemoral axis.

Results: Mean patient age was 67.6 years (range: 36-90), 59% were female. Mean BMI was 35.2 kg/m2. Mean mechanical alignment was 0.53° ± 3.33 valgus (range 12.55° valgus to 8.42° varus) and 6.18° ± 2.82 valgus (range 16.3° valgus to 1.62° varus) for anatomic. Nineteen patients (18%) had a postoperative mechanical alignment >3 degrees valgus, and 9 patients (8%) were greater than 3 degrees varus.

Conclusion: The incidence of valgus malalignment is greater than varus following TKA with a hinged prosthesis. Future studies should focus on the impact of alignment on patient reported outcomes.

Level of Evidence: IV

Keywords: arthroplasty, total knee arthroplasty, design, implant, hinge, mechanical

INTRODUCTION

Total knee arthroplasty is a widely accepted and safe procedure with consistent and mostly favorable results in patients who undergo this procedure for a variety of indications. Though most patients benefit from the use of unconstrained implant design, complex patient factors may demand an increased level of constraint to achieve a stable, balanced knee joint. The use of hinged knee prostheses in modern total knee arthroplasty (TKA) is a potentially beneficial approach to addressing severe deformity, bone loss, or ligamentous insufficiency in challenging primary and revision cases.[1,2] Prior reports have demonstrated that, while there continues to be significant heterogeneity in indications, these constrained implants show good long-term outcomes with survivorship of 51-92% at 10 years.[3] However, concern remains over the inconsistency of survivorship, complications, and outcomes data, particularly when considering reported increased complication rates compared to conventional implants.[4] The technical complexity of these cases and implant systems may also influence the outcome. Restoration of the joint line and appropriate mechanical axis remains a significant challenge in these cases, especially in the setting of poor bone stock and or loss of bony landmarks.[5] Though there exists ongoing debate in the literature regarding optimal mechanical axis, particularly when considering the performance of modern implants, the optimal angle of overall limb alignment following total knee arthroplasty is generally accepted to be within 0-3 degrees from the mechanical axis.[6] The prosthesis itself plays a significant role in mechanical alignment based on the established implant design, particularly the distal femoral valgus cut. While final alignment is also subject to other factors, such as surgical technique and patient anatomy, implant design targeting neutral alignment should show averaged results achieving this distribution of alignment.

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At present, relatively little data exists in the literature regarding mechanical limb alignment following hinged TKA. The purpose of this study was to review postoperative limb alignment in hinged total knee arthroplasty performed at our institution. We hypothesized that postoperative radiographs would show mechanical alignment with greater average valgus angulation than previously reported elsewhere in the literature.

METHODS

Following institutional IRB approval (IRB ID #201904825), we conducted a retrospective review of all hinged TKA procedures performed at a single academic institution between 2008 and 2021. Patients and cases were identified using common procedural terminology (CPT) code 27445 and 27487 (Repair, Revision, and/or Reconstruction Procedures on the Femur (Thigh Region) and Knee Joint) for procedures performed within this period. Patient demographic data, including age, sex, height, weight, and body mass index (BMI) were recorded. Other data, including date of procedure, length of follow-up, medical comorbidities, operative and clinical reports were collected. Radiographic data of the operative extremity, including preoperative, postoperative, and limb alignment imaging was collected for analysis.

Patients were included if they had undergone implantation of a hinged knee prosthesis at our institution within the above study period. Patients were excluded if there was inadequate imaging, follow up of less than 6 months, the procedure was performed for oncologic reasons, or the patient was less than 18 years old at the time of the procedure. One-hundred seventeen hinged total knee arthroplasties performed in 114 patients were identified for inclusion. Ten total procedures were excluded, including 5 patients with inadequate follow-up and 5 additional cases that did not have adequate imaging for analysis. This left 107 procedures performed on 104 patients for analysis.

Alignment analysis

The mechanical axis (hip-knee-ankle angle) and anatomic tibiofemoral axis were measured by authors CH and TG, as illustrated in Figure 1.

Statistics

Descriptive statistics were performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

RESULTS

One-hundred seven procedures in 104 patients were available for analysis after application of exclusion criteria. The average age at the time of surgery was 67.6 years old (range 36 to 90 years). Patient sex for the procedures totaled 43 male and 64 female. Average BMI was 35.2 (minimum 17.4, maximum 57.4). The laterality of all procedures was 61 right knees and 46 left knees.

Figure 1. Database mechanical and anatomic limb axis measurements

Implant systems used included 51 Legion HK (Smith & Nephew, London, UK), 16 S-ROM NOILES RHK (Depuy Synthes, Raynham, MA, USA), 16 Modular Rotating Hinge System (Stryker, Kalamazoo, MI, USA), 13 Limb Preservation System (Depuy Synthes, Raynham, MA, USA), 6 NexGen Rotating Hinge Knee (Zimmer Biomet, Warsaw, IN, USA), 4 Global Modular Replacement System (Stryker, Kalamazoo, MI, USA), and 1 Endo-Model (Waldemar Link GMBH, Butzbach, Germany). Surgery was performed for primary total knee arthroplasty in 5 patients, and revision in 102 patients. Indications for surgery included 36 for aseptic loosening, 31 for instability, 18 for prosthetic joint infection, 7 for periprosthetic fracture non-union, 5 for periprosthetic fracture, 3 for extensor mechanism failure, 2 for hardware failure, 2 for post-traumatic osteoarthritis, 1 for Charcot arthropathy, 1 for arthrofibrosis, and 1 for fracture.

Table 1. Radiographic Analysis of Mechanical and Anatomic Axis Alignment, Illustrating 2-3 Degrees of Excessive Valgus

Characteristics and Alignment	
	Total N = 107 Arthroplasties N = 104 Patients
Age	67.6 (36 to 90)
Sex	
Male	43 (40%)
Female	64 (60%)
BMI (kg/m2)	35.2 (17.4 to 57.4)
Anatomic Angle*	6.18° ± 2.82° (-1.62 to 16.3)
Mechanical Angle*	0.53° ± 3.33° (-8.42 to 12.55)
>3 degrees valgus	19 (18%)
>3 degrees varus	9 (8%)

*Angles are reported as the mean ± standard deviation, with the range in parentheses.

The average postoperative mechanical alignment (hip-knee-ankle angle) for all procedures was 0.53 degrees +/- 3.33 degrees valgus (range 12.55 degrees valgus to 8.42 degrees varus). Anatomic alignment was 6.18° ± 2.82 valgus (range 16.3° valgus to 1.62° varus). Twenty-eight knees in total showed a postoperative mechanical alignment of more than 3 degrees from the neutral mechanical axis alignment. Nineteen knees had postoperative valgus greater than 3 degrees. 9 knees had postoperative varus greater than 3 degrees.

DISCUSSION

Indications for hinged total knee arthroplasty are inconsistently reported throughout the literature. Furthermore, there is relative heterogeneity in the literature influenced not only by variation in indications, but also in evolution of implant design over time. The overall survivorship is reported to be good,[1-3,7,8] even in some cases comparable or better than less constrained implant designs,[4,9] or when used in obese patients.[10] Indications for primary hinge TKA are also highly variable.[11,12] Finite element analysis has shown that stresses at the bone-implant interface may be less for modern rotating hinge prostheses than condylar constrained implants.[13] Overall, survivorship appears to be acceptable, and indications, whether for revision or primary settings, tend to focus on gross global instability, recurvatum, and neuromuscular disorders.

The optimal mechanical alignment following total knee arthroplasty, despite historical acceptable targets at or near neutral alignment, continues to be debated and is likely subject to individual patient characteristics and specific implant design. The implant systems used in this study utilized either a 6 or 7-degree valgus distal femoral design, targeting an overall neutral mechanical axis.[14-20] Though much data exists on primary arthroplasty, relatively little exists regarding optimal alignment for hinged total knee arthroplasty. Parratte et al. reported on the 15-year survivorship of modern cemented total knee implants. They hypothesized that alignment within 3 degrees of neutral mechanical axis would result in greater survivorship. However, their analysis of outliers versus mechanically neutral knees did not demonstrate a significant difference in survivorship. Though a specific target malalignment threshold could not be defined, they concluded that less than 3 degrees from neutral alignment was a reasonable target.[6] Yilmaz et al. reported on measurements of postoperative joint line restoration and its influence on patient-reported outcomes after hinged TKA. While they did not find an association between joint line restoration and outcomes, they did report an association between patient-reported patellar scores and overall outcome scores.[5] Though they did not report on coronal alignment, the predominant influence of outcome scores on patellar factors may suggest that improved coronal alignment, particularly avoidance of valgus outliers, could have a positive influence on patient reported outcomes after hinged TKA.

Prior literature on mechanical alignment after hinge TKA is sparse, limited to small case series. The largest to our knowledge, performed by Wignadasan et al., reported on postoperative alignment in 41 knees with an average alignment of 0.2 +/- 2.0 degrees varus.[21] Another study by Barrack et al. reported on 14 hinged total knees and demonstrated an average alignment of 7 degrees valgus (range 5-10 degrees).[22] Hwang et al. reported an average of 3.0 degrees valgus in a series of 13 hinged TKAs.[23] Pietsch et al. reported on the alignment of 10 TKAs performed with handheld computer navigation, consisting of 5 hinged and 5 constrained designs. Nine were reported as within 3 degrees of neutral axis, with one outlier in varus.[24] Our study reported an average alignment of 0.53 degrees valgus, with a significant number of outliers (28 out of 107), most of them valgus (19 out of 28). Introducing a small adjustment of 0.5 degrees varus to the implant design would have eliminated 2 valgus outliers to within 3 degrees of neutral alignment. However, this would also create an additional six varus outliers. Conversely, increasing valgus by 0.5 degrees for all implants would have corrected no varus outliers, but would have pushed six additional knees valgus outside of acceptable range.

To our knowledge, this is the largest series of hinged TKA procedures specifically reporting postoperative alignment, showing an approximately 0.5-degree aver-

age valgus trend in overall postoperative alignment. Importantly, we showed a higher number of valgus outliers compared to varus. Though most of these outliers would not necessarily have been resolved with a small adjustment in the design of the coronal alignment of the femoral cut, it does suggest that overall implant designs for hinged total knee prostheses have room for improvement.

Limitations of this study include its retrospective nature, which may have subjected the data to bias. Patients were not randomized to surgeon, leaving potential unaccounted influence in indications and surgical technique, as each patient was treated at the individual surgeon's discretion. However, all surgeons involved in this study were fellowship-trained in adult reconstruction with extensive experience in complex revision TKA, including hinged prostheses. Furthermore, patients were not randomized to implant system, nor was there an even number of procedures performed with each, potentially causing one or more systems to have a disproportionate effect on the data. However, most implant systems seen in this study use a 6-degree design, potentially minimizing this variability. Lastly, this study did not capture patient reported outcomes, and the relationship of our reported data and the relationship between final alignment in hinged TKA and patient perception of outcome is not known yet.

CONCLUSION

Overall limb axis alignment is usually within the acceptable range of 0 +/- 3 degrees following hinged total knee arthroplasty. Surgeons can be confident that, when soundly indicated and executed, that usage of these prostheses will be effective in restoring limb alignment. However, surgeons should also be aware of tendencies of individual implant systems and the existence of alignment outliers when using these devices. This is particularly relevant since hinged implants tend to be used in challenging cases where native anatomy, bone stock, and other patients make restoration of limb alignment technically difficult. Our data demonstrate that there is a tendency towards valgus outliers, and we suggest that both surgeons as well as future implant designs take this into account. Future studies should focus on the influence, if any, these alignment trends have on clinical and patient-reported outcomes and implant survivorship.

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SELF-REPORTED MARIJUANA USE IS ASSOCIATED WITH INCREASED NARCOTIC PRESCRIBING FOLLOWING HIP AND KNEE ARTHROPLASTY

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ABSTRACT

Background: Opioid-related deaths continue to rise annually in the United States, prompting a search for alternative or adjunct pain management strategies. Concurrently, marijuana has become increasingly legal, widely used, and culturally accepted. Within orthopedic surgery, there is growing interest in exploring the potential role of marijuana as a component of multimodal pain control. This study aimed to evaluate the impact of self-reported marijuana use on postoperative opioid prescribing patterns in patients undergoing hip and knee arthroplasty.

Methods: This retrospective study reviewed the medical records of patients treated by a single hip and knee arthroplasty surgeon. Patients were divided into two cohorts based on self-reported marijuana use: those who reported use and those who denied use. The primary outcome was the total morphine milligram equivalents (MME) prescribed within the first 90 days following surgery. Statistical analysis was conducted to compare prescribing patterns between the two groups.

Results: 97 patients were surveyed with a mean age of 64 years old. There were 61 females (62.9%) and 26 (37.1%) males. There were 39 (40.2%) primary total hips and 58 (59.8%) primary total knees. Patients who self-reported marijuana use were prescribed significantly higher MMEs within the 90-day postoperative period compared to those who denied marijuana use (983 MME vs. 501 MME, p=0.019). The difference in opioid prescribing patterns suggests that marijuana use may not mitigate postoperative opioid requirements and could potentially be associated with higher opioid consumption.

Conclusion: Self-reported marijuana use was associated with increased opioid prescribing in the early postoperative period following hip and knee arthroplasty. These findings highlight the need for further investigation into the relationship between marijuana use and postoperative pain management to better inform clinical practice and optimize multimodal analgesic strategies.

Level of Evidence: III

Keywords: marijuana, arthroplasty, pain control

INTRODUCTION

In 2021, there were over 110,000 opioid-related deaths in the United States and approximately 16,000 deaths were directly related to prescription-opioid use.[1] Orthopedic surgeons are the third highest prescribers of opioid prescriptions among physicians in the United States.[2] Thus, it is important for surgeons to understand their own prescription patterns and identify which patients may be at greater risk for nontherapeutic opioid use.[2] There also has been an expansion of marijuana legalization and use in the United States and marijuana is considered a useful adjunct in treating refractory neuropathic and chronic cancer pain in addition to traditional regimens.[3]

There is indirect evidence to suggest that marijuana use may reduce opioid consumption and overall number of opioid prescriptions.[4,5] For example, from 1999-2010, the 13 states that had medical marijuana laws in place experienced a 25% lower annual opioid overdose mortality rate compared with states without these laws.[6] However, the current literature regarding the impact of marijuana use on orthopedic pain and narcotic consumption is mixed.[5,7] Our goal is to examine the impact of self-reported marijuana use on post-operative narcotic use following total hip and knee arthroplasty.

METHODS

Participants

The study was approved by institutional review board of UConn Health System (No. XX-XXX-X). We conducted a retrospective review of 302 patients 18 years or older who had total hip or knee arthroplasty surgery by a single surgeon over the course of 1 calendar year from August 2021-September 2022. Patients were excluded if they had filled opioid prescriptions within 90 days prior to surgery.

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Survey

A survey was distributed to eligible patients via phone call. This allowed for division of the cohort into two groups: those who report any marijuana consumption in the 90 days after surgery and those who do not. If patients reported marijuana use, the survey asked whether the patient used THC (tetrahydrocannabinol, the psychoactive component of marijuana) or CBD (cannabidiol, the non-psychoactive component), the frequency of use of either product, the route of consumption, the intended reason for use, and any perceived benefit from marijuana use.

Outcome

The primary outcome of the study was to determine whether there was a difference in the quantity of opioid prescriptions in the two cohort groups. To determine this, a review of the Connecticut Prescription Monitoring and reporting System was performed and opiate prescriptions were recorded. The primary outcomes were reported as morphine milliequivalents (MME) prescribed in the 90 days postoperatively and number of opioid prescriptions ordered by any provider in the 90 days following surgery. Secondary endpoints included demographic differences between the groups.

Statistics

Differences in the mean values of continuous variables were determined using Student t -or Mann-Whitney tests for parametric and nonparametric data, respectively. Chi-square analyses were used to identify differences in categorical data. A P-value of less than 0.05 was considered to be statistically significant. All statistical calculations were performed utilizing the SPSS system (Version 29, Chicago, Illinois).

RESULTS

There were 161 eligible patients that met inclusion criteria. Of these, 98 (60.9%) responded to the survey, with only 1 patient declining participation. The 97 patients had a mean age of 64 years old (Table 1). There were 61 females (62.9%) and 26 (37.1%) males. There were 39 (40.2%) primary total hips and 58 (59.8%) primary total knees. Seventy-two patients (74.2%) denied any marijuana use within 90 days after surgery while 25 (25.8%) reported marijuana use.

Table 1. Breakdown of Our Patient Cohort by Age, Sex and Surgery Type

Category		n (%)
Age (years)		64.1
Sex	Male	36 (37.1%)
	Female	61 (62.9%)
Surgery type	THA	39 (40.2%)
	TKA	58 (59.8%)

Our primary finding was that opioid use in patients that reported use of marijuana was increased (Figure 1). Those that used marijuana products were prescribed significantly more MME after surgery, with an average of 983 MME compared to 501 MME in the non-marijuana group (p=0.019). There were more opioid prescriptions after surgery with an average of 2.6 prescriptions compared to 1.6 in the non-marijuana user group (p<0.001, Figure 2). The marijuana group was also prescribed more days of narcotics, with an average of 22 days compared to 12.5 days in the non-marijuana use group (p<0.001, Figure 2).

Those that used any marijuana products were significantly younger than those that did not (66 vs 59 years old, p=0.004). There was no significant difference in marijuana use between males and females (30.0% females vs 30.6% females that used, p=0.408). The majority of those that used THC dominant products reported that they used daily (n=11, 55%), typically via inhalable (n=14, 70%) or edible routes (n=6, 30%), and typically for pain control purposes (n=15, 75%, Table 2). Conversely, those that used CBD products did so with less frequency with most using <1 per month (n=3, 25%) or 1 day a week (n=3, 25%), via topical (n=6, 50%) or inhalable (n=4, 33%) routes, and for pain control purposes (n=11, 91.7%).

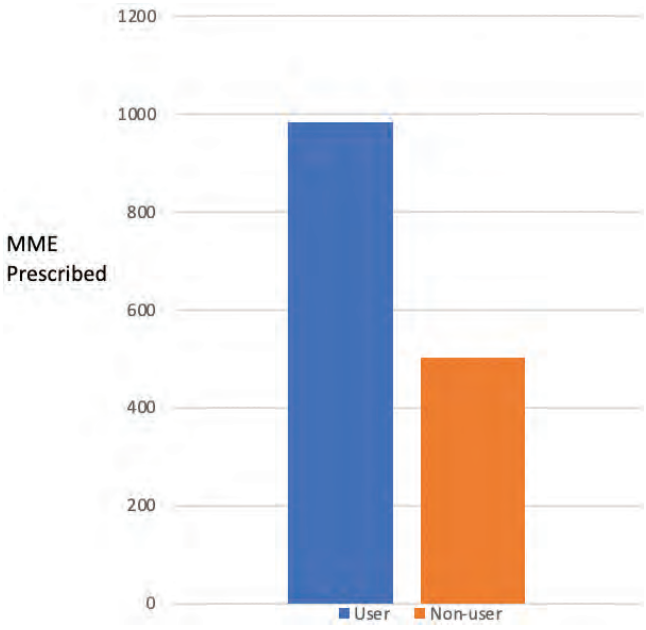

Figure 1. Total MME prescribed in MJ Users vs Non-Users. Marijuana users were prescribed significantly more MMEQ in the 90 days post operatively compared to non-users.

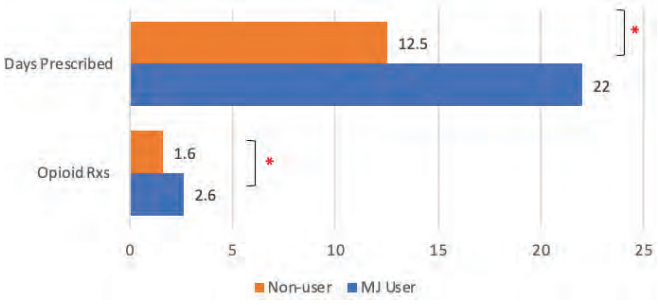

Figure 2. Number of Days and Total Number of Narcotic Prescriptions. Patients who use marijuana were prescribed significantly more opioid prescriptions and more days of narcotics prescribed.

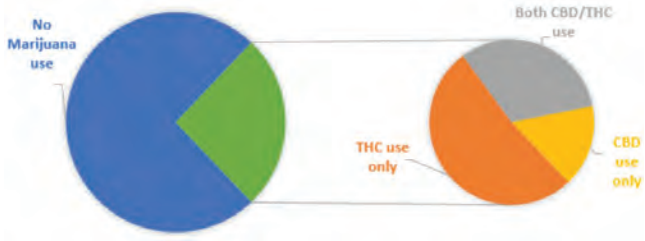

Figure 3. Type of Marijuana Product Use. A majority of our patients did not report marijuana use, but within the cohort who did self-report use most of them used THC only, followed by users who used CBD and THC, and least common were patients who only used CBD.

Of those that utilized any marijuana products, 13 patients (13.4%) reported THC dominant use only, 4 (4.1%) reported CBD dominant use only, and 8 (8.2%) used both CBD and THC dominant products (Figure 3). In a subgroup analysis of those that utilized THC only compared to those that did not use any THC products, there was again a redemonstration of difference in age (58.4 v. 65.5, p=0.019) with no difference in sex (p=0.181). There were more MMEs prescribed in the THC use group (831 v. 572) but this did not reach statistical significance (p=0.130). Those that used THC had significantly more opiate prescriptions (2.45 v. 1.7, p=0.003) and had more days of opiates prescribed (20 v. 13.7, p=0.035).

Marijuana users were asked to report on perceived benefits of marijuana use after surgery. Most (n=18, 86%) marijuana users report that marijuana achieved its intended use. Of these 18 patients, 89% (n=16) used marijuana primarily for pain control, and 11% (n=2) used marijuana primarily to help them sleep.

DISCUSSION

As marijuana legalization and use increases in the United States, it is important for orthopedic surgeons to understand how this may impact their patients.[8] Our primary finding is that patients who self-reported marijuana use in the 90 days following arthroplasty were prescribed significantly more narcotics compared to non-marijuana users. Marijuana users were prescribed higher doses, and a greater number of prescriptions totaling more days compared with those who denied marijuana use.

Table 2. Self-Reported Marijuana Users' Habits and Rationale For Use

Category		n (48%)
Frequency of use	1 day per week	7 (35%)
	Multi-times per week	2 (10%)
	Daily use	11 (55%)
Rationale for use	Pain control	15 (75%)
	Anxiety	4 (20%)
	Recreation	1 (5%)
Method of ingestion	Inhalable	14 (70%)
	Edible	6 (30%)

There are published works consistent with this finding. Liu et al. (2018) performed a retrospective matched cohort study between 310 patients following major orthopedic surgery and found that cannabis use was associated with higher pain scores and poorer quality of sleep in the early postoperative period.[9] Bhashyam et al. (2018) performed a multi-level study on patient self-reported marijuana use during injury recovery and discovered that marijuana use was associated with increased amount and duration of opioid use.[10] This finding raises important questions without clear answers. Do marijuana users have greater opioid requirements following surgery to achieve the same pain control as non-marijuana users? Are marijuana users more open to taking narcotics and asking for refills regardless of pain levels?

There are also studies which contrast to our findings. Medina et al. (2019) performed a cross-sectional study including over 900 patients and found that marijuana use was associated with less pain and better lower extremity activity rating scale scores when compared to non-users after orthopedic surgery.[11] Hickernell et al. (2018) performed a retrospective study comparing arthroplasty patients who received 5 mg dronabinol twice daily in addition to their standard multimodal pain regimen versus those who only received the standard regimen. Results demonstrated lower mean hospital length of stay and post-operative opioid use in the dronabinol group but did not reach statistical significance.[12] These studies exemplify the need for further research and a better understanding on this topic.

Despite our primary outcome and findings described above, we did observe a trend which may be more consistent with literature that has found marijuana to be a potentially useful post operative adjunct.[12,13] The majority of the marijuana group (86%) reported that using marijuana was helpful in achieving its intended use. For most, this was pain control. Interestingly, despite reporting marijuana use was helpful for pain control, the same patients were being prescribed more narcotics.

We found the average age of patients reporting any kind of marijuana use following hip and knee arthroplasty was 59 compared to 66 for non-marijuana users. This is consistent with other published works.[10,13] Medina et al., in a cohort of 900 patients, found increased marijuana use was associated with younger age, history of fewer operations, and history of smoking cigarettes.[10] This is also consistent from a psychosocial perspective as younger patients may be more open to using or reporting use. We did not observe a difference in use between males and females, but other studies have reported increased use in males. This epidemiological understanding of marijuana use can help clinicians target their questions and counseling before surgery.

Our study has limitations. The number of patients studied was small and limited to one surgeon's practice. The retrospective nature of study limits the ability to make causal statements and leaves patients open to recall bias. We used opioid prescriptions written in the postoperative period as a proxy for opioids consumed postoperatively. Some marijuana users may have denied use in our survey.

CONCLUSION

In a single orthopedist's practice, we observed significantly more opioid use in self-reported marijuana users compared to nonusers following hip and knee arthroplasty.

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THE CAUSES AND COSTS OF SURGICAL SITE INFECTION IN TOTAL HIP AND TOTAL KNEE ARTHROPLASTY: A RETROSPECTIVE REVIEW OF 4,973 PROCEDURES

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ABSTRACT

Background: The purpose of this article is to delineate risk factors associated with SSI (surface, deep tissue, and periprosthetic joint infections) in hip and knee total joint replacement (TJR) surgeries for both primary and revision procedures.

Methods: Retrospective case-control study of non-emergent TJR procedures performed at a tertiary level academic medical center between 2014-2018. Multivariable logistic regression was used to determine which factors are associated with an increased risk for SSI in TJR.

Results: 4,973 procedures (2,543 knee and 2,430 hip arthroplasties) were performed on 4,014 unique patients. There were 82/4,973 total SSI: 43/2,430 (1.8%) in the THA group and 39/2543 (1.5%) in the TKA group. Risk factors associated with the development of an SSI included a female gender (65% increased odds ratio), BMI (increased odds ratio 3% for every 1-point increase in BMI (10-point BMI increase = 30% increased odds), length of surgery (8% increase for every additional 10 minutes of surgical time). Chronic renal disease and anemia double the odds of an SSI and cardiac arrythmias increased the odds by 88%. A history of skin integrity issues more than doubled the odds and a previous skin ulcer more than tripled the odds of an SSI. Using a multilayered dressing reduces the odds and not using one more than doubles the odds of suffering an SSI. An SSI increased length of stay by two days and cost of stay by $38,000.

Conclusion: SSI are problematic and with the changing demographics of TJR patients their incidence will increase. Addressing modifiable risk factors such as early treatment of anemia and postoperative dressing choice may reduce the SSI burden and cost of a TJR. Adapting care routines for non-modifiable risk factors such as chronic diseases and gender may have additional patient benefit.

Surgical Site Infection (SSI) is one of the most frequently reported types of hospital acquired infections resulting in increased length of stay, increased healthcare costs and increased morbidity and mortality. This study reviewed 2,543 total knee arthroplasties and 2,430 total hip arthroplasties (4,973 procedures) completed on 4,014 unique patients. Multivariable analysis showed the odds of developing an SSI was increased for patients who were female, younger, had a history of a pressure ulcer or skin integrity issues, anemia, chronic renal disease, a cardiac dysrhythmia, a higher BMI, a longer surgical procedure, and the use of specific types of surgical site dressings. The mean length of stay for a patient who suffered an SSI increased by 1.8 days, the length of time they were on antibiotics doubled to a mean of 16 days, and the mean cost of treatment increased by $38,300. Addressing modifiable causes of SSI such as skin integrity issues and anemia preoperatively, reducing intraoperative time, and changing the type of dressing used postoperatively may improve patient outcomes, improve quality of care, and reduce healthcare costs.

Level of Evidence: III

Keywords: surgical site infection, SSI, healthcare costs, modifiable SSI factors, total joint arthroplasty

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INTRODUCTION

Surgical Site Infection (SSI) is one of the most frequently reported types of hospital acquired infections.[1] Periprosthetic joint infection (PJI), a type of SSI which occurs in joint replacement surgeries is one of the most common reasons for a total joint revision.[2-4] Joint replacements which must be revised due to an SSI are more difficult and more expensive to revise than other common

causes of revision such as aseptic loosening, malalignment, instability, and other mechanical revisions.[2] Revision surgery is less likely to be successful, has a higher rate of complications, requires longer hospital lengths of stay, higher rates of readmission, and higher risk of mortality when an SSI is present.[5-6] For these reasons, factors associated with of SSI in total joint surgeries should be defined and disseminated to help reduce SSI rates. The purpose of this article is to delineate risk factors associated with SSI (surface, deep tissue, and periprosthetic joint infections) in 4,973 hip and knee total joint replacement (TJR) surgeries completed at a tertiary academic medical center with multiple surgeons performing both primary and revision procedures.

METHODS

After receiving institutional human subjects review board approval, all total joint replacement (TJR) procedures performed between January 2014 to October 2018 were retrospectively retrieved from the electronic medical records (EMR). All elective primary and revision TJR procedures were included in this data pull. Emergent procedures such as those performed for hip fractures were excluded due to the focus of this study identifying the causes of SSI in TJR. Variables linked to SSI in previous literature were included in the analysis (see Table 1 for the complete list of variables analyzed in this study). The diagnosis of an SSI was determined by ICD-9 or ICD-10 coding in the billing data related to the patient, review of clinical notes for terms such as surgical site infection, periprosthetic infection, infection, increased white counts, and other terms associated with SSI. Records of procedures identified as having a potential SSI were hand reviewed by study staff (CO, NN) to verify that the SSI was related to the TJR. The facility where this study was conducted started using multi-layer dressing (Mepilex Border Incisional AGTM (MBI-AG) or the newer Mepilex Border Post-Op AGTM (MBPO-AG) which seal the wound on a surgical incision during the data collection period. Patients are instructed to keep the dressing in place for seven days postoperatively. Surgeons performing total joint arthroplasties during the study time period closed incisions in their usual way without changes to their technique.

Electronic abstraction from the EMR was utilized to obtain (1) patient demographic and life style characteristics, such as age, sex, race, ethnicity, smoking, and frequent alcohol use; (2) preoperative health conditions such as BMI, American Society of Anesthesiologists (ASA) physical status and comorbidities (e.g., heart attack, congestive heart failure, peripheral vascular disease, etc.); (3) perioperative factors such as duration of surgery, type of surgery (THA vs. TKA), use of MBI-AG/MBPO-AG dressing, type of anesthesia, inpatient procedure, use of betadine skin scrub; and (4) post-operative factors, such as the hospital length of stay, the number of dressing changes/7 days, duration of antibiotic use, antibiotic re-doses, and the number of distinct antibiotics. Total number of TJR procedures, primary and revisions, and known infections were verified by staff in the orthopedic surgery department. Cost of the procedure information was abstracted from the billing database for all procedures and merged with clinical data by unique patient identifier number.

For this analysis, anemia was defined as reported hemoglobin <7.0 per laboratory result. Body Mass Index (BMI) was either abstracted as recorded or calculated from height and weight as reported in the medical record. Diabetic status was abstracted per ICD-9 or 10 diagnostic coding and not per laboratory blood sugar values. American Society of Anesthesiologist (ASA) physical status was collapsed into three groups instead of the traditional five. ASA 1 level was defined as "Normal Healthy" patients, ASA 2 was defined as "Mild Systemic Disease" patients, and ASA 3 and 4 levels were combined into the "Severe Disease" patient category due to small numbers of procedures involving ASA 4 patients (n=39 procedures). There were no ASA 5 patients in the data. Skin integrity issues were dichotomized so that "0" indicated no skin integrity issues and "1" indicated presence of skin stripping, blisters, edema, erythema, rash, and/or maceration. Chronic diseases, taking corticosteroids, past pressure ulcer, Mepilex/Mepilex border dressing, general anesthesia, emergency operative procedure, inpatient procedure, betadine, dressing changes/7 days, antibiotics re-doses were each categorized as "1" indicating yes/presence of the condition or "0" indicating no/absence of the condition. Number of distinct antibiotics were categorized into three groups: 1) receiving one type of antibiotic, 2) receiving two types of antibiotics, and 3) receiving three to eight different types of antibiotics.

Statistical Analysis

SAS software was used to perform data analysis. Descriptive statistics were calculated for the overall sample of TJR procedures, and separately for the procedures with an SSI and those without an SSI, as means and standard deviations for continuous variables and frequencies and percentages for categorical variables. Initially, bivariate analyses were used to examine relationships between SSI and all study variables. Wilcoxon rank-sum test was used for continuous variables and Fisher's exact test was used for categorical variables. P-value < 0.05 was used to identify statistically significant relationships.

Next, multivariable analysis was used to identify risk factors for SSI. A multiple logistic regression model was developed with SSI as a binary dependent variable. Because of a small number of SSI events in the data (1.6%

Table 1. Descriptive Statistics for All Study Variables and Relationships with Surgical Site Infections: N=4,973

			Surgical site infection				
	Overall sample		Yes (n=82)		No (n=4,891)		
Variable	Mean±SD		Mean±SD		Mean±SD		p[d]
Age (years)	63.1±12.0		62.6±14.8		63.1±11.9		0.919
BMI pre-surgery	32.2±7.1		34.0±8.0		32.1±7.0		0.045
Surgery time (minutes)	149.3±38.7		166.8±41.6		149.0±38.5		<0.001
Duration of antibiotic (days)	8.3±11.0		16.0±14.2		8.1±10.8		<0.001
Length of stay[a] (days)	2.5±2.8		4.3±3.6		2.5±2.7		<0.001
Total cost (in $1,000)	60.9±42.4		98.6±76.4		60.3±41.3		<0.001
Variable	N	%	n	%	n	%	p[e]
Sex							0.057
Male	2,296	46.2	29	1.3	2,267	98.7	
Female	2,677	53.8	53	2.0	2,624	98.0	
Race							0.497
White	4,643	93.4	75	1.6	4,568	98.4	
African-American	182	3.7	6	3.3	176	96.7	
Hispanic/Latino	78	1.6	1	1.3	77	98.7	
All others	70	1.4	0	0.0	70	100.0	
Ethnicity							1.000
Hispanic	73	1.5	1	1.4	72	98.6	
Non-Hispanic	4,900	98.5	81	1.7	4,819	98.4	
Smoking							0.470
Yes	128	2.6	3	2.3	125	97.7	
No	4,845	97.4	79	1.6	4,766	98.4	
Frequent Alcohol							1.000
Yes	33	0.7	0	0.0	33	100.0	
No	4,940	99.3	82	1.7	4,858	98.3	
ASA physical status							0.039
Normal healthy	2,325	46.8	40	1.7	2,285	98.3	
Mild systemic disease	1,460	29.4	15	1.0	1,445	99.0	
Severe disease/constant threat to life	1,188	23.9	27	2.3	1,161	97.7	
Chronic Diseases							
Heart attack							0.127
Yes	117	2.4	4	3.4	113	96.6	
No	4,856	97.7	78	1.6	4,778	98.4	
Congestive heart failure							0.777
Yes	209	4.2	4	1.9	205	98.1	
No	4,764	95.8	78	1.6	4,686	98.4	
Other cardiovascular disease							0.311
Yes	2,082	41.9	39	1.9	2,043	98.1	
No	2,891	58.1	43	1.5	2,848	98.5	

Note: GERD is gastroesophageal reflux disease; DVT is deep vein thrombosis/pulmonary embolism; MBI-AG is Mepilex Border Incisional AG™ and MBPO-AG is Mepilex Border Post-Op AG™.
[a]one missing value for these variables in the non-SSI records; [b]p-value for Wilcoxan rank sum test; [c]p-value for Fisher's exact test.

Table 1. Descriptive Statistics for All Study Variables and Relationships with Surgical Site Infections: N=4,973 (Continued)

			Surgical site infection				
	Overall sample		Yes (n=82)		No (n=4,891)		
Variable	N	%	n	%	n	%	p[e]
Cardiac dysrhythmia							0.009
Yes	921	18.5	25	2.7	896	97.3	
No	4,052	81.5	57	1.4	3,995	98.6	
Peripheral vascular disease							0.551
Yes	187	3.8	4	2.1	183	97.9	
No	4,786	96.2	78	1.6	4,708	98.4	
Cerebrovascular disease							0.402
Yes	377	7.6	8	2.1	369	97.9	
No	4,596	92.4	74	1.6	4,522	98.4	
Hypertension							0.025
Yes	3,301	66.4	64	1.9	3,237	98.1	
No	1,672	33.6	18	1.1	1,654	98.9	
Psychiatric disease							0.010
Yes	2,146	43.2	47	2.2	2,099	97.8	
No	2,827	56.9	35	1.2	2,792	98.8	
Chronic pulmonary disease							0.326
Yes	979	19.7	12	1.2	967	98.8	
No	3,994	80.3	70	1.8	3,924	98.3	
Dyslipidemia							0.569
Yes	1,950	39.2	35	1.8	1,915	98.2	
No	3,023	60.8	47	1.6	2,976	98.5	
Peptic ulcer or liver disease							0.700
Yes	454	9.1	6	1.3	448	98.7	
No	4,519	90.9	76	1.7	4,443	98.3	
Diabetes mellitus							0.018
Yes	1,013	20.4	26	2.6	987	97.4	
No	3,960	79.6	56	1.4	3,904	98.6	
Chronic renal disease							<0.001
Yes	559	11.2	20	3.6	539	96.4	
No	4,414	88.8	62	1.4	4,352	98.6	
Malignancy							0.135
Yes	836	16.8	19	2.3	817	97.7	
No	4,137	83.2	63	1.5	4,074	98.5	
Rheumatoid disease							0.634
Yes	296	6.0	6	2.0	290	98.0	
No	4,677	94.1	76	1.6	4,601	98.4	
Thyroid disease							0.334
Yes	1,007	20.3	20	2.0	987	98.0	
No	3,966	79.8	62	1.6	3,904	98.4	

Note: GERD is gastroesophageal reflux disease; DVT is deep vein thrombosis/pulmonary embolism; MBI-AG is Mepilex Border Incisional AG™ and MBPO-AG is Mepilex Border Post-Op AG™.
[a]one missing value for these variables in the non-SSI records; [b]p-value for Wilcoxan rank sum test; [c]p-value for Fisher's exact test.

Table 1. Descriptive Statistics for All Study Variables and Relationships with Surgical Site Infections: N=4,973 (Continued)

			Surgical site infection				
	Overall sample		Yes (n=82)		No (n=4,891)		
Variable	N	%	n	%	n	%	p[e]
Anemia							<0.001
Yes	3,323	66.8	69	2.1	3,254	97.9	
No	1,650	33.2	13	0.8	1,637	99.2	
DVT[c]							0.154
Yes	1,626	32.7	33	2.0	1,593	98.0	
No	3,347	67.3	49	1.5	3,298	98.5	
GERD[b]							0.218
Yes	1,433	28.8	29	2.0	1,404	98.0	
No	3,540	71.2	53	1.5	3,487	98.5	
Skin Related Issues							
Taking corticosteroids							0.029
Yes	3,475	69.9	48	1.4	3,427	98.6	
No	1,498	30.1	34	2.3	1,464	97.7	
Skin integrity issues							<0.001
Yes	612	12.3	25	4.1	587	95.9	
No	4,361	87.7	57	1.3	4,304	98.7	
Past pressure ulcer							0.009
Yes	78	1.6	5	6.4	73	93.6	
No	4,895	98.4	77	1.6	4,818	98.4	
TJR Procedural Factors							
Surgery performed							0.578
TKA	2,543	51.1	39	1.5	2,504	98.5	
THA	2,430	48.9	43	1.8	2,387	98.2	
MBI-AG or MBPO-AG dressing							<0.001
Yes	3,276	65.9	38	1.2	3,238	98.8	
No	1,697	34.1	44	2.6	1,653	97.4	
General anesthesia							0.055
Yes	1,056	21.2	25	2.4	1,031	97.6	
No	3,917	78.8	57	1.5	3,860	98.5	
Emergency operative procedure							1.000
Yes	86	1.7	1	1.2	85	98.8	
No	4,887	98.3	81	1.7	4,806	98.3	
Inpatient procedure[a]							0.266
Yes	4,855	97.7	82	1.7	4,773	98.3	
No	117	2.4	0	0.0	117	100.0	
Number of arthroplasties							0.358
1	3,146	63.3	56	1.8	3,090	98.2	
>1	1,827	36.7	26	1.4	1,801	98.6	

Note: GERD is gastroesophageal reflux disease; DVT is deep vein thrombosis/pulmonary embolism; MBI-AG is Mepilex Border Incisional AG™ and MBPO-AG is Mepilex Border Post-Op AG™.
[a]one missing value for these variables in the non-SSI records; [b]p-value for Wilcoxan rank sum test; [c]p-value for Fisher's exact test.

Table 1. Descriptive Statistics for All Study Variables and Relationships with Surgical Site Infections: N=4,973 (Continued)

			Surgical site infection				
	Overall sample		Yes (n=82)		No (n=4,891)		
Variable	N	%	n	%	n	%	p[e]
Betadine							0.088
Yes	144	2.9	5	3.5	139	96.5	
No	4,829	97.1	77	1.6	4,752	98.4	
Post-operative factors							
Dressing changes/7 days							0.126
Yes	75	1.5	3	4.0	72	96.0	
No	4,898	98.5	79	1.6	4,819	98.4	
Antibiotics re-doses							0.005
Yes	4,091	82.3	57	1.4	4,034	98.6	
No	882	17.7	25	2.8	857	97.2	
Number of distinct antibiotics							<0.001
1	3,474	69.9	27	0.8	3,447	99.2	
2	1,064	21.4	30	2.8	1,034	97.2	
3-8	435	8.8	25	5.8	410	94.3	

Note: GERD is gastroesophageal reflux disease; DVT is deep vein thrombosis/pulmonary embolism; MBI-AG is Mepilex Border Incisional AG™ and MBPO-AG is Mepilex Border Post-Op AG™.
[a]one missing value for these variables in the non-SSI records; [b]p-value for Wilcoxan rank sum test; [c]p-value for Fisher's exact test.

of all TJR procedures analyzed), a penalized likelihood-based approach called Firth logistic regression method was utilized. Firth logistic regression is used to minimize potential estimation issues caused by small samples, rare events, and complete separation in the data. Patients' age and sex were included as independent variables in the model regardless of their statistical significance in bivariate analysis and multivariable analysis. Health conditions and procedure-related factors were tested for inclusion in the model if they were significant in bivariate analysis and kept in the model if they were significant in multivariable analysis. An interaction between sex and BMI was tested to determine if sex might moderate the relationship between SSI and BMI. Post-operative factors and total cost were not included in the model because the purpose of this paper was to identify risk factors for an SSI that manifested either before or during the procedure. Continuous variables were centered at the sample means. Potential clustering effects of procedures within patients was not adjusted for in the model because the majority of patients (78.3%) had only one TJR procedure during this time period. Model-based odds ratios (OR) and 95% confidence intervals (CI) were estimated for all independent variables in the model.

RESULTS

The study sample consists of 4,973 TJR procedures completed between January 1, 2014 and November 1, 2018, including 2,543 (51.1%) total knee arthroplasty procedures (TKA) and 2,430 (48.9%) total hip arthroplasty procedures (THA). Of the total 4,014 unique patients in the study, 3147 (78.3%) had one TJR procedure, 786 (19.6%) had two TJR procedures, and 81 (2.0%) had 3-4 procedures during this time frame. Of the 82 patients who suffered an SSI, 39 occurred for the TKA procedures (47.6%) and 43 occurred for the THA procedures (52.4%). Of 82 SSI events which occurred in 75 patients: 69 patients had one SSI, 5 patients had two SSI events, and 1 patient suffered from three SSI events.

Descriptive Statistics and Bivariate Analyses

Table 1 reports descriptive statistics for the overall sample of procedures, and for the procedures with an SSI and those without an SSI. The age of the patients in this sample of TJR procedures ranged from 21 to 102 years (Mean=63.1±12.0), the race was mostly white (93.4%), and the ethnicity was non-Hispanic (98.5%), while the sex split as 46.2% males and 53.8% females. Results of bivariate analysis are also shown in Table 1.

Table 2. Logistic Regression Model for Surgical Site Infections (N=4,973)

Variable	b	SE	Wald χ^2	p	Odds ratio	95% CI[c]
Intercept	-5.80	0.35	282.30	<.001		
Age (years)[a]	-0.02	0.01	4.79	0.029	0.81	[0.68, 0.98]
Sex (Female vs. Male)	0.50	0.23	4.72	0.030	1.65	[1.05, 2.59]
BMI pre-surgery	0.03	0.01	3.95	0.047	1.03	[1.00, 1.06]
Dysrhythmia (Yes vs. No)	0.63	0.25	6.21	0.013	1.88	[1.14, 3.10]
Chronic renal disease (Yes vs. No)	0.72	0.27	6.95	0.008	2.06	[1.20, 3.53]
Anemia (Yes vs. No)	0.76	0.30	6.49	0.011	2.13	[1.19, 3.82]
Skin integrity issues (Yes vs. No)	0.90	0.25	12.53	<.001	2.45	[1.49, 4.02]
Past pressure ulcer (Yes vs. No)	1.12	0.48	5.56	0.018	3.07	[1.21, 7.79]
Surgery time (minutes)[b]	0.01	0.00	8.46	0.004	1.08	[1.03, 1.14]
Mepilex or border dressing (No vs. Yes)	0.74	0.22	10.73	0.001	2.09	[1.34, 3.25]

Note: Age, BMI pre-surgery, and surgery duration were centered at the sample means.
[a]Odds ratio calculated for 10 year increments; [b]Odds ratio calculated for 10 minute increments. [c]95% CI = 95% Wald confidence interval.

Demographic and life style characteristics. An SSI was not associated with age, sex, race, ethnicity, smoking and frequent alcohol use.

Health conditions. Development of an SSI was associated with: skin integrity issues (p<0.001), anemia (p<0.001), chronic renal disease (p<0.001), a history of previous pressure ulcer(s) (p=0.009), cardiac dysrhythmias (p=0.009), psychiatric disease (p=0.010), diabetes mellitus (p=0.018), hypertension (p=0.025), taking corticosteroids (p=0.029), higher ASA physical status (p=0.039), and greater BMI (Mean = 34.0±8.0 vs. 32.1±7.0, p=0.045). Development of an SSI was not significantly associated with a previous heart attack, congestive heart failure or other cardiovascular disease, peripheral vascular disease, cerebrovascular disease, chronic pulmonary disease, peptic ulcer or liver disease, malignancy, rheumatoid diseases, dyslipidemia, thyroid disease, gastroesophageal disease, and deep vein thrombosis/pulmonary embolism.

TJR procedure-related factors. An SSI was associated with longer surgery duration (Mean = 166.8±41.6 minutes vs. 149.0±38.5 minutes, p<0.001) and not using a Mepilex Border Incisional AGTM or Mepilex Border Post-Op AGTM dressing (p<0.001). An SSI was not significantly associated with the type of surgery (THA vs. TKA), general anesthesia, emergency procedure, or preoperative scrub with betadine.

Post-operative factors. An SSI was associated with a longer length of stay (Mean = 4.3±3.6 days vs. 2.5±2.7 days, p<0.001), greater total cost (Mean = $98.6±76.4 thousand dollars vs. $60.3±41.3 thousand dollars, p<0.001), longer duration of antibiotic use (Mean = 16.0±14.2 days vs. 8.1±10.8 days, p<0.001), antibiotic re-doses (p=0.005), and a greater number of distinct antibiotics (p<0.001). An SSI was not significantly associated with the number of dressing changes.

Multivariable Analysis

The final multiple logistic regression model for an SSI is reported in Table 2. For all variables included in the model, the table shows unstandardized coefficients' estimates (b), standard errors (SE), Wald chi-square test values, p-values, odds ratios, and 95% Wald confidence intervals. TJR procedures involving older patients had lower odds of an SSI than procedures involving younger patients (OR=0.81 for a 10-year increment, 95% CI=0.68-0.98). TJR procedures involving female patients had greater odds of an SSI than procedures involving male participants (OR=1.65, 95% CI=1.05-2.59). The following health conditions increased the odds of an SSI: past pressure ulcer/s (OR=3.07, 95% CI=1.21-7.79), skin integrity issues (OR=2.45, 95% CI=1.49-4.02), anemia (OR=2.13, 95% CI=1.19-3.82), chronic renal disease (OR=2.06, 95% CI=1.20-3.53), cardiac dysrhythmia (OR=1.88, 95% CI=1.14-3.10), and higher BMI (OR=1.03, 95% CI=1.00-1.06). An interaction between sex and BMI was not included in the final model because it was not statistically significant (p=0.108). Longer procedures had greater odds of an SSI than shorter procedures (OR=1.08 for a 10-minute increment (95% CI=1.03-1.14). Procedures that did not use a Mepilex dressing (MBI-AG or MBPO-AG) had greater odds of an SSI than procedures using a Mepilex/Mepilex Border (OR=2.09, 95% CI=1.34-3.25).

DISCUSSION

Total joint replacement (TJR) including total knee arthroplasty (TKA) and total hip arthroplasty (THA) are safe and effective treatment options for advanced osteoarthritis and provide significant gains in quality of life for patients who receive them.[7] A certain percentage of TKA and THAs will get a surgical site infection (SSI) for any number of reasons. An SSI is extremely costly to treat[2] and our data (a TJR with an SSI cost on average $38,300 more to treat than a TJR without an SSI) and causes increased morbidity and mortality for the patients.[5-6] The Agency for Healthcare Research and Quality reported 600,000 primary THA and 715,000 TKA surgeries were completed in 2018.[8] Due to many factors including the aging of the US population those numbers are predicted to double by 2030 and more than double again by 2040.[9] Unfortunately, the current SSI rates for total joint surgery, reported between 1.99%-2.18% for THA and 2.05%-2.18% for TKA nationally are predicted to rise up to 6.5% for THA and 6.8% for TKA patients with the increased volume of surgeries.[10] These increased rates of SSI along with the increased number of procedures performed will increase stress on the already overburdened healthcare system, result in millions of extra hospital days for TJR patients, and cost multiple billions of dollars extra at a time when healthcare costs already account for roughly 17% of the U.S. gross domestic product. Identifying factors that are related to development of SSI in TJR patients is important. This analysis reviewed all available data related to 4,973 completed TJR procedures who were up to 4.7 years post primary surgery. Previous studies in orthopedics and surgery in general have considered a great number of factors as causative of SSI. This study included virtually every variable found when reviewing the literature along with some variables not previously studied due to difficulty in collecting the data.

SSI rates reported in this study (1.5% for TKA and 1.8% for THA) are within the range reported in the literature.[10-11] Multiple cross-checks of abstracted data and clinical verification were completed to make sure all potential SSI procedures were included in the analysis. The facility where the study was completed has staff assigned to follow up on all orthopedic SSI patients to determine if anything might have been done differently to prevent the infection. As society ages, BMIs increase, and humans live longer with more chronic conditions, it is important to determine factors associated with SSI for TJR patients. This study found that procedures involving female patients had an increased odds of an SSI by an estimated 65% over procedures involving males. It also found that being older decreased the odds of an SSI by an estimated 19% for every 10 years of age. BMI had an estimated 3% effect on increasing the odds of an SSI in TJR patients per each point of increased BMI meaning a 10-point increase in BMI (e.g. from 35 to 45) would increase the odds of an SSI by approximately 30%. The odds of an SSI increase by an estimated 8% for every 10 additional minutes of surgical time. These two points together signal a potentially greater increased risk for larger BMI patients since those surgeries frequently take longer to complete. Chronic renal disease and anemia more than doubled the odds of an SSI indicating that these medical conditions are probably important risk factors. We chose to define anemia as a laboratory documented hemoglobin level less than 7.0 which may seem low but has been increasingly reported as the threshold below which patient complications rise and, recommended by transfusion specialists, the number at which providers should consider transfusion. In our analysis, a hemoglobin less than 7.0 increased the risk of TJR patients suffering a surgical site infection which itself may be a reason to transfuse the TJR patient earlier. Cardiac dysrhythmias increase the odds of an SSI by an estimated 88%. Having a history of prior skin integrity issues more than doubled the odds of developing an SSI and a previously documented pressure ulcer more than tripled the odds of an SSI. It is undeniable that skin integrity issues and a history of previous pressure injuries have the greatest effect on increasing a TJR patient's chances of suffering an SSI postoperatively. The use of a multi-layer dressing, one designed to address skin integrity issues, on the incision postoperatively has a significant protective effect against the development of an SSI. Not using such a dressing in TJR procedures more than doubled the odds of developing an SSI.

CONCLUSION

Surgical site infections are problematic for patients, surgeons, and extremely costly for the healthcare system. The current rate of SSI/PJI is predicted to increase at the same time as the overall number of TJR surgeries is predicted to rise. This combination of factors will increase the number of SSI/PJI in THA/TKA patients and the overall burden on the already stretched healthcare system. Many factors affecting SSI development like chronic diseases and sex are not modifiable but may indicate the need to pay additional attention to the recovery process to detect an SSI sooner. Other factors such as early treatment of anemia and postoperative dressing choice are modifiable and may reduce the SSI burden for the individual patient and healthcare system.

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YOUNG PATIENTS HAVE POOR COMPLIANCE WITH CLINICAL AND RADIOGRAPHIC SURVEILLANCE RECOMMENDATIONS AFTER TOTAL HIP ARTHROPLASTY

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ABSTRACT

Background: Clinical and radiographic follow-up after total hip arthroplasty allows early detection of wear or failure and is particularly important in the younger THA population given potentially increased demands on implants. The purpose of this study is to characterize patient compliance with follow-up in the young hip arthroplasty population.

Methods: Patients ≤50 years who underwent primary THA at a single institution were included. Patients were given verbal instruction to schedule and attend follow up visits at years 1, 2, and 4-to-6 post- operatively. Multivariate analysis using Poisson regression was conducted to identify predictors associated with compliance. There were 344 patients with average age 38.0 years (range, 13-50). 55.5% of the patients were female.

Results: There were 178 (51.7%), 101 (29.4%), and 44 (12.6%) patients who complied recommendations at years 1,2, and 4-to-6 years, respectively. Females were more likely to attend 2-year follow up (p = 0.04) then males. Patients with post-op complications were more likely to attend 2-year follow up. (p = 0.01). There was no association between other studied variables and follow-up compliance at 1, 2, or 4-to-6-years post op.

Conclusion: Patient compliance was around 50% at 1 year follow-up after surgery and declined substantially over time in this young population. Overall, these data indicate that patients less than 50 years at the time of surgery are mostly noncompliant with follow-up recommendations and may not require routine surveillance or need improved methods of surveillance such as telemedicine or electronic surveys.

Level of Evidence: III

Keywords: arthroplasty, outcomes, follow-up, surveillance

INTRODUCTION

The volume of total hip arthroplasty (THA) procedures performed annually in the United States increased 177% between 2000 and 2019 and demand continues to rise.[1-3] In addition to increasing volume, THA is being performed more frequently in younger, heavier, and more physically active patients.[4-7] Rates of revision total hip arthroplasty (rTHA) are also projected to rise with projections estimating a 43%-70% increase in frequency of rTHA between 2014 to 2030.[8]

While advancements in implant design and surgical technique have led to improved implant survivorship, the burden of THA failure and revision remains high and is most often due to infection, mechanical failure, metallosis, instability, fracture, or osteolysis.[2,9-11] The reasons for rTHA may differ between young and old patients; one study reported increased implant loosening or wear in younger patients and higher dislocation or infection in older patients.[12] There are also differences in the indications for THA in young vs old patients with more young patients presenting with arthritis secondary to avascular necrosis (AVN), developmental dysplasia of the hip (DDH), or post-traumatic arthritis compared to primary osteoarthritis in older patients.[13] Differences in arthritis etiology, activity level, and life-expectancy likely all contribute to a significantly higher lifetime risk of revision in young vs old THA patients.[14]

Periodic post-operative evaluation is recommended after THA to assess outcomes and monitor for early signs of failure. However, we are currently lacking standardized recommendations for the frequency or quality of follow up.[15,16] Previous studies have reported poor compliance with recommended follow-up protocols.[17,18] Recently, the Centers for Medicare and Medicaid Services (CMS) has implemented mandatory Patient-Reported Outcome Measures (PROMs) collecting for THA, which will link reimbursement with post-operative PROMs in Medicare patients. Thus, compliance with follow-up

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protocols is critical for ensuring quality outcomes as well as securing full reimbursement. There is a need to identify factors associated with follow-up compliance especially in young THA patients who may benefit from early detection of complications or impending failure that may require rTHA. The aim of this study was to investigate positive and negative predictors for compliance with recommended follow-up among young (<50 years of age) patients undergoing THA.

METHODS

A total of 344 patients 50 years of age or younger underwent primary total hip arthroplasty performed by one surgeon (JCC) at a single institution between July of 2012 and May of 2018. All patients consented to an institutional review board-approved protocol for prospective data collection. There were two deaths at the time of follow-up with 1 being 10 months from the time of surgery and the other being 2 years and 2 months from the time of surgery. Both deaths were from unrelated causes. This left 343 patients available for 1 year follow-up and 342 patients available for the 2-6 year follow-up.

At the time of hospital discharge, all patients were given appointments to be seen for follow-up at six weeks and three months postoperatively per surgeon protocol. At the three-month visit, they were given verbal instructions by the primary surgeon to return at one year postoperatively. At the one-year visit, the patients were again verbally instructed by the surgeon to return in one year for a two-year postoperative visit. For annual appointments, the patient was given the month and the year of the next appointment (verbally and in written form on the billing sheet). At checkout, the patient was given the option to either: (1) immediately schedule their future appointment or (2) contact the office by telephone at a later date to schedule the routine annual follow-up. We did not perform follow-up telephone calls or mail notifications to remind these patients of their appointments. Patients who did not follow up at the one-year visit were not pursued for further follow up but were scheduled if they initiated scheduling follow-up visits. Data for all patient visits were recorded prospectively. For patients who received bilateral joint arthroplasty, only data from the first procedure were utilized.

Patient demographics and history were collected as part of an institutional registry. Demographics studied included age, gender, BMI, race, years of education, occupation, and proximity of home address to the medical center. Clinical variables collected for analysis included date of surgery, date of follow-up appointments, preoperative diagnosis, prior hip surgery, prior history of hip infection, post-operative complications. All patients completed the following PROMs: UCLA Activity Score, modified Harris Hip Score (mHHS), WOMAC Physical Function Score (WOMACp), and the SF-12 Physical Component Summary Scale (SF-12p). Because of its skewed and abnormal distribution, proximity to the medical center was dichotomized according to the distribution of distances the patients lived from the medical center. Proximity was categorized based on the 75th percentile distance from the medical center of 50 miles. This categorization allows comparison between patients who lived within 50 miles of the medical center and patients who lived more than 50 miles away.

Patient compliance with 1- to 6-year follow-up was the primary outcome variable analyzed. A 90-day window of eligibility was chosen for each annual follow-up visit. For example, a patient could successfully return for the 1-year follow-up visit as long as they returned to the office within the period from 90 days before to 90 days after the 1-year postoperative date.

Demographic and clinical variables for patients who did and did not return for follow-up were compared with the use of Poisson regression. Variables that were significant ($p < 0.05$) in univariate logistic regression analyses were analyzed in a multivariate logistic regression analysis predicting compliance. A stepwise selection method was used to identify significant variables and used to create a confounder adjusted model for these variables. Adjusted odds ratios and corresponding 95% confidence intervals are reported for variables in the multivariate model, and adjusted for all other variables in the model. For categorical predictors, the reference category for the adjusted odds ratio is indicated with an adjusted odds ratio of 1.0. For continuous predictors and unless otherwise noted, adjusted odds ratios reflect the increase in the odds of returning for follow-up per a 1-unit increase in the variable. Adjusted odds ratios for age are expressed in units of 10 years. Data are reported as the mean and the standard deviation or as the number of patients (and the percentage of the group).

RESULTS

The patient cohort was mostly female (56%) and white (86%); all demographics are reported in Table 1. Clinical follow-up compliance for all hip arthroplasty patients was 51.7% (178/344) at the 1-year visit, 29.4% (101/343) at the 2-year visit, and 12.6% (43/342) at the 4-6-year visit. (Table 1). Of the 344 patients included in final analysis, the most common pre-operative diagnosis was osteoarthritis (n=203). Other pre-operative diagnoses included developmental dysplasia (60), avascular necrosis (57), femoroacetabular impingement (12), post-traumatic arthritis (10), and rheumatoid arthritis (2). Female patients had higher rates of compliance at the 2-year follow up compared to male patients (65/191 (34%) females vs

36/153 (23.5%) males, p = 0.04). There were no differences in follow up among males and females at the 1 or 4-6-year follow-up. There was no difference in follow-up compliance based on BMI, race, education, occupation, proximity to medical center, or prior hip surgery or infection. (Table 1). There were higher rates of compliance at the 2-year follow up in patients who had a post-op complication (6/101, 5.9%) vs those who did not (3/242, 1.2%) (p = 0.01). There was no difference at the 1 or 4-6-year follow-up between patients with or without complications. The complications reported within the study period were: 3 deep infections, 2 hematomas requiring evacuation, 2 prosthetic hip dislocations, 1 femoral stem subsidence requiring revision, 1 deep vein thrombosis. Timing from surgery to complication was 10 days to 20 months and only 3 complications occurred between the 1- and 2-year follow-up. There were no additional complications reported after 2-year follow-up. (Table 2)

There were no differences in any of the variables studied between rates of patient follow up at the 1-, 2-, or 4-6-year follow-up time points. (Table 3) There was no association between baseline UCLA, mHSS, WOMAC PFS, and SF-12p baseline scores and patient follow up. Multivariate analysis of age, race, and gender revealed older age at the time of surgery as the only variable positively correlated with follow-up (relative risk = 0.98, confidence interval = 0.95-0.99, p-value = 0.02). (Table 4)

DISCUSSION

As the demand for THA increases there could be a corresponding increase in post-op surveillance. This is especially relevant for young patients who have longer survival projections compared to geriatric patients. Current recommendations for surveillance are variable and it is unknown if there are specific factors associated with patients complying with surveillance recommendations.[19] In the current study, we found low rates of patient compliance with instructions for routine surveillance follow-up with decreasing compliance at the 1, 2, and 4-6 year intervals. The only time-point that had any positive associations with follow-up was the 2-year follow-up visit with increased compliance in females and patients with a post-op complication. However, most complications occurred within the first year of surgery.

Surveillance is aimed at timely identification of implant problems with the goal of addressing problems prior to catastrophic failures. Early identification and intervention may be financially beneficial as well as lead to improved

Table 1. Patient Demographic Information and Follow Up Compliance

Patient characteristic	All	Attended 1 year follow-up			Attended 2 year follow-up			Attended 4-6 year follow-up		
	344	Yes (n=178)	No (n=166)	p=value	Yes (n=101)	No (n=242)	p-value	Yes (n=43)	No (n=299)	p-value
Age (average years, SD)	38.01 (10.68)	38.25 (10.51)	37.72 (10.87)	0.3	38.11 (10.40)	38.04 (10.8)	0.48	38.61 (9.4)	37.98 (10.86)	0.36
Gender, N (%)				0.54			0.04			0.52
Male	153 (44%)	82 (46%)	71 (43%)		36 (36%)	116 (48%)		17 (40%)	134 (45%)	
Female	191 (56%)	96 (54%)	95 (57%)		65 (64%)	126 (52%)		26 (60%)	165 (55%)	
BMI (average, SD)	28.08 (5.65)	27.86 (5.63)	28.32 (5.68)	0.23	27.48 (5.44)	28.34 (5.7)	0.1	28.05 (4.83)	28.35 (5.77)	0.37
Race, N (%)				0.23			0.08			0.39
White	296 (86%)	157 (88%)	139 (84.%)		92 (91%)	203 (84%)		39 (91%)	257 (86%)	
Non-white	48 (14%)	21 (12%)	27 (16%)		9 (9%)	39 (16%)		4 (9%)	42 (14%)	
Years of education (average, SD)	14.63 (3.0)	14.48 (2.7)	14.76 (3.3)	0.4	14.96 (2.6)	14.51 (3.1)	0.11	15.12 (2.4)	14.57 (3.1)	0.13
Occupation, N (%)										
Working full time	205 (60%)	110 (62%)	95 (58%)	0.38	64 (63%)	144 (59%)	0.50	30 (69%)	176 (59%)	0.17
Working part time	38 (11%)	18 (10%)	20 (12%)	0.57	12 (12%)	23 (10%)	0.51	6 (14%)	32 (11%)	0.53
Disabled	27 (8%)	12 (7%)	15 (9%)	0.43	10 (10%)	17 (7%)	0.37	2 (5%)	25 (8%)	0.4
Not working	38 (11%)	24 (13%)	14 (8%)	0.14	9 (9%)	31 (13%)	0.3	3 (7%)	35 (12%)	0.36
Student	36 (10%)	14 (8%)	22 (13%)	0.1	6 (6%)	27(11%)	0.18	2 (5%)	31 (10%)	0.23
v	201 (58%)	96 (54%)	105 (63%)	0.08	59 (58%)	141 (58%)	0.98	22 (51%)	178 (59%)	0.3
	143 (42%)	82 (46%)	61 (37%)		42 (42%)	101 (42%)		21 (49%)	121 (41%)	
Prior hip surgery, N (%)	145 (42%)	78 (43.8%)	67 (40.3%)	0.52	43 (42.5%)	101 (41.7%)	0.89	18 (41.8%)	126 (42.1%)	0.98
Prior hip infection	4 (1.2%)	2 (1.1%)	2 (1.2%)	0.94	2 (2%)	2 (0.8%)	0.36	1 (2.3%)	3 (1%)	0.45
Post-op Complication	9 (2.6%)	7 (3.9%)	2 (1.2%)	0.11	6 (5.9%)	3 (1.2%)	0.01	0 (0%)	9 (3%)	0.25

SD = Standard Deviation.

Table 2. Post-Operative Complication Incidence and Timing

Complication	Number	Time post-op	Revision surgery
Deep infection	3	11 months	Y
		16 months	Y
		20 months	Y
Hematoma	2	10 days	Y
		13 days	Y
Dislocation	2	6 months	Y
		18 months	N
Femoral stem subsidence	1	11 months	Y
Deep vein thrombosis	1	2 weeks	N

patient outcomes. For example, in a study of revision THA, Kamath et al. found median surgical cost was 24% greater in patients who had urgent surgery compared to those who were elective and urgent revisions were associated with longer median hospital stay, higher risk of post-op ICU admission, and increased risk of blood transfusion.[20] However, over-surveillance may be costly to surgeons and patients if there are low rates of identified problems at these follow-up visits. This is especially relevant given the outstanding performance of highly cross-linked polyethylene over the first two decades of use. In a study investigating the fate of patients who did not return for scheduled follow up, King et al. found that patients who missed follow up had similar outcomes and low rates of reoperation compared to patients who followed up as instructed.[21] We did not perform any investigation to find patients who did not follow-up on their own in this study. However, we did not identify any patients returning with complications outside of their routinely scheduled surveillance visits between 2-and 6-year follow up.

As of now, there are no definitive recommendations regarding the frequency of follow-up for total joint arthroplasty. The American Association of Orthopaedic Surgeons (AAOS) has previously suggested "periodic radiographic and clinical examination of surgical results, throughout lifetime".[22] The frequency of follow-up has come into question given the potential burden on patients to return to clinic and health care costs associated with in-person follow-up.[23] Further, radiographs are typically obtained at follow-up visits resulting in radiation exposure and cost to patients with unclear value in asymptomatic patients.[24,25] Especially in young THA patients, we should be judicious in the use of pelvic radiation and consider limiting radiographic surveillance when able.

In this study, patients were instructed to return to clinic at specific intervals. However, patients may also prefer alternatives to in-person follow up. A study by Sethuraman et al. questioned 100 asymptomatic patients at routine follow-up evaluations after total knee arthroplasty and found that forty-five patients would have preferred not to return to the doctor's office because of the inconvenience and a perceived lack of benefit.[26] Alternative follow-up options including virtual consultation, mailed questionnaires, and remote radiographs have been shown to be reliable, cost-effective, and associated with high patient satisfaction.[27,28] We hypothesized that patients who live far away or those who are working full-time may have lower rates of compliance with follow-up, however in our study we did not find any association between proximity to medical center, occupation, or years of education and compliance with follow-up. This differs from the findings in a study by Schexnayder et al. who found greater travel distance to be associated with lower rates of compliance at the 1-year follow-up visit.[18] Thus, alternative follow-up options may be of value to all patients regardless of how far they live from clinic locations. The protocol given to patients in this study was a one-time verbal instruction from the treating surgeon, which is likely not sufficient. In addition to virtual or alternative follow-up options, phone or electronic message reminders would also likely increase patient follow-up compliance.

Young patients undergoing THA may have unique risks compared to geriatric patients. Takenaga et al. examined 100 young patients who had undergone a total hip arthroplasty, with young defined as age < 50 years and found rates of pelvic osteolysis around 25% at minimum 10-year follow up.[29] The introduction of highly cross-linked polyethylene (HXLPE) has led to decreased osteolysis and wear. The problem has not been eliminated; in a study examining young patients with HXLPE THA, Rames et al. found CT diagnosed osteolysis in 35% of hips at average 16-year follow up.[30] Improvements in implants and bearing surfaces may lead to lower rates of wear, however longer term follow up in young patients is still needed. Because of this, we recommend that young patients continue to be monitored at ten years after arthroplasty, with increased monitoring if wear and lysis problems are identified.

The only factors that were associated with follow-up compliance were female gender and post-op complication, which was only significant at the 2-year follow-up visit. Female gender has been shown to be predictive in other fields such as a study by Chou et al. that found females were more likely to attend 6-week, 6-month, and 12-month follow up visits after total shoulder arthroplasty (TSA).[31] Similar findings in orthopaedic trauma patients found male gender was a risk for non-compliance with

follow-up appointments.[32] Patients with post-op complications have been shown to have lower risk of being lost to follow up after TSA.[33] It is important to note the potential implications of this in research if there are higher rates of follow up in patients who have had a complication. While the difference reached statistical significance at the 2-year follow-up time point, we found no difference in compliance with follow up at the 4-to-6-year time point, so this may not impact longer-term follow up. Age is another factor that may be associated with follow-up compliance, younger patients have been found to have lower rates of follow-up compared to older patients.[31] We only included young (<50 years-old) patients in this study, which may contribute to the low compliance rates. New CMS guidelines requires post-operative PROMs collection in order to receive reimbursement. This requires high rates of patient compliance in order to meet participation requirements. While this is only required for Medicare patients at this time, insurers may consider similar programs to include younger patients as well. Another reason it is critical to understand factors associated with follow-up compliance.

There are potential limitations of this study. First, our cohort consisted of patients from a single surgeon's practice in a limited geographic area comprising of both urban and rural populations in the Midwest. These

Table 3. Comparison of Patient Characteristics in Compliant Patients at 1, 2, and 4-6-Years

Patient Characteristic	Yes, follow up at 1 year (n=178)	Yes, follow up at 2-years (n=101)	Yes, follow up at 4-6 years (n=43)	p-value
Age (average years, SD)	38.25 (10.51)	38.11 (10.40)	38.61 (9.4)	0.98
Gender, N (%)				0.22
Male	82 (46%)	36 (36%)	17 (40%)	
Female	96 (54%)	65 (64%)	26 (60%)	
BMI (average, SD)	27.86 (5.63)	27.48 (5.44)	28.05 (4.83)	0.48
Race				0.72
White	157 (88%)	92 (91%)	39 (91%)	
Non-white	21 (12%)	9 (9%)	4 (9%)	
Years of education (average, SD)	14.48 (2.7)	14.96 (2.6)	15.12 (2.4)	0.56
Occupation, N (%)				0.76
Working full time	110 (62%)	64 (63%)	30 (69%)	
Working part time	18 (10%)	12 (12%)	6 (14%)	
Disabled	12 (7%)	10 (10%)	2 (5%)	
Not working	24 (13%)	9 (9%)	3 (7%)	
Student	14 (8%)	6 (6%)	2 (5%)	
Proximity to medical center				0.66
≤50 miles	96 (54%)	59 (58%)	22 (51%)	
>50 miles	82 (46%)	42 (42%)	21 (49%)	
Prior hip surgery, N (%)	78 (43.8%)	43 (42.5%)	18 (41.8%)	0.96
Prior hip infection, N (%)	2 (1.1%)	2 (2%)	1 (2.3%)	0.78
Complications, N (%)	7 (3.9%)	6 (5.9%)	0 (0%)	0.56

SD = Standard Deviation.

Table 4. Predictors of Patient Follow Up Including Outcomes Scores

Predictors	Risk Ratio/Relative Risk	Confidence limit lower	Confidence limit upper	P value
Age at Surgery	0.98	0.95	0.99	0.02
Race (White vs others)	1.54	0.55	4.35	0.40
Gender (Male vs female)	1.25	0.67	2.31	0.47
Baseline UCLA activity level	1.09	0.94	1.27	0.24
Baseline mHHS	0.98	0.95	1.01	0.17
Baseline WOMAC PFS	1.02	0.99	1.05	0.13
Baseline SF-12p	0.99	0.96	1.02	0.49

mHHS = modified Harris Hip Score. WOMAC PFS = WOMAC Physical Function Score. SF-12p = SF -12 physical function component.

factors may contribute to bias due to the demographic makeup of the student cohort and the practice style of the surgeon. Second, other contributors to patient outcomes such as comorbidities may have impacted adherence to the follow-up plan and were not analyzed in this study. Third, our cohort consisted of a subset of patients willing to participate in a prospective research study, predisposing our study to self-selection bias. These patients may have been more likely to return for follow-up due to being a more motivated cohort. The overall low compliance rates of our cohort may be of more value than in our statistical findings as the small differences of the variable in between the cohorts may be of low clinical relevance. Finally, there are alternatives means to achieve follow-up including automated reminders as well as remove therapeutic monitoring or virtual visits, which were not considered in this study. In particular with this younger group of patients, wearable technology, electronic messaging and reminders, and other technology solutions may contribute to improved compliance with recommended follow up.

CONCLUSION

Young THA patients have poor rates of compliance with in-person follow up. Post-operative surveillance for these patients remains important given the risk of osteolysis and wear despite improvements in implant materials. Alternative radiographic and clinical surveillance programs with increased convenience or reduced cost to patients may provide a more effective screening mechanism to detect early implant failure. Female sex and post-op complications were the only factors associated with increased compliance in this study. Thus, we must continue to work on methods to improve overall compliance and perhaps to study how to best identify those at higher risk of such complications who need more frequent surveillance.

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DOES APPROACH MATTER? DIRECT ANTERIOR VERSUS POSTERIOR APPROACH IN CONVERSION TOTAL HIP ARTHROPLASTY

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ABSTRACT

Background: Conversion total hip arthroplasty (THA) after prior hip surgery is generally associated with higher rates of complications when compared to primary THA. There is a paucity of evidence examining the influence of surgical approach on outcomes of conversion THA. This study compares complication rates between direct anterior approach (DAA) and posterior approach (PA) in patients with prior hip or acetabular fracture fixation undergoing conversion THA.

Methods: Records were reviewed for patients undergoing conversion total hip arthroplasty with prior hip or acetabular fracture fixation from January 1, 2006 to June 30, 2023 at a single institution. Complication rates were assessed at 90 days and at final follow-up. A total of 104 patients were included in the study, with 75 in the PA cohort and 29 in the DAA cohort.

Results: There were no significant differences in complication rates between cohorts at both 90 days and at final follow-up (mean 754 days) including rates of dislocation, intraoperative fracture, postoperative periprosthetic fracture, periprosthetic joint infection, superficial surgical site infection, and wound dehiscence.

Conclusion: Conversion THA on patients with prior hip or acetabular fracture fixation can be successful from either an anterior or posterior approach. Each approach may offer unique benefits and disadvantages depending on patient-specific factors. Further research is needed to evaluate long-term outcomes and complication rates associated with each surgical approach.

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INTRODUCTION

Primary total hip arthroplasty (THA) is a common, highly effective procedure for the treatment of severe osteoarthritis (OA). Compared to primary THA, conversion THA (following prior hip or acetabular fracture fixation) has been associated with increased treatment costs, infection, dislocation, periprosthetic fracture, mechanical complication, and revision surgery.[8,17,18] With an increasingly aging population, the rate of hip fractures is projected to rise by over 10% by 2030.[26] With rates of failed fixation ranging from 15% to 41% for nondisplaced and displaced fractures of the femoral neck, the volume of conversion THA is likely to increase.[5,24] As a result, optimization of outcomes following conversion THA for complications after prior hip fracture fixation is crucial. Despite this, there is a paucity of evidence currently available on this topic.

The direct anterior, direct lateral, and posterior approaches are the most common surgical approaches utilized in THA.[21] The direct anterior approach (DAA) has recently grown in popularity. Relative the posterior approach (PA), DAA lends itself to easier use of intraoperative fluoroscopy and has been reported to be associated with low rates of hip instability.[15] Currently, the totality of evidence regarding the superiority of one approach is ambiguous, with benefits and drawbacks likely inherent with each technique.[20]

Studies to date comparing outcomes of DAA vs PA have focused on primary and revision THA specifically.[6,29] These individual approaches may hold potential in reducing risks of complications in patients undergoing more challenging conversion procedures who are at higher risk for dislocation, infection, and other major complications.[19] The purpose of this study was to explore the association between surgical approach (DAA versus PA) and complication rates in patients undergoing conversion THA with a history of prior hip or acetabular fracture fixation. We hypothesized that the DAA cohort would have lower rates of dislocation but higher rates of wound complications than the PA cohort.

METHODS

Data Source and Patient Selection

Following institutional board review and approval, electronic medical records were queried for patients undergoing conversion THA (CPT Code 27132) from January 1, 2006 to June 30, 2023. These procedures were performed by one of multiple fellowship trained arthroplasty surgeons at a single high-volume institution. Patients with prior or active joint infections, previous surgeries other than fixation of hip or acetabular fracture, concurrent femoral shaft fracture, pathologic hip fractures, and those with less than 30 days of follow-up were excluded from the study unless early revision was required.

A total of 435 records were reviewed following query for conversion THA procedures. After applying the exclusion criteria, there were 104 patients (104 hips) out of 142 patients with a prior hip fracture included in the study, with 75 undergoing conversion THA via a PA and 29 via a DAA. The remainder of the records were excluded due to the following reasons: 79 were duplicates, 19 had present or prior infection, 21 were revision THAs, 2 had concomitant femoral shaft fractures at time of injury, 173 had received procedures other than fixation of hip or acetabular fracture, 32 had insufficient follow-up data, and 5 had operations related to pathologic fractures or malignancy.

Table 1. Baseline Patient Characteristics

Characteristic	Posterior n = 75	Anterior n = 29	P-value[1]
Age (n,%)	61.4 (16.7)	59.7 (14.8)	0.6
Sex (n,%)			>0.9
Male	29 (39)	11 (38)	
Female	50 (61)	18 (62)	
CCI (Mean, SD)	2.4 (2.0)	1.9 (1.7)	0.2
Preop Opioid Use (n,%)	24 (32)	11 (39)	0.5
Obesity (n,%)	20 (27)	8 (28)	>0.9
Smoking (n,%)	8 (11)	2 (6.9)	0.7
Hypertension (n,%)	37 (49)	11 (38)	0.3
Diabetes (n,%)	10 (13)	1 (3.4)	0.3
CKD (n,%)	0 (0)	2 (6.9)	0.08
RA (n,%)	3 (4.0)	2 (6.9)	0.7
Prior VTE (n,%)	3 (4.0)	2 (6.9)	0.6

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test.
Legend: CCI = Charlson Comorbidity Index, CKD = Chronic Kidney Disease, RA = Rheumatoid Arthritis, VTE = Venous Thromboembolism.

Baseline Patient Data and Comorbidities

The following baseline patient data and comorbidities were collected during review of patient records: age, sex, Charlson Comorbidity Index, preoperative opioid use, obesity, smoking, hypertension, diabetes, chronic kidney disease (CKD), rheumatoid arthritis (RA), and prior venous thromboembolism (VTE). Preoperative opioid use was defined as regular, weekly opioid use required to manage hip-related pain before surgery. Comorbidities were assigned based on presence of at least one physician-labeled diagnosis in the patients' records. There were no significant differences in baseline patient characteristics (Table 1).

Table 2. Prior Operative History

Characteristic	Posterior n = 75	Anterior n = 29	P-value[1]
Prior Surgical Procedure (n,%)			0.3
ORIF	55 (73)	24 (83)	
CRPP	20 (27)	5 (17)	
Number of Prior Operations (n,%)			0.2
1	69 (92)	29 (100)	
2	6 (8)	0	
Time to Conversion[3]			
(Years) (Mean, Range)	3 (0,10)	2 (1,14)	0.7
Fracture Location (n,%)			0.5
Acetabular	16 (21)	8 (27.6)	
Femoral Neck	35 (47)	12 (41.4)	
Intertrochanteric	15 (20)	7 (24.1)	
Subtrochanteric	7 (9.3)	1 (3.4)	
Acetabular + Femoral Neck	0 (0)	1 (3.4)	
Acetabular + Intertrochanteric	2 (2.7)	0 (0)	
Hardware Type (n,%)			0.6
CMN	24 (32)	6 (20.7)	
SHS	6 (8.0)	2 (6.9)	
Screws/Pins	29 (39)	15 (51.7)	
Plate & Screws	16 (21)	6 (20.7)	
Conversion Diagnosis (n,%)			0.6
PTOA	47 (63)	17 (59)	
Failed Fixation	22 (29)	8 (28)	
AVN	5 (6.7)	3 (10)	
Intractable Pain	1 (3.3)	0 (0)	

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test.
Legend: ORIF = Open Reduction Internal Fixation, CRPP = Close Reduction Percutaneous Pinning, CMN = Cephalomedullary Nail, SHS = Sliding Hip Screw, PTOA = Post Traumatic Osteoarthritis, AVN = Avascular Necrosis.

Prior Operative History

Information was collected regarding the index hip procedure performed for each patient: open reduction internal fixation (ORIF) vs closed reduction percutaneous pinning (CRPP). Data was also collected regarding the number of prior hip fracture related operations, time from hip fracture surgery to conversion, original fracture diagnosis, type of hardware used, and diagnosis for conversion. Hardware type was classified as cephalomedullary nail (CMN), sliding hip screw (SHS), screws or pins, and plates and screws. Diagnoses for conversion were classified into post-traumatic osteoarthritis (PTOA), failed fixation (including nonunion, malunion, and hardware failure), avascular necrosis (AVN), and intractable pain.

There were no significant differences in prior operative history (Table 2). In the PA cohort, 59 patients (79%) had a prior hip fracture while 18 patients (21%) had a prior acetabular fracture. In the DAA cohort, 21 (72%) and 9 patients (28%) had a prior acetabular fracture and hip fracture, respectively.

Surgical and Implant Characteristics

The surgical characteristics of each cohort were also obtained, which included information on operative time, estimated blood loss, anesthesia type, and fixation method (cement versus uncemented). For each prior fracture type (i.e. acetabular and femoral), the following were recorded: hardware removed and technique utilized, use of the prior surgical approach, and need for an additional incision for hardware removal. Information on surgical implants was also collected, including stem type, femoral head size, and liner type (i.e. neutral, elevated rim, or dual mobility). Femoral stems were categorized according to the updated classification system for cementless stems.[14]

Overall, patients receiving DAA had higher utilization of spinal anesthesia over general anesthesia compared to patients with PA (13 vs 69%, $P < 0.001$) (Table 3). There were no significant differences in operative time or estimated blood loss between cohorts.

Surgical Technique

Incisions from previous operations were used where appropriate, and additional incisions made if necessary for the removal of existing hardware. Hardware present from prior hip fracture ORIF or CRPP was completely removed during THA except for 5 cases, which were managed with staged removal followed later by conversion THA. For prior acetabular fractures, only hardware impairing placement of the acetabular component was removed. The standard Kocher-Langenbeck approach was utilized for PA cases, and the Hueter interval was utilized for the DAA cases in this study.[7,9]

Precise information on the specific surgical approaches employed during index operation was not consistently reported by the operating surgeons and could not be collected, and only whether the surgeons used the prior incision was consistently noted. In patients with prior acetabular fractures, patients undergoing PA were more likely to have the original incision utilized from the previous surgery (72 vs 22%, $P = 0.037$) while in patients with prior hip fractures, patients undergoing DAA were more likely to require an additional incision for hardware removal (20.3 vs 67%, $P < 0.001$).

Contemporary uncemented acetabular and femoral components were used in all cases. Mean (range) number of supplemental acetabular screws placed for fixation of the acetabular component were 0.6 (0-2) in the DAA cohort and 1.4 (0-7) in the PA cohort ($P < 0.001$). Bone grafts were used for the acetabular component in 4 cases (5.3%) in the PA cohort and 2 cases (6.9%) in the DAA cohort ($P=0.7$). Implant selection was determined by surgeon discretion. A majority of patients (97%) received highly cross-linked polyethylene liners (HXLPE). Metal on metal bearings were used in 2 cases (3%), and dual-mobility constructs were used in 12 cases (12%). There were no significant differences in bearing surface (Table 4). Patients in the posterior cohort had higher utilization of an elevated lipped liner (33 vs 0%) or dual-mobility (13 vs 6.9%) construct ($P < 0.001$) relative to patients undergoing DAA THA. Otherwise, there were no significant differences in stem type or femoral head size.

Complications and Outcomes

The outcomes of interest collected in this study were incidence of intraoperative fracture, postoperative periprosthetic fracture, dislocation, wound dehiscence, superficial surgical site infection (SSI), periprosthetic joint infection (PJI), deep vein thrombosis (DVT), transfusion, extended length of stay (LOS), and readmission at 90 days. In addition, rates of periprosthetic fracture, dislocation, PJI, femoral stem loosening, acetabular cup loosening, and aseptic revision were assessed at latest follow-up. Extended LOS was defined as stays longer than the 75th percentile for the entire cohort, which was 3 days.[16] All patients who developed PJI underwent subsequent reoperation for infection while patients with a diagnosed superficial SSI received a single course of an oral antibiotic.

Data Analyses

All statistical calculations were performed in R-Studio (RStudio Team, Boston, MA).[23] Baseline patient characteristics, prior operative history, and surgical and implant characteristics were analyzed using Chi-square tests for categorical variables and Welch two-sample t-tests for

Table 3. Surgical Characteristics

Characteristic	Posterior n = 75	Anterior n = 29	P-value[1]
Overall			
Operative Time (Minutes) (Mean, SD)	132 (58)	157 (61)	0.056
Anesthesia Type (n,%)			<0.001
Spinal	10 (13)	20 (69)	
General	63 (84)	6 (21)	
Spinal + General	2 (2.7)	3 (10)	
Estimated Blood Loss (mL) (Mean, SD)	584 (407)	486 (274)	0.2
Fixation Method (n,%) Press-Fit	75 (100)	29 (100)	>0.9
Bone Graft Utilized (n,%)	2 (6.9)	4 (5.3)	0.7
Supplemental Acetabular Screws (mean, range)	0.6 (0 – 2)	1.4 (0-7)	<0.001
Prior Acetabular Fractures	n = 18	n = 9	
Hardware Removal (n,%)			>0.9
Partially Removed	6 (33)	3 (33)	
Fully Removed	3 (17)	2 (22)	
Fully Retained	9 (50)	4 (45)	
Original Incision Used (n,%)			0.037
Yes	13 (72)	2 (22)	
No	5 (28)	7 (88)	
Additional Incision for Hardware Removal (n,%)			0.3
Yes	1 (5.6)	0 (0)	
No	17 (94.4)	9 (100)	
Prior Hip Fractures	N = 59	N = 21	
Hardware Removal (n,%)			0.5
Previously Removed	3 (5.1)	0	
Partially Removed	51 (1.7)	1 (5)	
Fully Removed	54 (92)	20 (95)	
Original Incision 0Used (n,%)			0.3
Yes	17 (29)	3 (14)	
No	40 (68)	18 (86)	
NA	2 (3.4)	0 (0)	
Separate Incision for Hardware Removal (n,%)			< 0.001
Yes	12 (20.3)	14 (67)	
No	47 (79.7)	7 (33)	

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test.

Table 4. Implant Design & Characteristics

Characteristic	Posterior n = 75	Anterior n = 29	P-value[1]
Cementless Stem Type (n,%)			0.082
Short Stem (I)	1 (1.3)	1 (3.4)	
Single Wedge Taper (II)	35 (47)	19 (66)	
Double Wedge Taper (III)	4 (5.3)	2 (6.9)	
Conical, splined (IV)	0	1 (3.4)	
Cylindrical, fully coated (V)	3 (4.0)	0	
Modular, revision stem (VI)	32 (43)	6 (21)	
Femoral Head Size (n,%)			0.7
28	1 (1.3)	0 (0)	
32	9 (12)	6 (21)	
36	48 (64)	18 (62)	
38	0	1 (3.4)	
40	5 (6.7)	2 (6.9)	
44	2 (2.7)	0 (0)	
33*	1 (1.3)	0 (0)	
38*	1 (1.3)	1 (3.4)	
40*	3 (4)	0	
42*	2 (2.7)	0	
44*	0	1 (3.4)	
46*	1 (1.3)	0	
48*	2 (2.7)	0	
Liner Type (n,%)			<0.001
Neutral	40 (53)	27 (93)	
Elevated	25 (33)	0 (0)	
Dual Mobility	10 (13)	2 (6.9)	
Bearing Surface			0.07
Metal on Polyethylene	18 (25)	2 (7)	
Ceramic on Polyethylene	44 (60)	24 (83)	
Other	11 (15)	3 (10)	

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test.
*Modular Dual Mobility Outer Head Size.

quantitative variables. Similarly, Chi-square tests and Welch two-sample t-tests were used to compare rates of postoperative complications. Subgroup analysis was performed for complications by index operation (acetabular vs hip), with patients with both fracture types included in both groups (n=3). Multivariable analysis could not be performed due to small cohort sizes and low event rates for all complications. Preoperative and postoperative radiographs of two selected patients undergoing DAA and PA were provided in Figure 1 as case examples for the patients in this cohort. Statistical significance was considered at $P < 0.05$.

RESULTS

At 90 days (Table 5), there were no significant differences in complication rates between the PA and DAA cohorts, including intraoperative fracture (2.7 vs 6.9%, P = 0.3), postoperative periprosthetic fracture (0 vs 6.9%, P = 0.076), dislocation (1 vs 0%, P > 0.9), wound dehiscence (1.3 vs 10%, P = 0.065), or superficial SSI (4 vs 14%, P = 0.093). Among the 4 intraoperative fractures, there were 2 acetabular fractures and 2 calcar fractures. Both acetabular fractures were fractures of the medial wall fracture, one not recognized intraoperatively resulting in early protrusio and subsequent revision while the other did not necessitate further intervention. Both postoperative periprosthetic fractures were Vancouver B2 fractures secondary to early postoperative stem subsidence and loosening requiring revision. Rates of PJI at 90-days were also not significantly different (1.3% vs 0, P > 0.9). At final follow-up (mean 465 vs 862 days, P = 0.01), there were no significant differences in rates of any complication (Table 6): periprosthetic fracture (0 vs 6.9%, P = 0.076), dislocation (1 vs 0%, P > 0.9), PJI (6.7 vs 3.4%, P > 0.9), femoral stem loosening (1.3 vs 3.4%, P = 0.5), acetabular component loosening (1.3 vs 0%, P >0.9), or aseptic revision (6.7 vs 6.9%, P > 0.9).

Subgroup analysis of complications at 90 days (Table 7) and final-follow-up (Table 8) by fracture location revealed no significant differences in complications between approach except in patients with prior hip fracture, who had higher rates of SSI with DAA at 90 days (3.4 vs 19%, P = 0.04).

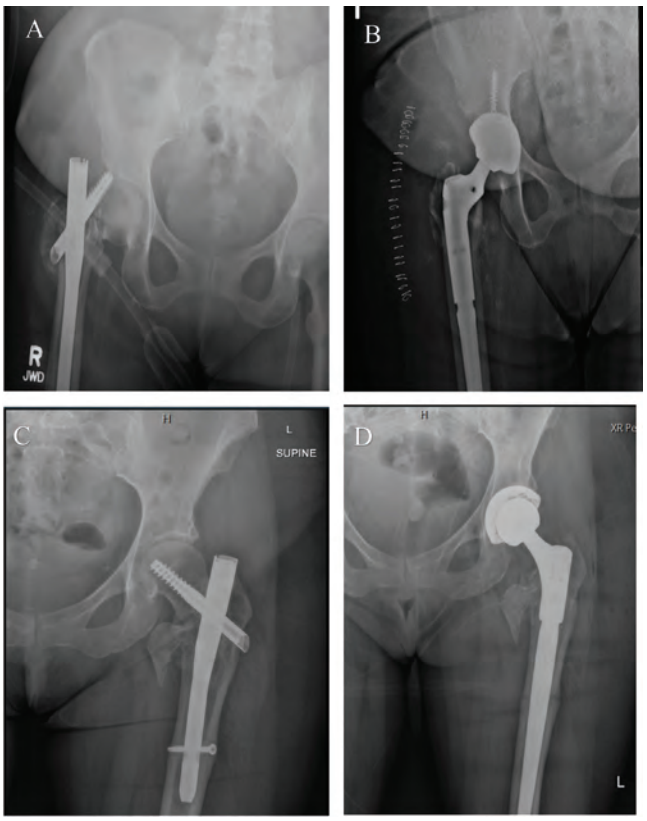

Figure 1A to 1D. Preoperative and Postoperative Images from Select Surgical Cases: (1A & 1B) Preoperative and Postoperative Radiographs of Conversion THA of Prior Intertrochanteric Fracture Fixation – Direct Anterior Approach. (1C & 1D) Preoperative and Postoperative Radiographs of Conversion THA of Prior Intertrochanteric Fracture Fixation – Posterior Approach.

DISCUSSION

At 90-days after conversion total hip arthroplasty, there were no significant differences in complication rates between conversion THA performed via direct anterior and posterior approaches. A theoretical advantage of an anterior approach in conversion THA is reduced risk of dislocation. Patients undergoing THA with prior failed hip fracture fixation have been described to be at greater

Table 5. Univariable Analysis of 90-Day Complications after Conversion THA

Characteristic (n,%)	Posterior n = 75	Anterior n = 29	P-value[1]
Intraoperative Fx	2 (2.7)	2 (6.9)	0.3
Periprosthetic Fx	0 (0)	2 (6.9)	0.076
Dislocation	1 (1.3)	0 (0)	>0.9
Wound Dehiscence	1 (1.3)	3 (10)	0.065
SSI	3 (4.0)	4 (14)	0.093
PJI	1 (1.3)	0 (0)	>0.9
DVT	0 (0)	1 (3.4)	0.3
Transfusion	10 (13)	2 (6.9)	0.5
Extended LOS	16 (22)	3 (10)	0.2
Readmission	4 (5.3)	4 (14)	0.2

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test, [3]Mean (SD).
Legend: Fx = Fracture, SSI = Surgical Site Infection, PJI = Periprosthetic Joint Infection, VTE = Venous Thromboembolism, LOS = Length of Stay.

Table 6. Univariable Analysis of Complications after Conversion THA at Final Follow-up

Characteristic	Posterior n = 75	Anterior n = 29	P-value[1]
Time to Final Follow-Up (Days) (Mean, SD)	862 (1,101)	465 (436)	0.01
Periprosthetic Fx (n,%)	0 (0)	2 (6.9)	0.076
Dislocation (n,%)	1 (1.3)	0 (0)	>0.9
PJI (n,%)	5 (6.7)	1 (3.4)	>0.9
Femoral Loosening (n,%)	1 (1.3)	1 (3.4)	0.5
Acetabular Loosening (n,%)	1 (1.3)	0 (0)	>0.9
Aseptic Revision (n,%)	5 (6.7)	2 (6.9)	>0.9

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test.
Legend: SSI = Surgical Site Infection, PJI = Periprosthetic Joint Infection, VTE = Venous Thromboembolism, LOS = Length of Stay.

Table 7. Subgroup Analysis of 90-Day Complications by Fracture Location

Characteristic (n,%)	Posterior n = 75	Anterior n = 29	P-value[1]
Acetabular Fracture	n = 18	n = 9	
Intraoperative Fx	0 (0)	0 (0)	
Periprosthetic Fx	0 (0)	0 ()	
Dislocation	1 (5.6)	0 (0)	>0.9
Wound Dehiscence	1 (5.6)	1 (11)	>0.9
SSI	1 (5.6)	0 (0)	>0.9
PJI	0 (0)	0 (0)	
DVT	0 (0)	1 (11)	0.3
Transfusion	0 (0)	0 (0)	0.5
Extended LOS	1 (5.9)	0 (0)	>0.9
Readmission	2 (11)	0 (0)	0.5
Hip Fracture	n = 59	n = 21	
Intraoperative Fx	2 (3.4)	2 (9.5)	0.3
Periprosthetic Fx	0 (0)	2 (9.5)	0.07
Dislocation	0 (0)	0 (0)	
Wound Dehiscence	0 (0)	1 (4.8)	0.3
SSI	2 (3.4)	4 (19)	0.04
PJI	1 (1.7)	0 (0)	>0.9
DVT	0 (0)	0 (0)	
Transfusion	10 (17)	2 (9.5)	0.5
Extended LOS	16 (27)	3 (14)	0.4
Readmission	3 (5.1)	4 (19)	0.07

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test, [3]Mean (SD).
Legend: Fx = Fracture, SSI = Surgical Site Infection, PJI = Periprosthetic Joint Infection, VTE = Venous Thromboembolism, LOS = Length of Stay.

risk of dislocation, reoperation and revision.[12] A large body of evidence has demonstrated reduced incidence of dislocation and revision for instability with direct anterior approach in primary and revision THA, although recent evidence has called this into question.[2,3,11,24]

In the present study, there were no statistically significant differences seen in dislocation rate; however, only 1 dislocation occurred in the entire study population in a PA patient. The low rate of instability in this cohort may be attributed to several factors including surgeon experience, robust posterior capsule repair and soft tissue reconstruction during closure, and increased use of high stability bearings in patients receiving PA. These confounding factors along with low event rates and relatively early follow-up time did not allow us to identify any difference if one does exist. That being stated, the majority of hip dislocations occur in the first 3 postoperative months, and therefore with contemporary implants and techniques, our results suggest that use of either approach can lead to favorable outcomes.

Research has also linked DAA to increased risk of postoperative infections and wound complications, particularly in obese patients.[1,6,13,28] Incision location near the groin and overlying abdominal folds, longer operative times, thin skin and fascia, and higher shear forces in this region have been theorized to contribute to these increased risks.[22,28] While we did not find a significant difference in these outcomes between approach cohorts, we noted a trend towards higher rates of wound dehiscence and SSI in the DAA cohort. However, in the subgroup analysis of SSI among prior hip fractures, SSI was more common among patients receiving DAA THA. Rates of PJI, however, were similar at between cohorts at 90 days.

Similarly, prior research has suggested a potential for increased risk of early periprosthetic fracture and intraoperative fractures with DAA.[4,13,25,27] Prior data has demonstrated that this risk is most pronounced early in surgeons' experience due to reduced visualization and femoral elevation during exposure.[10] Accordingly, there were increased rates of intraoperative and early periprosthetic fracture seen with DAA in our study, though this was not statistically significant.

There are multiple limitations to consider. This study employed a retrospective cohort study design; therefore, there may have been unmeasured differences between cohorts that influenced the observed outcomes. Selection of patients to receive a specific approach based on surgeon discretion could also serve as a substantial confounder as certain patients may be more suited for a particular approach given their existing hardware, prior incisions, or presence of certain comorbidities. For example, patients with prior acetabular fracture were

Table 8. Subgroup Analysis of Complications at Final Follow-up by Fracture Location

Characteristic	Posterior	Anterior	P-value[1]
Acetabular Fracture	n = 18	n = 9	
Time to Final Follow-Up (Days) (Mean, SD)	1,169 (1,039)	610 (566)	0.08
Periprosthetic Fx (n,%)	0 (0)	0 (0)	
Dislocation (n,%)	1 (5.6)	0 (0)	>0.9
PJI (n,%)	4 (22)	0 (0)	0.3
Femoral Loosening (n,%)	0 (0)	0 (0)	
Acetabular Loosening (n,%)	1 (5.6)	0 (0)	>0.9
Aseptic Revision (n,%)	5 (6.7)	2 (6.9)	>0.9
Hip Fracture	n = 59	n = 21	
Time to Final Follow-U (Days) (Mean, SD)	813 (1,157)	379 (357)	0.01
Periprosthetic Fx (n,%)	0 (0)	2 (9.5)	0.07
Dislocation (n,%)	0 (0)	0 (0)	
PJI (n,%)	2 (3.4)	1 (3.8)	>0.9
Femoral Loosening (n,%)	1 (1.7)	1 (4.8)	0.5
Acetabular Loosening (n,%)	0 (0)	0 (0)	
Aseptic Revision (n,%)	3 (5.1)	2 (9.5)	0.6

[1]Welch Two Sample t-test; Pearson's Chi-squared test; Fisher's exact test.
Legend: SSI = Surgical Site Infection, PJI = Periprosthetic Joint Infection, VTE = Venous Thromboembolism, LOS = Length of Stay.

more likely to have a PA, which is likely a function of the widespread use of the posterior approach for acetabular fixation.[9] We were also not able to determine the exact surgical approach used in the index operation for fracture fixation. Additionally, due to small cohort sizes and low event rates, we were unable to employ statistical methods to control for cohort differences. Moreover, there was a significant difference in follow-up length between cohorts as DAA was utilized more recently by the participating surgeons at our institution. Consequently, survivorship bias could play a major role in the complication rates observed at final follow-up. Nevertheless, most complications of interest, including all fractures, dislocations, and wound complications, occurred within the first 90 days after surgery. Finally, we did not assess patient-reported outcomes to ascertain differences in function or quality of life after surgery.

In summary, no significant differences in complication rates were observed between DAA and PA at 90 days or at final follow-up although there were insignificant trends towards increased rates of wound complications and periprosthetic fracture in the DAA cohort. The results of this study do not indicate a clearly superior surgical approach when performing conversion THA in patients with prior hip or acetabular fracture fixation. We suggest surgeons continue to utilize surgical approaches which they are most familiar with as this may be a crucial factor in clinical success regardless of approach. Further research with larger sample size is warranted to evaluate long-term outcomes and further delineate complication rates associated with each surgical approach.

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RADIOGRAPHIC PERFORMANCE OF A NOVEL FEMORAL STEM DESIGN

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ABSTRACT

Background: In the United States, cementless fixation is the gold standard for elective total hip arthroplasty (THA). Many modern cementless stem designs have re-introduced collared stem options in recent years which have demonstrated a lower risk of fracture. Minimal studies, however, outline radiographic performance of this novel stem design. As such, the primary purpose of this single-center study was to determine the radiographic performance, including defining patterns of radiographic incorporation and remodeling, associated with this novel, single stem design.

Methods: Data within the institutional data repository was queried for patients who underwent a primary or conversion THA between January 1st, 2016 and July 31st, 2022. Patients were included in the study if they were 18 years of age or older and had a minimum of a one-year follow-up visit. Patients were excluded if they did not have a radiograph at the one-year follow-up or if the stem was placed in a revision setting. Continuous data were reported as means and standard deviations (± SD), and categorical data were reported as number of cases (n) and percentages (%).

Results: A total of 592 encounters (562 patients) were included in the final analyses. At the one-year postoperative visit, no stems met the criteria for radiographic loosening, 502 (85.2%) patients had distinct radiographic osseointegration of their stem as defined by at least one radiographic spot weld. There was an 18.7% incidence of calcar-collar gaps on initial radiographs and 66.7% of these filled in by one-year. The intraoperative fracture rate was 0.7% without any cases of secondary stem revision or loosening and only 0.8% of stems showed subsidence (i.e., all less than 5 mm) without loosening or revision. Thigh pain within the first year was reported in 1.7% of patients. The all-cause stem revision at one-year was 0.2%.

Conclusion: This study demonstrated excellent rates of healing of this novel stem design. Additionally, this novel stem was associated with low rates of periprosthetic fracture, stem revision, and thigh pain.

Level of Evidence: IV

Keywords: total hip arthroplasty, collared femoral stem, uncemented femoral stem

INTRODUCTION

In the United States, cementless fixation is currently the gold standard for elective total hip arthroplasty (THA). Between 2012 and 2019, nearly 96% of all primary THAs utilized a cementless fixation, including more specifically, a femoral component.[1] Stability of uncemented implants depends on the initial fit and stability of the implant within the bone. The long-term stability depends on the biological anchoring of the implant to the bone or osseointegration.[1-3]

Cementless femoral fixation has continued to evolved over the last two decades with changes in stem design, including the length and morphology of the stem, and bone preparation techniques.[4,5] Modern stems have shortened and often curved designs to aid insertion through minimally invasive approaches and allow for bone preservation and more proximal osseous loading. Three dimensional metaphyseal "fit-and-fill" stem designs have recently become more popular and are thought to facilitate a more stable and more proximal fixation. This stem design has also demonstrated a lower incidence of periprosthetic fractures compared to flat, single taper, wedge stems.[5,6] In addition, bone preparation techniques have evolved with some implant companies utilizing a hybrid broaching system consisting of both extraction and compaction with a single broach. Many modern cementless stem designs have re-introduced collared stem options in recent years to confer axial and rotational stability while reducing fracture risk.[5,7-12]

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The ACTIS® stem (DePuy Synthes Orthopaedics, Warsaw, IN) was introduced in 2016 and combines many of these modern adaptations into a novel design; a triple-tapered (coronal, sagittal, and axial planes) stem designed for metaphyseal fit and fill, with or without a fully coated collar. This shortened stem morphology was developed for patients with various femoral anatomy, and the preparation utilizes hybrid broach technique with compaction and extraction. The entire stem is hydroxyapatite coated and the proximal half of the stem including the collar has a beaded ingrowth surface. The relatively new design has been associated with a lower risk of early fractures, revisions, decreased radiographic findings of migration, and comparable patient-reported outcomes to other older uncemented stems.[13-15] In addition, the American Joint Replacement Registry (AJRR) report from 2022 demonstrates the lowest cumulative percent revision at one- and three-years postoperatively using the ACTIS® stem compared to other stems.[16] More recently in the 2023 AJRR report, the ACTIS® stem was identified to have the lowest cumulative revision percentage among other active stems (Odd Ratio: 0.70; CIs: 0.80, 0.98).[17]

To date, few studies have outlined radiographic performance of this novel stem design or patterns of bony incorporation or remodeling. As such, the primary purpose of this single-center study was to determine the rate of osseointegration of the stem at one-year follow-up. Our secondary purpose of this study was to determine the rate, timing, and patterns of radiographic incorporation and remodeling associated with this single stem design. Our tertiary aim was to determine the rate and type of stem-related complications during the first year postoperatively.

METHODS

After institutional review board approval, a retrospective review was performed using the institution's integrated data repository (IDR) and electronic medical record (EMR) system. The IDR is considered a large-scale database that collects patient information across the medical center through the EMR (Epic Systems, Madison, WI). Chart review was performed to identify any data the IDR was unable to provide. Data within the repository was queried for patients who underwent a primary or conversion THA (i.e., CPT codes 27130, 27132) with the ACTIS® stem between January 1st, 2016 and July 31st, 2022. Patients were included in the study if they were 18 years of age or older and had a minimum of a one-year follow-up visit. Patients were excluded if they did not have a radiograph at the one-year follow-up visit or if the stem was placed in a revision setting. Patient characteristics (i.e., age, sex, race, ethnicity), Dorr classification[18] and operative data were collected.

Study Objectives

First, the primary objective of this study was to determine the rate of osseointegration of the ACTIS® stem at one-year postoperatively. Digital radiographs were assessed for osseointegration by a single reviewer at four time points (i.e., preoperatively, and six-weeks, six-months, and one-year postoperatively). The single reviewer had five years of experience as an orthopedic surgical resident and was currently completing a one-year fellowship in adult reconstruction. To standardize the review for osseointegration, a standardized review protocol was outlined for consistency. This standardized review protocol was created and reviewed with five fellowship-trained arthroplasty physicians. Gruen Zones were evaluated for spot-welding, lucency, and formation of a neocortex.[19] Stems were classified as well incorporated or loose based on these findings and the Engh classification.[20] Femoral stems were defined as loose if any radiolucent lines >2 mm, progressive radiolucency surrounding the stem, subsidence > 5 mm, or component migration (varus or valgus). Stems were defined as well incorporated, or osseointegrated, if there was a presence of at least one spot weld in the seven Gruen Zones and the absence of the aforementioned radiographic signs of loosening.[20]

The secondary objective was to determine the patterns of radiographic healing of this stem. All radiographs were analyzed for patterns of radiographic healing utilizing the Gruen Zones, including radiolucency, calcar gap and healing.[20] Each Gruen Zone was analyzed at all time points for every stem and radiographic changes were reported.

Lastly, the tertiary objective was to determine the rate of complications associated with the ACTIS® stem. All radiographs were evaluated for stem-related complications, which included subsidence, stress shielding, and periprosthetic fractures. Additionally, chart review was performed preoperatively and at the one-year follow-up visit to determine the rate of thigh pain. The patient charts containing the phrase "thigh pain" were individually reviewed. Patients with postoperative thigh pain were included and those with thigh pain secondary to radiculopathy were not included.

Data Analysis

Statistical analyses were conducted using SPSS Version 28 (IBM SPSS inc., Chicago, IL, USA). Continuous data (i.e., age, body mass index [BMI], length of stay [LOS]) were reported as means and standard deviations (± SD). Categorical data (e.g., sex, laterality, approach) were reported as number of cases (n) and percentages (%).

RESULTS

A total of 562 patients were identified for this study through the IDR data query. Of those, 30 patients underwent a bilateral procedure capturing a total of 592 encounters which were included in the final data set. The average age of patients was 64.83 ± 11.53 years (range = 18-92) with an average BMI of 29.59 ± 6.53 (range = 9.50-52.40) (Table 1). The average LOS was 1.58 ± 1.70 days (range = 0-17.07). Patients were mostly female (57.1%), non-Hispanic (92.9%), and White (83.6%) (Table 1). Mean time between postoperative visits were as follows: 6.11 ± 1.96 weeks (range = 1.14 – 16.14) for the six-week visit, 24.58 ± 11.29 weeks (range = 5.00 – 64.00) for the six-month visit, and 59.57 ± 32.03 weeks (range = 32.43 – 273.14) for the one-year visit. Most patients underwent a posterior approach THA (79.4%; Table 2) and had a Dorr B femoral classification (81.3%; Table 2). Indications for surgery included osteoarthritis (97.8%; N = 779), femoral head osteonecrosis (26.5%; N = 157), hip dysplasia (7.9%; N = 47), and femoral neck fracture (8.6%; N = 51; Table 2).

Of the 111 (18.7%) patients who had radiographic evidence of a gap between the calcar and the collar of the prosthesis at the time of surgery, 74 (66.7%) of these patients had osseous integration of this calcar gap by the one-year follow-up visit (Table 3; Figure 1a and 1b). Each of these patients underwent radiographic measurement to confirm stability of the stem without subsidence. At the one-year postoperative visit, no stems met criteria for loosening and 502 (85.2%) patients had distinct radiographic osseointegration of their ACTIS® stem defined by at least one area of radiographic spot welding.

Additionally, the rate of osseointegration at six-weeks and six-months was 1.7% and 54%, respectively (Table 4). At the one-year postoperative visit, 22.6% (N = 133) of patients had radiographic healing in all four proximal Gruen Zones (i.e., zones 1, 2, 6, and 7) (Table 4; Figure 2 and Figure 3). In addition, 60.3% and 60.8% of patients demonstrated osseointegration in Gruen Zone 1 and 7, respectively (Table 5). Greater than one-third of all stems demonstrated formation of neocortex and lucency in Gruen Zones 3, 4, and/or 5 (Table 4; Figure 4 and Figure 5).

Table 1. Patient Demographics

		Frequency (%) (N = 562)	
Sex			
	Male	241 (42.9)	
	Female	321 (57.1)	
Ethnicity			
	Hispanic	22 (3.9)	
	Non-Hispanic	522 (92.9)	
	Unknown	18 (3.2)	
Race			
	Asian	4 (0.7)	
	Black	57 (10.1)	
	Hispanic	1 (0.2)	
	Multiracial	1 (0.2)	
	Other	13 (2.3)	
	White	470 (83.6)	
	Unknown	16 (2.8)	
	Mean ± SD	Minimum	Maximum
Age	65.83 ± 11.53	18	92
BMI	29.56 ± 6.53	9.50	52.40
LOS, days	1.58 ± 1.70	0.00	17.07

Table 2. Preoperative Patient Characteristics

	Frequency (%)[a] (N = 592)
Laterality	
Left	271 (45.8)
Right	320 (54.1)
Bilateral	1 (0.2)
Approach	
Anterior	121 (20.4)
Direct Lateral	1 (0.2)
Posterior	470 (79.4)
Osteoporosis	
No	457 (77.2)
Yes	135 (22.8)
Osteoarthritis	
No	13 (2.2)
Yes	579 (97.8)
Femoral Head Osteonecrosis	
No	435 (73.5)
Yes	157 (26.5)
Femoral Neck Fracture	
No	545 (92.1)
Yes	47 (7.9)
Hip Dysplasia	
No	541 (91.4)
Yes	51 (8.6)
Dorr Classification	
A	103 (17.4)
B	481 (81.3)
C	7 (1.2)

[a]The sum may not equal 100% because percentages were rounded.

A total of 8 (1.4%) patients sustained a periprosthetic fracture, including intraoperatively (N = 4) and postoperatively (N = 4; Table 3). Of the patients with a postoperative periprosthetic fracture, two patients underwent a revision surgery (i.e., open reduction internal fixation [N = 1], femoral component revision [ACTIS® stem; N = 1]), while the remaining two were treated non-operatively. An additional five patients (0.8%) underwent a revision procedure (i.e., acetabular component [n = 4], constrained liner [n = 1]) postoperatively due to instability. The average time to revision for the seven patients was 73.62 ± 85.36 weeks (range = 5.29 - 233.43). There was a total of five stems (0.8%) that subsided at the one-year follow-up visit, and of those, two of these occurred in patients who suffered a periprosthetic fracture. None of the stems subsided greater than 5 mm and all went on to radiographic osseointegration at one year follow-up. Additionally, none of the stems that subsided underwent revision surgery. Lastly, there were 10 (1.7%) patients who still reported thigh pain at the one-year postoperative visit.

Table 3. Postoperative Patient Characteristics

	Frequency (%)[a] (N = 592)
Postoperative Calcar Gap	
No	481 (81.3)
Yes	111 (18.8)
Calcar Gap Filled	
No	28 (25.2)
Partial	9 (8.1)
Yes	74 (66.7)
Periprosthetic Fracture	
No	584 (98.6)
Yes	8 (1.4)
Intraoperative	4 (50.0)
Postoperative	4 (50.0)
Vancouver Classification	
Intraoperative	
A2	1 (100.0)
Postoperative	
AG	3 (30.0)
B1	3 (30.0)
B2	1 (10.0)
C	3 (30.0)
Postoperative Revision	
No	584 (98.5)
Yes	7 (1.2)
Reason for Revision	
Fracture	2 (28.6)
Instability	5 (71.4)
Revision of ACTIS® Femoral Stem	0 (0.0)
No	591 (99.8)
Yes	1 (0.2)
Thigh Pain within 1-year	
No	582 (98.3)
Yes	10 (1.7)
Stem Subsidence within 1-year	
No	587 (99.2)
Yes	5 (0.8)

[a]The sum may not equal 100% because percentages were rounded.

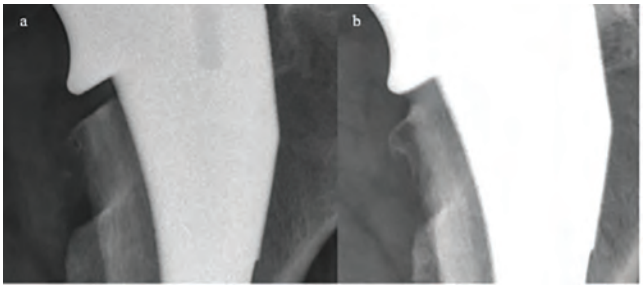

Figure 1A to 1B. (1A) Calcar Gap evident on immediate postoperative radiograph, (1B) Osseointegration with filling in of the Calcar gap and osseointegration in Gruen zone 7 by one-year postoperatively.

Table 4. Postoperative Rates of Radiograph Healing Characteristics

	6-weeks postoperative (N = 576) N (%)	6-months postoperative (N = 215) N (%)	1-year postoperative (N = 589) N (%)
Radiographic Osseointegration			
No	566 (98.3)	99 (46.0)	87 (14.8)
Yes	10 (1.7)	116 (54.0)	502 (85.2)
Healing for Gruen Zones 1, 2, 6, 7			
No	575 (99.8)	197 (91.6)	456 (77.4)
Yes	1 (0.2)	18 (8.4)	133 (22.6)
Formation of neo-cortex & Lucency			
Zone 3	10 (1.7)	71 (33.0)	254 (43.1)
Zone 4	6 (1.0)	42 (19.5)	214 (36.3)
Zone 5	18 (3.1)	75 (34.9)	267 (45.3)

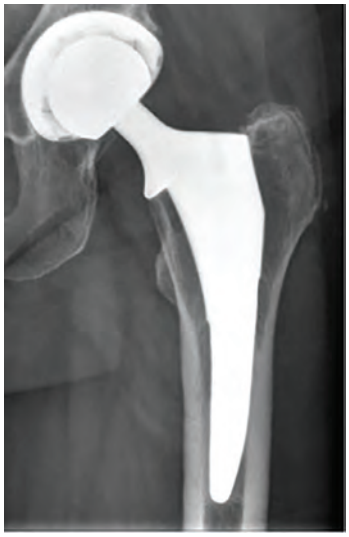

Figure 2. ACTIS® Femoral Stem showing osseointegration in Gruen Zones 1, 2, 6 and 7 including integration of the collar. Bony integration is favorable for loading and force transfer through the proximal bone.

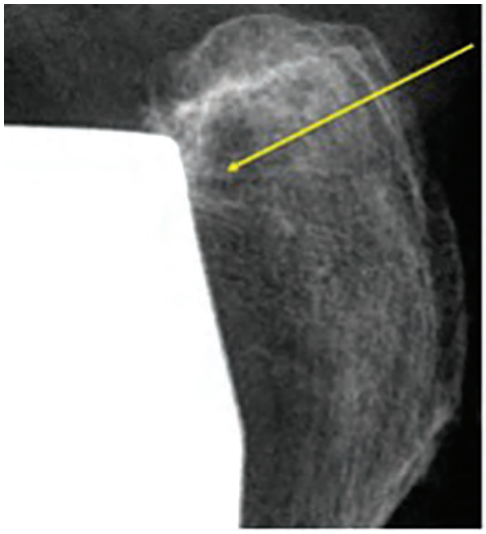

Figure 3. Radiographic spot weld in Gruen Zone 1.

DISCUSSION

To our knowledge, this is the first study to evaluate the rate of radiographic healing as well as the pattern of healing of this novel femoral stem design. The ACTIS® stem showed reliable overall radiographic healing rates (85.2%) at one-year postoperatively. Also, there were no stems that were found to be loose at one year follow-up. Additionally, the stems demonstrated a low revision rate when assessed at the one-year postoperative follow-up visit.

We found that the ACTIS® stem has a distinctive pattern of healing within our population. Most modern stems predictably show radiographic healing in zones 2 and 6 but show variable healing in zones 1 and 7.[21] In addition, zones 3, 4, and 5 show variable healing depending on stem design. This stem showed a pattern of spot welding in the proximal four Gruen Zones (i.e., zones 1, 2, 6, 7) as well as lack of healing, formation of neocortex, and/or lucency in the distal three Gruen Zones (i.e., zones 3, 4, 5). The combination of predictable proximal healing with the low incidence of distal spot-welding results in a bone preserving, proximal pattern of healing. The radiographic formation of neocortex and lack of spot weld in zones 3, 4 and 5 is beneficial to avoid proximal stress shielding. We believe that this unique pattern of radiographic healing is secondary to the novel design features of the stem in question.

We found a low rate of overall complications in this study with a 0.7% rate of intraoperative fracture, a 0.7% incidence of postoperative fracture, a 1.2% all-cause revision rate, a 0.2% rate of ACTIS® stem revision, and a 1.7% incidence of thigh pain. The incidence of thigh pain with short cementless designs is reported to be up to 24%.[22] As such, the current study adds valuable single institution results and specific patterns of radiographic osseointegration to recent registry data demonstrating excellent clinical performance of the ACTIS® femoral stem.[16,17]

Limitations

There are several limitations within our study that warrant discussion. First, this was a retrospective chart review study with a one-year minimum follow-up visit. As such, our data was queried from our IDR, which could have caused for missed patients for this study. Also, there was no direct comparison group in this study. Additionally, radiographic interpretation can be subjective and may vary between reviewers. To account for this variation, a single reviewer assessed the radiographs at the multiple visits postoperatively. Even though intrarater reliability for this reviewer was not calculated, there was a standardized review protocol in place for consistency. Lastly, our institution's quality and consistency of the lateral imaging prevented us from including those images in the present study. However historical studies evaluating osseous changes around stems have focused and reported only on zones 1-7.[23-26]

CONCLUSION

Overall, this study demonstrated excellent rates of healing of this novel stem design, especially in the proximal four Gruen Zones and the calcar in a proximally loading, bone preserving manner. In addition, this stem was associated with low rates of periprosthetic fracture, stem revision, and thigh pain.

Table 5. Radiographic Review by Gruen Zone

	6-weeks postoperative (N = 576) N (%)	6-months postoperative (N = 215) N (%)	1-year postoperative (N = 589) N (%)
Zone 1			
Spot weld	6 (1.0)	78 (36.3)	355 (60.3)
Lucency	23 (4.0)	9 (4.2)	14 (2.4)
Spot weld & Lucency	1 (0.2)	9 (4.2)	17 (2.9)
Zone 2			
Spot weld	6 (1.0)	59 (27.4)	280 (47.5)
Formation of neocortex	1 (0.2)	1 (0.5)	3 (0.5)
Lucency	5 (0.8)	10 (4.7)	17 (2.9)
Spot weld & Lucency	0 (0.0)	6 (2.8)	19 (3.2)
Formation of neocortex & Lucency	0 (0.0)	0 (0.0)	1 (0.2)
Zone 3			
Spot weld	0 (0.0)	4 (1.9)	42 (7.1)
Formation of neocortex	6 (1.0)	56 (26.1)	200 (34.0)
Lucency	4 (0.7)	12 (5.6)	21 (3.5)
Spot weld & Lucency	0 (0.0)	0 (0.0)	2 (0.4)
Spot weld & Formation of neocortex	0 (0.0)	0 (0.0)	8 (1.4)
Formation of neocortex & Lucency	0 (0.0)	3 (1.4)	33 (5.6)
Zone 4			
Spot weld	0 (0.0)	4 (1.9)	23 (3.9)
Formation of neocortex	6 (1.0)	32 (14.9)	186 (31.6)
Lucency	0 (0.0)	4 (1.9)	10 (1.7)
Formation of neocortex & Lucency	0 (0.0)	6 (2.8)	18 (3.0)
Zone 5			
Spot weld	0 (0.0)	5 (2.3)	42 (7.1)
Formation of neocortex	7 (1.2)	61 (28.4)	218 (37.0)
Lucency	8 (1.4)	10 (4.7)	21 (3.5)
Spot weld & Formation of neocortex	0 (0.0)	1 (0.5)	1 (0.2)
Formation of neocortex & Lucency	1 (0.2)	4 (1.9)	28 (4.7)
Zone 6			
Spot weld	3 (0.5)	39 (18.1)	239 (40.6)
Formation of neocortex	1 (0.2)	6 (2.8)	17 (2.9)
Lucency	9 (1.5)	12 (5.6)	20 (3.4)
Spot weld & Lucency	0 (0.0)	4 (1.9)	15 (2.5)
Formation of neocortex & Lucency	0 (0.0)	0 (0.0)	2 (0.3)
Zone 7			
Spot weld	4 (0.7)	69 (32.1)	358 (60.8)
Formation of neocortex	0 (0.0)	0 (0.0)	1 (0.2)
Lucency	3 (0.5)	9 (4.2)	6 (1.0)
Formation of neocortex & Lucency	0 (0.0)	1 (0.5)	1 (0.2)

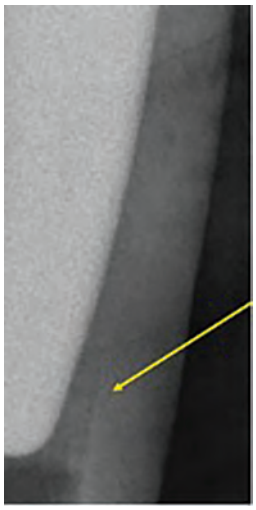

Figure 4. Radiographic neocortex formation in Gruen Zones 3 and 4.

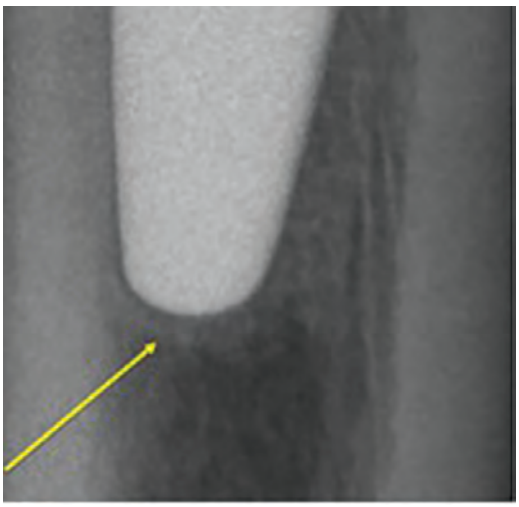

Figure 5. Radiographic lucency in Gruen Zone 4.

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RECOGNITION AND RECURRENCE OF ANEURYSMAL BONE CYST SECONDARY TO GIANT CELL TUMOR: A CASE SERIES AND REVIEW OF THE LITERATURE

Ahmet Salduz, MD, PhD[1,2]; Michael D. Russell, MD, MBA, MPH[1]; Benjamin J. Miller, MD, MS[1]

ABSTRACT

Background: Aneurysmal bone cysts (ABCs) are rare, benign bone lesions with distinct genetic and pathological characteristics. Secondary ABCs arising from giant cell tumors (GCTs) are associated with higher recurrence rates compared to primary ABCs. This study aimed to evaluate recurrence rates and risk factors for primary ABCs, secondary ABCs in GCT, and GCTs, with a focus on radiologic and clinical predictors.

Methods: This retrospective cohort study analyzed 44 patients with histologically confirmed primary ABC (n=24), secondary ABC in GCT (n=8), or GCT (n=12), treated surgically with adjuvants between 2010 and 2020. Tumors were staged using the Enneking/MSTS system, and recurrence rates were assessed using Kaplan-Meier survival analyses and Chi-square tests. The mean follow-up period was 49.4 months.

Results: The overall recurrence rate was 11%, with a 5-year recurrence-free survival rate of 89%. Recurrence-free survival was 92% for primary ABCs, 92% for GCTs, and 75% for secondary ABCs. Significant risk factors included soft tissue extension in primary ABCs (p = 0.037) and mixed radiologic appearance in GCTs (p = 0.033). Secondary ABCs were more common in patients over 20 years and often presented with multiloculated cystic areas.

Conclusion: Recurrence rates are similar among primary ABCs, secondary ABCs, and GCTs. However, secondary ABCs exhibit recurrence behaviors closer to GCTs, particularly in patients with advanced age and complex radiological features. These findings highlight the importance of meticulous tumor resection and the careful use of adjuvants to reduce the risk of recurrence.

Level of Evidence: III

Keywords: aneurysmal bone cyst, giant cell tumor, recurrence, surgical outcomes, radiologic features

INTRODUCTION

Aneurysmal bone cysts (ABCs) are benign cystic lesions composed of blood-filled spaces separated by septa containing osteoclast-type giant cells, fibroblasts, and reactive woven bone. ABCs account for approximately 1% of all bone tumors and are predominantly observed in adolescents and young adults.[1] These lesions typically affect the metaphysis of long bones, with the femur, tibia, and spine being common locations.[1,2] Primary aneurysmal bone cysts (ABCs) are characterized by specific genetic alterations, such as the chromosomal translocation t(16:17), which involves the USP6 gene and plays a pivotal role in their pathogenesis. This distinction aids in differentiating primary ABCs from other similar benign bone lesions including tumors with secondary cyst formation.[1]

ABCs can arise either as primary lesions or secondarily within pre-existing bone lesions, such as giant cell tumors (GCTs). The treatment of ABCs remains a subject of debate, with no universally accepted standard approach. While traditional surgery, including curettage and resection, has been the mainstay,[3] minimally invasive methods such as sclerotherapy and selective arterial embolization are emerging as effective alternatives with potentially fewer complications.[2] However, current research does not provide sufficient robust evidence to support the efficacy of one treatment over another.[4] Secondary ABCs associated with giant cell tumors account for approximately 30–50% of cases and demonstrate higher recurrence rates than primary lesions, which are associated with worse prognoses.[5] This necessitates more aggressive and targeted surgical approaches to optimize outcomes.

While the radiologic, pathologic, and clinical characteristics of primary ABCs are well-documented, information regarding secondary ABCs is limited. This study aims to describe local recurrence rates and risk factors

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for primary ABC, secondary ABC in GCT, and GCT, particularly examining whether the behavior of secondary ABC aligns more closely with primary ABC or GCT.

METHODS

Between 2010 and 2020, 44 patients with histologically confirmed primary ABC, ABC secondary to GCT, or GCT, and a minimum of two years of follow-up were retrospectively reviewed. The mean age of the patients was 24.4 years (range: 6–81 years), and the mean follow-up was 49.4 months (range: 24–124 months). Diagnoses included 24 patients with primary ABC (54%), 12 with GCT (27%), and 8 with ABC secondary to GCT (18%). The most common tumor locations were the femur (n = 16) and tibia (n = 10) (Table 1 and Figure 1).

All surgeries were performed by a single surgeon (BJM) using adjuvants, including high-speed burrs, cauterization, and hydrogen peroxide. Tumor volumes were calculated using the formula $V=6\varpi\times L\times W\times H$, and lesions were staged according to the Enneking/MSTS benign bone tumor classification system. Data were analyzed using SPSS 20, with descriptive statistics, Chi-square tests, and Kaplan-Meier survival analyses used to evaluate recurrence rates and risk factors.

RESULTS

The overall recurrence rate for the cohort was 11% (5/44), with a 5-year recurrence-free survival rate of 89%. Recurrence-free survival rates were 92% for primary ABC, 92% for GCT, and 75% for ABC secondary to GCT ($p = 0.46$). However, the differences between recurrence-free survival rates were not statistically significant (Figure 2).

In the primary ABC group, the mean age was 14 years (range: 6–40 years). The recurrence rate was 8.3% (2/24). Surgical techniques included bone grafting in 22/24 patients (96%), excision in one, and curettage only in one. Soft tissue extension observed on MRI was associated with higher recurrence rates ($p = 0.037$) (Figure 3).

In the GCT groups (GCT and secondary ABC), the mean age was 36 years (range: 15–81 years), and the recurrence rate was 15% (3/20). All recurrences occurred in patients treated with bone grafting ($p = 0.067$).

Table 1. Patient Demographics, Tumor Locations, Treatment Modalities and Local Recurrence Rates by Tumor Type

	ABC	GCT	ABC Secondary to GCT
Age (Range)	14 (6-40)	42.8 (17-81)	25.1 (15-47)
Sex			
Male	13	0	3
Female	11	12	5
Location			
Femur	6	6	4
Tibia	7	2	1
Pelvis	2	0	1
Patella	0	0	1
Humerus	2	0	1
Radius	2	1	0
Fibula	2	1	0
Clavicle	2	0	0
Spine	1	0	0
Foot	0	2	0
Treatment			
Resection	1	0	0
Curettage with Bone Grafting	22	12	8
Curettage with Cementing	1	0	0
LR	2	1	2
Total	24	12	8

ABC: Aneurysmal Bone Cyst; GCT: Giant Cell Tumor; LR: Local Recurrence.

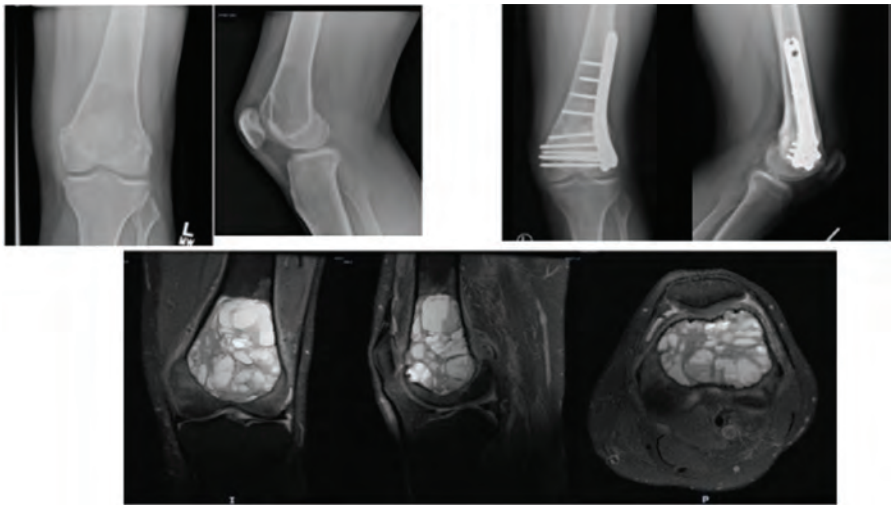

Figure 1. 29 years old male patient with ABC secondary to GCT in distal femur treated curettage, bone grafting and plating. MRI shows pure cystic changes.

MRI characteristics significantly influenced recurrence rates. MRI features were categorized as purely solid, purely cystic and mixed according to the number and extent of the cystic changes. Among patients with GCT and ABC secondary to GCT, recurrences occurred in 0/11 patients with purely solid lesions, 1/5 with purely cystic lesions, and 2/4 with mixed lesions ($p = 0.033$) (Figure 4).

No statistical differences in sex, MRI appearance, local recurrence, pathologic fractures, soft tissue extension, or tumor volume were observed between primary ABC and secondary ABC in GCT groups, except for age ($p = 0.013$). Secondary ABCs were more common in patients over 20 years old.

DISCUSSION

This study demonstrated that recurrence rates were comparable across primary ABC, ABC secondary to GCT, and GCT groups. However, soft tissue extension in primary ABC and mixed radiologic appearance in GCT were associated with higher recurrence risks. This correlates with the literature as showed by Wu et al., secondary ABCs arising from giant cell tumors exhibit higher recurrence rates compared to primary ABCs, indicating that the prognosis often aligns more closely with the primary lesion's behavior.[5]

Secondary ABCs occurred predominantly in older patients, with multiloculated cystic areas suggesting an association with underlying GCT.

Wu et al. found in their study that complete or subtotal resection, often combined with preoperative embolization, remains the gold standard for spinal ABCs, given their higher vascularity and proximity to critical structures.[5] Although their study focused on tumors of the mobile spine, our study suggests that a complete resection can be beneficial for other ABCs, ABC secondary to GCTs, and GCTs. Hence, our findings also emphasize the importance of thorough curettage or resection in managing these lesions.

The use of bone cement or bone grafting, following curettage significantly impacts recurrence rates. Meta-analyses have consistently demonstrated the superiority of bone cement over bone grafting in reducing recurrence rates after curettage, with bone cement achieving a 20% recurrence rate compared to 30% with grafting.[6] However, cement's inflammatory potential and difficulty in removal during recurrence should be carefully weighed. Our preference has been to use bone graft in skeletally immature and younger patients with ABC or GCT and methyl methacrylate in older patients. While intralesional curettage with adjuvants like phenol, hydrogen peroxide and cement remains the standard, alternative treatments such as sclerotherapy have demonstrated promising efficacy, achieving recurrence rates as low as 14-22% in some series.[4,7] Algawahmed et al. suggested that adjuvants like PMMA or liquid nitrogen have shown mixed results, with some evidence suggesting that meticulous tumor removal without adjuvants can achieve comparable outcomes.[8]

Advanced imaging techniques, including MRI and CT, play a pivotal role in preoperative planning, particularly in identifying fluid-fluid levels indicative of aneurysmal components and assessing soft tissue involvement.[9] Radiologic characteristics may provide prognostic information but distinguishing between primary and secondary ABC may not critically influence treatment outcomes, provided malignancy is excluded.

CONCLUSION

Local recurrence rates are similar across primary ABC, ABC secondary to GCT, and GCT - although GCT with an ABC component has the highest recurrence rate of the three. Soft tissue extension in ABC and cystic components in GCT may indicate higher recurrence risks. In non-adolescent patients, multiloculated cystic areas often suggest secondary ABC. Regardless of lesion type, diligent surgical techniques lead to favorable outcomes. Use of cement rather than bone graft in skeletally mature patients with mixed or purely cystic lesions, indicating a GCT with secondary ABC, may reduce the risk of local recurrence. Considering the diverse nature of lesion characteristics and patient demographics, adopting a personalized approach that combines surgical techniques with the strategic use of adjuvant therapies offers the best potential for long-term success while minimizing complications.

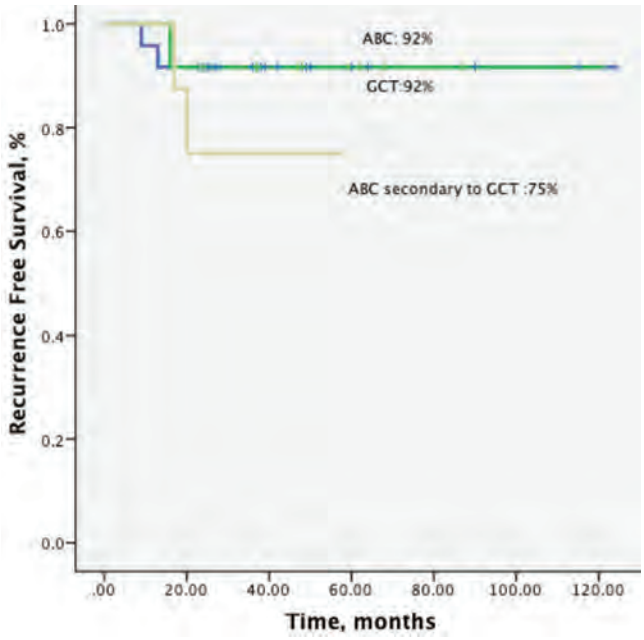

Figure 2. Recurrence free survival rate of the three groups with no significant differences (p=0.46).

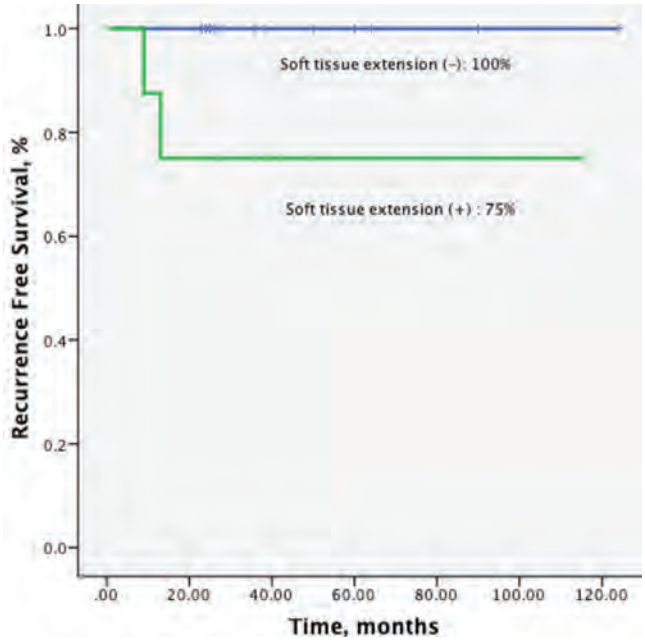

Figure 3. Recurrence free survival rate of ABC subgroups regarding soft tissue extension. Presence of the soft tissue extension has significantly worse recurrence free survival (p=0.037).

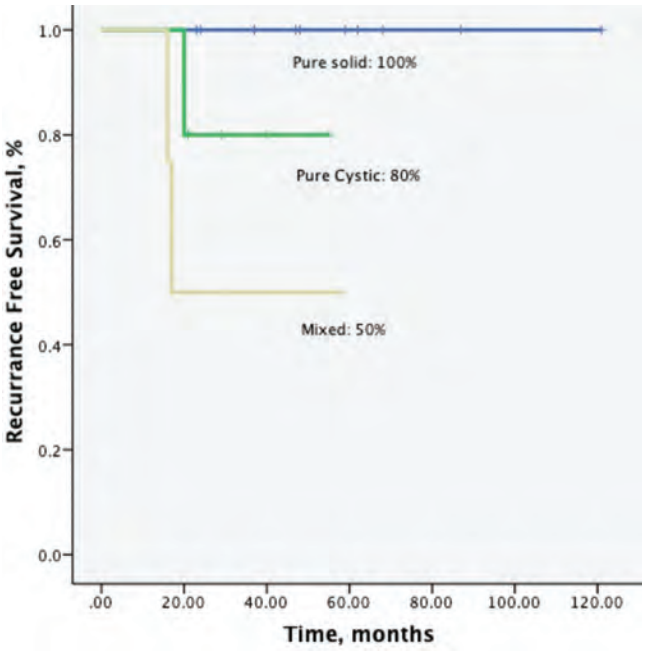

Figure 4. MRI appearance. Recurrence free survival rate was significantly different among three GCT subgroups regarding MRI appearance (p=0.033).

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COMBINED SURGICAL DISLOCATIONS AND PROXIMAL FEMORAL OSTEOTOMIES FOR TREATMENT OF COMPLEX PROXIMAL FEMORAL DEFORMITIES: A SYSTEMATIC REVIEW

Vivek Shah, MD, MSc[1]; Kyle O'Connor, MD[1]; Caleb Ford, MD[1]; Jeffrey Nepple, MD[1]; John Clohishy Sr., MD[1]

ABSTRACT

Background: Complex proximal femoral deformities such as slipped capital femoral epiphyses (SCFE) or residual Perthes disease pose challenging clinical problems due to the severity of pathological femoral head and neck changes from long-standing childhood disease. Utilizing the combination of surgical dislocation (SD) and proximal femoral osteotomy (PFO) is an option to address both the intra-articular pathologies as well as the maximal correction of the proximal femoral deformities. The purpose of this systematic review was to report clinical and radiographical outcomes for patients undergoing these combined procedures.

Methods: A systematic review of the literature was performed utilizing PRISMA guidelines. Databases queried were PubMed, OVID Medline, Embase, SCOPUS, Cochrane Central Register of Clinical Trials, and clinicaltrials.gov from their dates of inception to 7/03/2024. Studies were included if they reported outcomes for patients undergoing combined SDs and PFOs. Each study's data was manually retrieved from the full-text manuscript. The study design, surgical technique, indications, demographic and radiographic data, outcomes, and complications of each study were analyzed.

Results: There were six case series (Evidence Level IV) included in this review. There were 132 patients (46% female) with mean age of 16.5 years (range: 9-30). Etiologies were most commonly SCFE (50.8%) and Perthes (31.8%). Mean follow-up was 40.1 months (range: 3-127). The mHHS improved from 61.9±4.5 to 84.8±6.7. Complication rates were low at 11.4% with the most common complication being instrumentation failure (20%). Lateral slip angles improved from 58.5°±6.5° to 14.4 ±3.6° in 42 patients who underwent combined SD/PFO for SCFE. Alpha angles improved from 86.7°±6.7° to 50.9°±4.8°. Articular-trochanteric distance improved from 0.7±4.5mm to 23.4±3.1mm.

Conclusion: Combined SDs and PFO's should be considered a safe and effective treatment option for patients with severe femoral head and neck pathologies which were more likely from long-standing childhood diseases instead of severe deformities in the setting of SCFE or residual Perthes. This review demonstrated positive radiographic and clinical outcomes when these patients are treated, as well as a low complication and AVN rate. Further research should continue to study the combined approach in larger cohorts and at longer-term follow-up.

Level of Evidence: IV

Keywords: surgical dislocation, PFO, combined SD/PFO, SCFE, perthes, complex proximal femoral deformities

INTRODUCTION

Complex proximal femoral deformities, most commonly from childhood diseases such as slipped capital femoral epiphysis (SCFE), residual Legg-Calve-Perthes disease (residual Perthes), and developmental dysplasia of the hip (DDH), pose challenging clinical scenarios due to significant osseous deformities.[1-3] These deformities cause significant symptomatology such as pain and hip dysfunction as patients reach adolescence and young adult due to chronic osseous and soft tissue impingement from the bony overgrowth. As these changes are more significant than the typical pathology found in adult femoroacetabular impingement (FAI), open surgical dislocations is generally a preferred approach for comprehensive correction of severe deformities, rather than hip arthroscopy.[4]

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Furthermore, proximal femoral osteotomies (PFOs) may play a role in correcting the malformations if performing isolated surgical dislocations are insufficient.[5] Surgical dislocations allow direct visualization of the joint surface to address articular surface pathologies and areas of impingement while proximal femoral osteotomies allow for correction of angular or rotational deformities.[4,5] PFO's divided based on their anatomical localization into subcapital, base of the femoral neck, intertrochanteric and subtrochanteric osteotomies.[6] An in depth knowledge about the deformity and the anatomical situation is essential to choose the appropriate osteotomy.[6] These combined procedures have only been reported in a few studies in the literature and there is no systematic review that isolates SDs with PFOs to provide clinical and radiographic outcomes after these procedures and provides a generalizable representation of outcomes beyond a single surgeon's experience. The purpose of this review is to collect all available literature that describes these combined procedures and report clinical and/or radiographic outcomes as well as report complication rate.

METHODS

Search Strategy

This is a systematic review of the literature on combined SD and PFO outcomes. To determine a clinical question, the PICO(T) model was utilized (Population, Intervention, Comparison or control, Outcome, and Type of Study) using the intervention or therapy question type.[7] The PICO(T) question was "In patients with complex proximal femoral deformities, how does combined surgical dislocations and proximal femoral osteotomies (intervention, no comparison) affect clinical and radiographic outcomes (outcome) within case series and cohorts (type of study). We conducted this review using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[8] Databases searched were PubMed, OVID Medline, Embase, SCOPUS, Cochrane Central Register of Clinical Trials, and clinicaltrials.gov from their dates of inception to the date of our literature search which was 7/03/2024. Search terms included surgical hip dislocation, proximal femoral, proximal femur, trochanteric, trochanter, and osteotomy and the search results were matched to our PICO(T) question.

Selection criteria

All articles were reviewed by three independent authors (blinded). Articles included were studies with (1) complex disorders of the proximal femur treated by combined surgical dislocation and proximal femoral osteotomy and (2) clinical and/or radiographic data. Exclusion criteria included studies that did not satisfy these two inclusion criteria, non-English studies, basic science studies, animal studies, cadaver studies, technique papers, case reports, technique papers, conference abstracts, editorials, letters to the editor, supplements, and guidelines.

Quality Assessment

Next, non-randomized articles underwent quality assessment using the Newcastle-Ottawa Scale (NOS)[9] Points were given for each question and the total number determines the study. A total of 9 points are allowed (4 for selection, 2 for comparability, 3 for outcomes). Studies with ≥7 points were considered "good", 2-6 points were considered "fair", and ≤1 was considered "poor" quality. Only studies with good quality were included in this systematic review.

Data Extraction and Statistics

Data extraction was conducted by three independent authors (blinded). Data extracted included demographic, clinical, radiographic, and complication data. Data needed to be extractable to only patients undergoing combined SD and PFO. Demographic and outcomes data were pooled and reported as means with standard deviations. Complications were graded (Table 4) in a way proposed by Clavien and Dindo,[10] using a modified scheme of Grades I-V assigned based on required intervention and impact on long-term function and health. This scheme has been validated in hip preservation surgery and previously used to study complications of open preservation procedures.[11-13] Grades were assigned as follows:

Grade I: Complication requiring no treatment or no deviation from routine follow up

Grade II: Complication with deviation from routine follow up requiring outpatient treatment

Grade III: Complication with deviation from routine follow up requiring surgical, endoscopic, or radiographic intervention

Grade IV: Complication that is life threatening, requires ICU admission, or is not treatable with potential for disability

Grade V: Death

A major complication was defined as being a grade III or higher complication while a minor complication was considered to be grade II or lower.[14]

RESULTS

Search Strategy and Quality Assessment

The PRISMA diagram is depicted in Figure 1. There were 380 studies that were extracted from online databases. After removal of duplicates by EndNote, there

were 209 abstracts. After screening abstracts, there were 10 full texts that were analyzed for inclusion. After screening, six articles were included in this systematic review. All studies were considered good qualities.

Study Information and Demographic Data

There were six studies that were included in this review, and all had level of evidence of IV.[14-19] The years published were 2006-2022. Enrollment years for patients were from 2001 to 2020. All studies included patients that underwent combined SD/PFO as well as osteochondroplasties (OCPs) and two studies had a subgroup of patients (20 hips) undergoing concurrent periacetabular osteotomies (PAOs) (Table 1). Specifics of the procedures performed including type of proximal femoral osteotomy, whether relative neck lengthening was performed, and whether a locking plate or blade plate was used is indicated in Table 1.

There were 132 patients across these studies. Mean age was 16.5 years (range, 9-30) and 56/132 (46%) patients were female. Etiologies included SCFE (50.8%), residual Perthes or Perthes-like deformity (31.8%), DDH (8.3%), isolated FAI (8.3%), and posttraumatic AVN (0.08%). Most studies predominately discuss treatment and outcomes for SCFE patients while one study specifically highlighted patients with Perthes like deformities (Table 1). There are also some studies reporting mixed patient populations. Previous surgeries were reported in 73/132 (55%) patients. Mean follow-up was 40.1 months (range, 3-127) (Table 1).

Radiographic and Clinical Data

Radiographic data was presented for five studies. Lateral slip angles in 42 patients who underwent combined SD/PFO for SCFE improved from 58.5°±6.5° to 14.4°±3.6°. Alpha angles for all patients improved from 86.7°±6.7° to 50.9°±4.8°. Articular-trochanteric distance improved from 0.7±4.5mm to 23.4±3.1mm. The remainder of the parameters were distinct (Table 2). Patient reported outcome measures (PROMs) were reported in four studies. The modified Harris Hip Score (mHHS) for patients with all conditions improved from 61.9±4.5 to 84.8.±6.7. Otherwise, variable PROMs were reported in the studies (Table 3). The reoperation rate was 3.0% (4 hips) with no hips indicated as converting to total hip arthroplasty.

Complications

Complications were reported in all six studies. There were 15 complications (11.4%) in total. The rate of major and minor complications were 3.8% and 7.6%, respectively (5 and 10 hips, each). The major complications include one Grade IV complication which was a postoperative pulmonary embolism successfully treated with anticoagulation. There were four Grade III complications including an instrumentation failure from a blade plate backing out requiring revision surgery, another instrumentation failure (non-specified) requiring revision ORIF, one PFO nonunion requiring bone grafting and revision ORIF, and one non-union requiring revision PFO and grafting. There were six Grade II complications including a transient superficial peroneal nervel palsy and a transient sciatic nerve palsy, three delayed femoral unions all successfully treated with a bone stimulator, and one asymptomatic fibrous union of the greater trochanteric after perioperative fracture. Finally, there were four Grade I complications including both a Booker III and IV heterotopic ossification (neither requiring surgery), one mild avascular necrosis of the central femoral head without intervention required, and one keloid scar formation (Table 4).

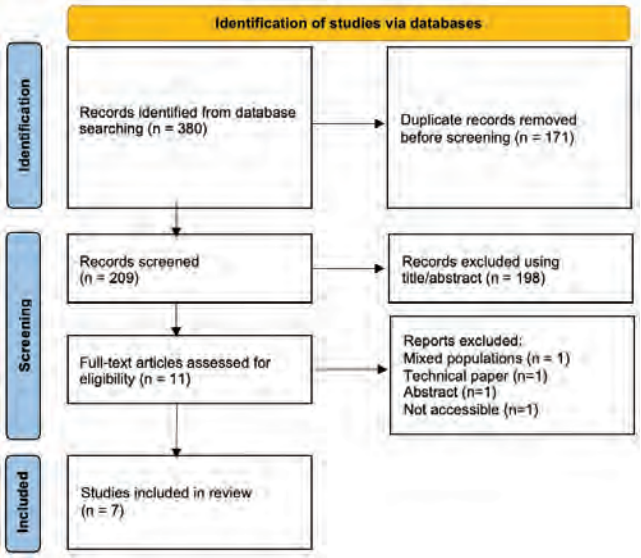

Figure 1. PRISMA diagram for search process.

DISCUSSION

Complex proximal femoral disorders resulting from childhood diseases such as slipped capital femoral epiphysis (SCFE), Legg Calve-Perthes disease (Perthes), and developmental dysplasia of the hip (DDH) present significant challenges in treatment due to severe osseous deformities and soft tissue impingement. Combined surgical dislocations (SDs) and proximal femoral osteotomies (PFOs) can address the severe pathological hip joint changes which has only been briefly discussed in the literature. The importance of this procedure is twofold: treatment of the articular disease by surgical dislocation and treatment of the femoral deformity by PFO. This systematic review summarized six articles

Table 1. Study Information and Demographic Data

Author	Institution	Year Published	Enrollment Years	PFO Details	N patients	Age	Female, n (%)	R hip affected, n (%)	Previous surgery, n (%)	Diagnoses	Follow up, months	Sub-analysis
Baraka	Cairo	2020	2013-2017	OCP/ITO Imhauser osteotomy Trochanteric transfer 1300 blade plate	23	14.4 (13-20)	9 (39)	10 (43)	11 (48)	SCFE	45 (24-66)	Correlation b/w mHHS and lateral slip and alpha angles
Erickson	Ohio	2017	2009-2015	OCP/ITO Imhauser osteotomy 900 blade plate	P: 6 D: 13	13.7 (12-19)	4 (21)	N/A	13 (68)	SCFE	P: 53.5 (27-61) D: 61.7 (23-120)	Primary vs delayed PFO after in situ pinning
Spencer	Boston	2006	2001-2003	OCP/ITO Imhauser osteotomy Blade plate	6	17 (13-22)	2 (33)	N/A	0 (0)	SCFE, impingement	12 (10-14)	None
Parilla	WashU	2022	2005-2020	OCP/ITO Femoral neck lengthening Blade plate	48	19.1 (5)	24 (50)	N/A	29 (60)	19 SCFE, 10 Perthes, 7 DDH, 11 isolated FAI, 1 post-traumatic AVN	34.8	None
Baraka	Cairo	2022	2014-2018	OCP/ITO Intertrochanteric neck lengthening 1300 blade plate PAO (6)	21	14.9 (9-30)	10 (48)	11 (52)	15 (71)	Perthes and Perthes-like deformities	54 (24-96)	None
Faure	Ottawa	2020	2008-2019	OCP/ITO Morscher osteotomy 1300 blade plate PAO (14)	15	17 (13-28) *	7 (47)	7 (47)	5 (33)	11 LCPD, 4 DDH	17 (3-127)	None
Total					132	16.5	56 (46)		73 (55)		40.1	

Reported as Mean (Range or Standard Deviation). *Reported as Median (Range). P: primary surgery. D: delayed surgery, i.e. SD/PFO performed six months after. OCP: osteochondroplasty, ITO: intertrochanteric osteotomy, PAO: periacetabular osteotomy, SCFE: Slipped Capital Femoral Epiphysis, LCPD: Leg Calves Perthes Disease, DDH: Developmental Dysplasia of the Hip, FAI: Femoroacetabular Impingement, AVN: avascular necrosis.

that reported improved radiographic and outcome measure data after combined SDs and PFOs, which offers a promising approach to address both articular pathologies and proximal femoral deformities in these patients with an acceptable complication rate in experienced surgeons hands.[14-19]

Patient Selection and Indications

Most patients in this review had SCFE (50.8%) or residual Perthes disease (31.8%), indicating that these procedures are particularly applicable for adolescents and young adults with complex hip deformities resulting from these childhood diseases. The inclusion of patients with DDH (8.3%) and isolated FAI (8.3%) suggests that the combined approach may also be valuable for a broader range of hip pathologies. In a large North American cohort, Clohisy et al. reported that intraarticular disease reaches a prevalence of 93% in isolated FAI.[20] Due to the high prevalence of cartilage and labral injuries and the fact that a lot of the complex proximal femoral disorders are too severe for arthroscopic procedures, open surgical dislocations are the most appropriate procedure for these patients to allow comprehensive deformity correction. Furthermore, PFOs help restore the proper biomechanics in the setting of coxa valga/vara, rotational deformities (femoral version), or limb length changes. These procedures aim to increase the arc of motion to decrease pain and hip mechanics.

Table 2. Radiographic Data

Author	Parameter	Preoperative	Postoperative	Delta
Baraka 2020	AP slip angle	47.39 (7.19)	9.87 (6.92)	N/A
	Lateral slip angle	57.07 (14.15)	12.7 (7.82)	N/A
	Alpha angle	91.26 (10.28)	52.07 (3.53)	N/A
	Articulo-trochanteric distance	11.96 (2.79)	23.26 (5.29)	N/A
Erickson	Slip angle	P: 68.0 D: 56.5	P: 17.8 D: 15.8	N/A
	Alpha angle	P: N/A D: N/A	P: 60.8 D: 55.8	N/A
	Femoral neck length	P: 24 D:24.5	P: 27.5 D: 27.6	N/A
	Greater trochanteric height	P: 7.3 D: 11.8	P: 1.7 D: 6.0	N/A
Baraka 2022	Neck-shaft angle	117.81 (13.86)	129.86 (4.92)	N/A
	Center-edge angle	16.62 (9.13)	26.29 (4.41)	N/A
	Alpha angle	81.81 (21.14)	49.52 (4.88)	N/A
	Articulo-trochanteric distance	-6.79 (7.91)	20.86 (9.43)	N/A
Faure	Articulo-trochanteric distance*	-6 (-19-4)	27 (7-37)	N/A
	Horizonal Femoral offset*	21 (0-43)	33 (4-46)	N/A
	Femoral Neck Valgus	N/A	N/A	11 (0-29)

Reported as Mean (Standard Deviation). *Reported as Median (Range). P: primary surgery. D: delayed surgery, i.e. SD/PFO performed six months after. AP: anterior/posterior.

Table 3. Patient Reported Outcome Measures

Author	PROM	Preoperative	Postoperative	Delta
Baraka 2020	mHHS	65.39 (7.64)	93.3 (3.23)	N/A
Spencer	WOMAC			
	Pain	9	5	N/A
	Function	26	13	N/A
Parilla	mHHS	58.3 (20)	78.7 (24)	20
	UCLA	5.9 (3)	7.3 (3)	1.4
	HOOS			
	Pain	62.6 (22)	80.9 (28)	18
	Symptoms	54.3 (23)	76.1 (26)	22
	ADL	70 (23)	87 (27)	17
	Sports	42.8 (25)	71.2 (32)	28
	QOL	34.9 (26)	66.9 (32)	32
	WOMAC			
	Pain	67.8 (23)	84.2 (27)	16
	Stiffness	57.4 (26)	76.3 (30)	19
	Function	70 (23)	87.3 (27)	17
	SF-12 Physical	37.6 (11)	48.2 (13)	11
	SF-12 Mental	50.6 (12)	55.1 (10)	5
Baraka 2022	mHHS	66.52 (8)	89.52 (7.78)	N/A

Reported as Mean (Standard Deviation). mHHS: modified Harris Hip Score, WOMAC: The Western Ontario and McMaster Universities Osteoarthritis Index, HOOS: Hip Disability and Osteoarthritis Score, SF: Short-Form, ADL: Activities of Daily Living, QOL: Quality of Life.

Table 4. Complications Graded Based on Clavien-Dindo Classification

Author	N (%) complications	Description of complications
Baraka 2020	1 (6.7)	1 Grade III (instrumentation failure from blade plate backing out requiring revision)
Erickson	2 (13.3)	2 Grade III (one instrumentation failure requiring revision ORIF, one PFO nonunion requiring bone grafting and revision ORIF)
Spencer	1 (6.7)	1 Grade II (transient superficial peroneal nerve palsy unsure how quickly resolved)
Baraka 2022	1 (6.7)	1 Grade I (keloid scar formation)
Parilla	7 (46.7)	3 Grade I (one mild AVN of central femoral head yet to require intervention at latest follow up, one Brooker III HO, one Brooker IV HO) 3 Grade II (three delayed femoral unions all successfully treated with a bone stimulator) 1 Grade III (one non-union requiring revision PFO and grafting in patient with only prior hip scope)
Faure	3 (20.0)	2 Grade II (one transient sciatic nerve palsy unsure how quickly resolved, one asymptomatic fibrous union of greater trochanter after perioperative fracture) 1 Grade IV (postoperative pulmonary embolism that regressed after anticoagulation)

ORIIF: open reduction internal fixation, PFO: proximal femoral osteotomy, AVN: avascular necrosis, HO: heterotopic ossification.

Long-term Outcomes and Follow-Up

The mean follow-up period in the reviewed studies was 40.1 months (range 3-127 months). While this provides valuable mid-term data, longer-term follow-up studies are needed to assess the durability of the results and the potential for progression to osteoarthritis or need for total hip arthroplasty in the future.

Efficacy and Safety of Combined Procedures

Our review of six studies, encompassing 132 patients with a mean age of 16.5 years, shows significant improvements in both radiographic parameters and clinical outcomes following combined SD and PFO procedures. Lateral slip angles showed notable improvements for patients undergoing these procedures for SCFE. Alpha angles showed similar improvements for all hips. These radiographic improvements correlate with enhanced clinical outcomes, as evidenced by the increase in modified Harris Hip Scores (mHHS) from 61.9 to 84.8. Rate of reoperations were low at 3.0% with no hips reported as converting to THA. Furthermore, there was a relatively low complication rate (11.4%) across these studies. The rate of major and minor complications were 3.8% and 7.6%, respectively (5 and 10 hips, each).

Complications

Our review reports a relatively low complication ate of 11.4% (15 complications in 132 patients). The rate of major and minor complications were 3.8% and 7.6%, respectively (5 and 10 hips, each). There was one Grade IV complication, four Grade III complications, six Grade II complications, and four Grade I complications. The most common complications were instrumentation failure due to various causes (4 cases) and delayed femoral unions all treated successfully with bone stimulators (3 cases). Importantly, none of these complications had lasting effects on patient outcomes, suggesting that the procedure has an acceptable safety profile when performed by experienced surgeons. A study from Gourineni et al. published in 2023, not included in our systematic review, aimed to describe short-term complications following relative femoral neck lengthening combined with extra-articular osteotomies of the proximal femur using surgical dislocation and extended retinacular flap development.[21] 72 patients underwent 79 combined procedures from 2005 to 2021 with 6 major and 5 minor complications occurring in 11 hips of 11 patients, at a rate of 13.9%, which is comparable to the 11.4% rate found in our review. Four hips developed avascular necrosis, three of which required multiplane correction, compared to the one case of mild AVN found in our review that has yet to require intervention at latest follow-up. Two hips developed non-unions which were fixed with locking plates. One hip had persistent abductor weakness which required hardware removal. Three hips developed symptomatic widening of the operated hip. All of these complications happened within 12 months of the index procedure.

The risk of avascular necrosis (AVN) following combined SD/PFO for complex proximal femoral pathologies, such as SCFE and Perthes disease, remains a concern due to the potential disruption of the femoral head blood supply. However, careful surgical technique, including meticulous preservation of the medial femoral circumflex artery, has been shown to mitigate this risk. Reported AVN rates vary depending on the specific pathology and surgical approach. Studies on surgical dislocation for SCFE, particularly combined with subcapital realignment, have demonstrated AVN rates up to 15%, with increased risks associated with severe slips and delayed intervention.[14,22] Combined SD/PFO has been associated with lower AVN rates when

performed meticulously and in well-selected cases, which align with the one mild case of AVN seen in this review, though outcomes remain influenced by disease stage and preoperative femoral head perfusion.[14,16] While these procedures offer substantial benefits in restoring femoral head sphericity and joint mechanics, the risk of AVN underscores the need for careful patient selection and adherence to atraumatic surgical principles to optimize outcomes.

Summary of Study Findings

In the first paper from Baraka et al. in 2020, they published on a series of 23 SCFE patients undergoing SD/PFO's.[15] All patients received OCPs to address alpha angles and PFOs to address coxa vara. Radiographically, after treatment, there was improvement in the mean AP slip angles (47.4° to 9.9°), lateral slip angles (57.1° to 12.7°), alpha angles (91.3° to 52.1°), and the articular-trochanteric distance (12.0 to 23.3 mm). The importance of these measurements towards the symptomatology of the complex hip disorder was exemplified by the correlations that were found between increasing alpha and lateral slip angles and worse preoperative mHHS. Therefore, treatment of these pathological findings helped to improve mHHS (65 to 93), decrease the limb length discrepancy (2.0 to 0.3 cm) as well as decrease the frequency of positive anterior impingement (100% to 13%) and Trendelenburg tests (83% to 9%). Furthermore, they only had one complication— an instrumentation failure requiring a revision that was due to non-compliance with weight bearing restrictions as well as vitamin D deficiency. This patient had an mHHS of 87 at final follow-up; therefore, it was a transient complication. In the subsequent paper that was published by Baraka et al. in 2022, they looked at 21 Perthes and Perthes-like patients.[16] Like their previous publication, they performed surgical dislocation as well as OCPs and PFOs in all patients. They subsequently performed periacetabular osteotomies (PAOs) in six of their patients as a staged second procedure for center-edge angles <15°. Radiographically, after treatment, there were improvements in the neck-shaft angle (117.8° to 129.9°), center-edge angle (16.6° to 26.3°), alpha angle (81.8° to 49.5°), and articular-trochanteric distance (-6.8 to 20.9mm). Furthermore, mHHS improved (67 to 90), limb length discrepancy decreased (2.5 to 0.6 cm), and the frequency of positive anterior impingement (95% to 14%) and Trendelenburg tests (81% to 14%) decreased.

In the paper by Erickson et al., they looked at 19 SCFE patients and divided the cohort into 6 patients that had primary surgical dislocation with OCP and PFO and 13 patients that underwent in situ pinning followed by surgical dislocation with OCP and PFO six months after the pinning.[17] The reason that 13 patients underwent staged procedures was because they had severe slip angles (>50°) compared with the 6 other patients who only had moderate slip angles (30°-50°). They found no difference between pre- or postoperative radiographic measurements between the groups. There were no PROMs that were reported for this study. For complications, one patient in the primary OCP/PFO group had instrumentation failure requiring revision that was likely due to non-compliance with weightbearing restrictions. Also, one patient in the delayed in situ pinning group required bone grafting and revision for nonunion at the PFO site. In the paper by Faure et al., they looked at 15 patients with Perthes and DDH and performed combined SD/PFO on all patients, OCP on 14 patients, and PAO on 14 patients.[18] After treatment, limb length discrepancy improved (-15.5 to -3mm). On femoral side, there was improvement in the articular-trochanteric distance (-6 to 27mm), horizonal offset (33 to 21mm), and valgus (11° improvement). There were three complications—1 pulmonary embolism, 1 fibrous nonunion, and 1 transient nerve palsy.

In the paper by Parilla et al. they looked at 48 patients with SCFE, Perthes, DDH, isolated FAI, and posttraumatic AVN for which they performed combined SD/PFOs on all patients.[14] There were no radiographic data presented in this paper. For PROMs, after treatment, there were improvements in mHHS (58.3 to 78.7), UCLA (5.9 to 7.3), HOOS pain (62.6 to 80.9), HOOS symptoms (54.3 to 76.1), HOOS ADL (70 to 87), HOOS sports (42.8 to 71.2), HOOS QoL (34.9 to 66.9), WOMAC pain (67.8 to 84.2), WOMAC stiffness (57.4 to 76.3), WOMAC function (70 to 87.3), SF-12 physical (37.6 to 48.2), and SF-12 mental (50.6 to 55.1). This study provided a detailed analysis of complications that were split into major (grade III) and minor (grade I and II). Major complications were those that required surgical intervention and minor complications, at most, required pharmacologic intervention. Major complications occurred at a rate 4.2% and minor complications occurred at a rate of 10.4%. The two major complications which were non-unions, one treated with revision surgery and the other with bone stimulation. The five minor complications were a small area of AVN, two cases of heterotopic ossification (HO), and two cases of delayed unions that were treated with bone stimulators. In the paper by Spencer et al., there were six patients with SCFE or isolated FAI.[19] All patients underwent combined surgical hip dislocation with OCPs and PFOs. For PROMs, the WOMAC was used with 0 being no pain. Pain improved from 9 to 5 and function improved from 26 to 13. Radiographic parameters were not reported for this study. There was one complication that was a transient superficial peroneal nerve palsy.

Surgical Technique Considerations

The combined SD and PFO approach allows for comprehensive treatment of both intra-articular and extra-articular pathologies. The surgical dislocation component provides direct visualization of the joint surface, enabling precise osteochondroplasty and treatment of intra-articular lesions.[5] This is particularly important given the high prevalence (93%) of intra-articular disease reported in isolated FAI cases. The proximal femoral osteotomy component allows for correction of angular deformities, addressing issues such as coxa vara/valga and rotational abnormalities.[5] Thus, the combined SD and PFO approach offers several advantages over isolated procedures for multiple childhood proximal femoral pathologies. For instance, Baraka et al. 2020 reported successful outcomes in SCFE patients with combined SD/PFO, demonstrating improvements in slip angles and restoration of hip range of motion versus surgical hip dislocation alone.[15] Similarly, Baraka et al. 2022, showed significant improvements in both radiographic parameters and clinical outcomes for Perthes patients as opposed to a single procedure.[16]

Future Directions

While our review provides valuable insights into the efficacy of combined SD and PFO procedures, there are several areas that warrant further investigation. Factors that may predict better or worse outcomes following combined SD and PFO procedures may be beneficial as well as the development of standardized outcome measures specific to hip preservation surgery in young patients with complex femoral deformities. Ultimately, long-term follow-up studies are needed to assess the durability of outcomes and rates of conversion to total hip arthroplasty.

Limitations

There were limitations to this systematic review. First, there were a low number of studies because concurrent SDs and PFOs are rarely performed and thus literature is scarce. Next, there are reporting biases when conducting research that inherently affect systematic reviews as well. Also, there were lack of control groups in these studies likely due to the severity of the disease and difficulty in properly controlling patient factors. Furthermore, there is some variability in the etiology for these patient populations which may affect outcomes. Further studies with control groups and with longer follow up would benefit our understanding of concurrent SDs and PFOs.

CONCLUSION

In conclusion, this systematic review provides evidence supporting the use of concurrent surgical dislocations and proximal femoral osteotomies for complex proximal femoral disorders, particularly in adolescents and young adults with SCFE and residual Perthes disease. There were six articles in this systematic review that demonstrated improvement in radiographic and clinical outcomes after treatment with low reoperation and complication rates for both pathologies, especially a low rate of AVN. Further research should investigate outcomes after these procedures with large, prospective databases, refined patient selection, a breakdown of proximal femoral pathologies, and longer follow up periods.

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OPIOID VERSUS NON-OPIOID POSTOPERATIVE PAIN MANAGEMENT FOR PEDIATRIC SUPRACONDYLAR HUMERUS FRACTURES

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ABSTRACT

Background: Opioid misuse is a leading cause of unintentional adolescent injury. Prescribing opioids for postoperative pain management in pediatric supracondylar humerus fracture fixation is controversial. This study compares opioid pain medication versus non-opioid pain medication use in outpatient pain control after such fixation.

Methods: This retrospective review involved subjects <18 years old who underwent closed reduction and percutaneous pinning (CRPP) of Gartland type II-IV supracondylar humerus fractures. Two cohorts received differing postoperative pain control: opioid medication and non-opioid medication based on standard of care for the practitioner. Exclusions included patients requiring open reduction, distracting injuries, or complications like compartment syndrome or vascular compromise. Primary outcomes were the number of call-ins for pain and pain rating at the first postoperative visit. Secondary variables included demographics, Gartland classification, return to the emergency department, and complications. Categorical variables were compared between groups using Chi-square tests. Continuous variables were compared between groups using t-tests, if normally distributed, or Wilcoxon Rank Sum tests if not. Between group differences in number of call-ins as well as postop ED and clinic visits were evaluated using Cochran-Armitage trends tests.

Results: The study included 399 participants prescribed opioids and 48 participants prescribed non-opioids. Demographic comparisons showed a near-equal sex distribution (p=0.28). The most common fracture was Gartland type III (opioid cohort: 57.6%, non-opioid cohort: 52%). Most subjects reported no pain at the first postoperative visit (opioid: 93.5%, non-opioid: 95.8%; p=0.75) and did not call-in regarding pain (opioid: 87.5%, non-opioid: 85%; p=0.89). The complication rate was similar between cohorts (opioid: 22.3%, non-opioid: 16.7%; p=0.37). The opioid cohort had a 3.5% early return to the emergency department, while the non-opioid cohort had no early returns (p=0.38).

Conclusion: Displaced supracondylar humerus fractures, a common pediatric orthopedic injury, are typically treated surgically. Opioid medications are often prescribed at hospital discharge. This study demonstrates nearly all patients achieved adequate pain control without opioids. Non-opioid pain medication provided effective pain management at the first postoperative visit, with no increase in emergency department returns or pain-related phone calls. These results suggest non-opioid pain medications can adequately control pain after CRPP of supracondylar humerus fractures.

Level of Evidence: III

Keywords: supracondylar humerus fracture, pediatrics, narcotics, opioids, pain management

INTRODUCTION

The United States is experiencing an exponentially increasing opioid epidemic with 13,053 pediatric opioid poisoning hospitalizations identified between 1997-2012.[1,2] From 2000-2015, the incidence rate of pediatric opioid-related hospitalizations was 3.71 per 100,000 children demonstrating a 2-fold increase during these years.[3]

While often thought of as a primarily adult issue, opioid misuse represents a leading cause of unintentional injury and even death in adolescents in the United States.[4] A retrospective analysis of >50,000 adolescents found that 27.5% used prescription opioids in the past year with significantly more of these subjects being female.[4] 3.8% of these adolescents reported opioid misuse, 25.4% of which were supplied by healthcare providers.[4] There is a high prevalence of opioid prescriptions for the adolescent population and misuse can lead to substance adverse events, abuse, and addiction. In an effort to re-

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duce these risks many efforts have been made at several institutions nationwide to reduce opioid prescriptions in the adolescent population.

Supracondylar humerus fractures represent the most common pediatric fracture requiring operative fixation with an average age of 6 years old.[5] The current literature estimates 70% of these fractures result from a child falling on an extended arm from a height.[6] The most commonly accepted practice for treatment of this injury when the fracture is displaced is closed reduction and percutaneous pinning, which is the most cost and time-effective with a reduced long-term risk of deformity.[5,6]

Most postoperative supracondylar humerus fracture fixation patients have the most significant reported pain on day 1 postoperatively.[7] While timing and management strategies vary based upon a number of factors, our institution at the initiation of our study prescribed a combination of opioids and non-opioid pain medications for postoperative pain upon hospital discharge.

Given the recent interest and risk profile, especially in the pediatric population, studies have shown similar analgesic effects between acetaminophen and fentanyl in postoperative care.[8] One study showed that acetaminophen use for pain relief reduced oxycodone consumption and improved pain scores.[8] An RCT at the emergency department level evaluated the effectiveness of oxycodone, ibuprofen, or combination therapy in treating pain for orthopedic injury in children 6-18 years old demonstrating no significant difference between the treatment groups.[9] A randomized control trial of 134 children with fractures tested 1:1 randomization of morphine to ibuprofen revealed no significant difference between the two groups in terms of pain control, with the morphine cohort reporting more side effects related to the medication than the ibuprofen group.[10]

Overall, there is increasing data in the literature to support discontinuation of opioid prescription in children post-supracondylar humerus fracture fixation. Studies have demonstrated well-tolerated pain control with the use of non-opioid medications in postoperative pediatric orthopedic patients with general fractures. This quality improvement study sought to bridge the knowledge gap to enhance the safety of postoperative pain treatment in this patient population and survey the impact on patient contacts to healthcare providers for uncontrolled pain at our institution.

METHODS

This study is a retrospective analysis of uncomplicated displaced supracondylar humerus fractures undergoing closed reduction and percutaneous pinning at our institution. After approval from the IRB the study was conducted in two parts, with further defining details of each listed below. Each part included all patients under the age of 18 treated operatively with closed reduction and percutaneous pinning for a Gartland II, III, IV supracondylar humerus fracture.[11] Adult patients, repeat injuries, injuries requiring open reduction, patients with other distracting injuries or fractures, and perioperative complications that could impact pain tolerance (i.e. vascular compromise or compartment syndrome) were excluded from the study. There is a standardized practice of admission for displaced supracondylar humerus fractures and operative treatment based upon prioritization of urgency. All included patients were treated on day of injury or the day following based upon time of presentation and urgency of their intervention.

Part 1

The Electronic Medical Record (EMR) was surveyed at our institution from January 2019 to December 2021 for patients meeting the above criteria. Patient demographics (age, sex, race, weight, BMI), injury laterality, surgical date, orthopedic staff involved, surgical approach (CRPP), complications, length of surgery, length of stay, amount of opioid pain medications prescribed (MME/kg), injury event details, Gartland classification, numerical pain scores were derived from the EMR. Postoperative data collected included number of postoperative clinic visits, number of returns to the emergency department, and number of patient phone calls relating to postoperative pain for the first three months postoperatively.

The principal hypothesis of this study was that opioid medications are not necessary for postoperative pain control in uncomplicated supracondylar humerus fractures (types II, III, IV) treated with closed reduction and percutaneous pinning (CRPP). As a part of this study a subset of patients who did not receive opioids prior to the clinical practice change (primarily by patient/parent preference) was identified and equally evaluated. Secondarily it was predicted that there will be few early returns to clinic, emergency department visits, or call ins to clinic for those treated with the current regimen of opioid medications.

Part 2

After the completion of part one a change of practice was made by one of the orthopedic staff to transition all uncomplicated CRPP patients to receiving no opioid medications at the time of discharge. After a six-month period the EMR was surveyed again for the same patient related data. The data was interpreted in a similar fashion to that in part one, with the focus this time comparing patients receiving opioids to not receiving opioids after the clinical practice change. In the second part of the study it was predicted that would be no significant increase in

early returns to clinic, emergency department visits, or call ins when compared to previously established rates in patients receiving opioids.

Statistical analyses

Patient and injury characteristics, pain score at presentation, the number of calls for pain, as well as visits for uncontrolled pain were described using frequency (percentage) for categorical variables and mean±SD or median (interquartile range) for continuous variables with or without a normal distribution, respectively.

Patient and injury characteristics and pain score at presentation was compared between groups using chi-square tests for categorical variables and independent t-tests or Wilcoxon Rank Sum tests for continuous variables with or without a normal distribution, respectively. We also utilized a Cochran-Armitage trend test to determine whether the number of calls or number of clinic or ED visits for uncontrolled pain differed between groups.

RESULTS

A total of 447 patients were included in the study, with 48 subjects in the non-opioid treated cohort and 399 subjects in the opioid treated cohort. Demographic characteristics such as race (p=0.98) and sex (p=0.28) were comparable between the two cohorts (Table 1). Median age was statistically different between the two cohorts at five years old for the non-opioid cohort versus six years old in the opioid cohort (p=0.03), but this difference is likely not clinically significant (Table 1). The most common Gartland fracture type was III, observed in 52% of the non-opioid cohort and 57% of the opioid cohort (Table 1). The length of surgery was shorter in the opioid cohort, with the non-opioid cohort having a median duration of 1 hour (IQR 1-3), compared to a median of 2 hours (IQR 1-2) in the opioid cohort (p=0.03). The median morphine milliequivalents (MME) for the opioid cohort was 1.8 (IQR 1.3-2.9).

The median length of hospital stay was significantly longer in the opioid cohort, with a median stay of 16 hours (IQR 13-18), compared to the non-opioid cohort, which had a median stay of 14 hours (IQR 10.5-17.3, p=0.01) as shown in Table 1. The complication rates were similar between the two cohorts, with the non-opioid cohort at 16.7% and the opioid cohort at 22.3% (p=0.31), as demonstrated in Table 2. Complications included: nerve palsy, wound complications, or pin site infections. The non-opioid cohort had no post-operative returns to the emergency department, whereas the opioid cohort had 14 out of 399 subjects return to the emergency department unplanned (p=0.38) (Table 2). Additionally, 12.5% of the non-opioid cohort contacted the clinic for pain concerns, compared to 15% of the opioid cohort (p=0.88) (Table 2). Table 2 also shows that the non-opioid cohort averaged two post-operative clinic visits, while the opioid cohort averaged three post-operative visits (p=0.36). At the first post-operative clinic visit, both cohorts had well-controlled pain, with only 4.2% of the non-opioid cohort and 6.5% of the opioid cohort reporting any pain at the visit (p=0.76), as demonstrated in Table 2. Finally, the opioid cohort requested a refill of pain medication 7% of the time (Table 2).

Overall, the two cohorts exhibited similar demographic profiles, fracture severities, and surgery durations. The opioid-treated cohort had a longer median hospital stay compared to the non-opioid cohort. The two cohorts had similar complication rates and well-controlled post-operative pain at the first clinic visit. The non-opioid cohort had no unplanned return visits to the emergency department and no increase in calls to the clinic for pain or medication refills.

DISCUSSION

Minimizing opioid prescriptions for pain management following pediatric fractures remains a focus of quality improvement across orthopaedic surgery departments nationwide.[8,12-15] Efforts in standardizing opioid prescribing protocols has been limited by the wide variation in surgeon narcotic prescribing practices, necessitating the need to first understand institutional opioid prescription patterns prior to implementation of an opioid limiting pain management protocol.[7,16-18] With supracondylar humerus fractures as one of the most common fractures in the pediatric population, they have served as an ideal injury to better understand opioid prescribing patterns, while developing more safe and efficacious analgesic regimens that limit the prescription of opioids.[5,7,12,15-20] This retrospective study adds to the existing body of evidence that there are no substantial differences in pain control, post-discharge resource utilization in the form of call ins, emergency department visits, or postoperative complications following the operative fixation of supracondylar humerus fractures. Through demonstration of clinical equipoise for patients managed at our institution, informed transition to a non-opioid postoperative pain regimen can be made for our department without hesitation regarding inadequate pain control and increased utilization of clinical resources.

In line with exiting literature, this study demonstrated insignificant differences in patient sex with 60.4% and 52.1% female distribution in the non-opioid and opioid use groups respectively.[18] Similar to prior studies Gartland III supracondylar humerus fractures were noted to be the most common fracture pattern in both the non-opioid and opioid groups at 52.08% and 57.64% respectively.[12,15,17,20] Despite the preponderance of

Table 1. Demographics of Non-Opioid versus Opioid Cohorts

Variable	Non-Opioid (n=48)	Opioid (n=399)	P-value
	Median (Interquartile Range) or n(%)	Median (Interquartile Range) or n(%)	
Age (years)	5 (3-6)	6 (4-7)	0.0333
MME	0	1.8 (1.3-2.9)	differ by definition
Length of Surgery (hours)	1 (1-3)	2 (1-2)	0.5753
Length of Stay (hours)	14 (10.5-17.3)	16 (13-18)	0.0104
Sex (n, % female)	29 (60.4%)	208 (52.1%)	0.2771
Race:			
Black	1 (2.08%)	17 (4.26%)	0.9831
Hispanic	3 (6.25%)	28 (7.02%)	
White	3 (6.25%)	27 (6.77%)	
Other	41 (85.42%)	327 (81.95%)	
Fracture Type:			
II	1 (2.08%)	65 (16.29%)	-
IIA	6 (12.50%)	19 (4.76%)	
IIB	8 (16.67%)	46 (11.53%)	
III	25 (52.08%)	230 (57.64%)	
IV	8 (16.67%)	39 (9.77%)	

Table 2. Comparison of Complications, Emergency Department (ED) Visits, Pain Calls, Clinic Visits, Postoperative Pain, and Refill Numbers Between Non-Opioid and Opioid Groups

Variable	Non-Opioid (n=48) N(%)	Opioid (n=399) N (%)	P-value
Complication	8 (16.7%)	89 (22.3%)	0.3705
ED	0	14 (3.5%)	0.3806
Calls for pain			
0	42 (87.50%)	399 (84.96%)	0.5924
1	4 (8.33%)	42 (10.53%	
2	2 (4.17%)	12 (3.01%)	
3	0	5 (1.25%)	
4	0	1 (0.25%	
Clinic Visit Number:			
0	1 (2.08%)	3 (0.75%)	0.0052
1	5 (10.42%)	36 (9.02%)	
2	26 (54.17%)	118 (29.57%)	
3	12 (25.00%)	188 (47.12%)	
4	4 (8.33%)	47 (11.78%)	
5	0	5 (1.25%)	
6	0	1 (0.25%)	
7	0	1 (0.25%)	
Pain at Postop	2 (4.2%)	26 (6.5%)	0.7552
Refill Number			
0	37 (77.08%)	372 (93.23%)	<0.0001
1	5 (10.42%)	24 (6.02%)	
2	6 (12.50%)	3 (0.75%)	

Gartland III fractures, distribution of fracture type was noted to be different between groups with the opioid use group having a higher number of Gartland II fractures at 16.29%, which may serve to artificially decrease the pain scores for the opioid use cohort. Counter to this possible confounding factor, the opioid use group was associated with an increased length of stay with a median stay of 16 hours compared to 14 hours in the non-opioid group which may be attributed to surgical complexity or monitoring in the setting of neurovascular injury in the postoperative period that may be the responsible for the prescription of narcotics and artificially increase in pain at postoperative visits and subsequent presentation to the ED not seen in the nonopioid group. Patients with the shorter length of stay may have been more eager to discharge, thus deferring opioid prescriptions on discharge to expedite leaving the hospital. Patients in the opioid use cohort were further demonstrated to have a higher median age at six years in comparison to five which may be attributed to older patients having increased capacity to express uncontrolled pain. This could potentially lead to increased prescription of opioids and relative increases in subsequent emergency department presentation. However, despite these theoretical confounders, Belardo et al. noted no differences in pain with any demographic factors or injury characteristics.[18] The authors felt that while statistically significant, this result was likely not clinically significant due to the overall similarities in age. Differences in demographic factors, injury characteristics, and clinical courses are critical for informing expected postoperative pain and informing potential factors that contribute to increased rate of opioid prescription in the postoperative period.

Despite the disparities between the opioid and non-opioid use groups identified in this study, the primary outcome of pain at follow-up was not statistically different between groups. This supports the notion that non-opioid medications can achieve comparable analgesia to opioids without risk of future dependence and untoward side effects. Multiple studies have demonstrated the ability of non-opioid medications to achieve equivalent pain control to opioid medications following supracondylar humerus fractures.[15,18] More generally, randomized clinical trials examining pain control following other orthopaedic injuries and fractures in the pediatric population have shown that nonopioid medication is comparable to opioid analgesia and associated with decreased opioid consumption with regimens including acetaminophen.[8-10] While the benefits and utility of non-opioid medications is well described in the pediatrics literature, there continues to be provider variability in the prescription of opioid medications.[17] In light of variable prescribing practices, the role of multimodal analgesia becomes increasingly important in attempt to decrease consumption of opioids postoperatively.[20] In review of pediatric patients with operative fractures outside of supracondylar humerus fractures, Keil et al. noted only 74% of patients receiving acetaminophen, 60% NSAIDs, while 95% of patients received opioids.[21] Stillwagon et al. reported a similar finding with 25% of patients receiving acetaminophen and 9% of patients receiving ibuprofen as firstline medications following CRPP of supracondylar humerus fractures.[7] This highlights an area for improvement in the prescription of multimodal pain control. Multiple regimens have been described including the use of intraoperative local bupivacaine injection and intravenous paracetamol by Kim et al. which have been associated with decreased opioid doses and shorter length of stay for operative Gartland III extension type supracondylar humerus fractures.[12] Adams et al. highlights that use of ketorolac was linked to decreased oxycodone use with lower pain ratings in the immediate postoperative period and a 40.4% decrease in costs associated with inpatient hospitalization. Other authors have advocated for the use of local bupivacaine and inpatient order sets to decrease opioid prescriptions.[17,19] Whether or not patients are prescribed opioids, non-opioid alternative in the form of perioperative medications or non-opioid discharge medications should be mainstays in the pain management of supracondylar humerus fractures.

Through discussion of opioid prescribing patterns at our institution, there has been a hesitation to completely abandon opioid prescribing due to the fear of increased demand on clinical resources for outpatients through telephone call ins, unplanned clinic visits, and unexpected return to the emergency department for evaluation. This retrospective review demonstrates that these perceptions are misguided, as there was no difference in the pain call ins between the non-opioid and opioid group with rates of 12.5% and 15%, respectively. Subsequent presentation to the emergency department was further not statistically different between the groups, however there was an increased relative rate of ED presentation in the opioid group at 3.5% versus 0% in the non-opioid group. These findings can likely be attributed to the adequacy of the nonopioid pain regimen in managing postoperative pain, while also setting appropriate pain expectations when counseling patients and families in the perioperative period for patients included in the prospective non-opioid arm of this study and potentially due to the aforementioned confounding factors. In a narrative review by Chaudry on implementing value based practices in supracondylar humerus fracture care, they note that the efficacy of a pain regimen plays a key role in call in rates and unexpected follow-up.[19] They further note that expectations management for pain postoperatively is

critical for guiding appropriate use of clinical resources for uncontrolled pain and could potentially identify patients that need to be evaluated for a complication in the setting of unexpected pain levels.[19] The importance of family education on expected pain postoperatively remains critical regardless of opioid prescriptions, as report of unexpected pain levels can raise a red flag for further workup for healthcare workers assisting in the triage and care of patients postoperatively.[7,16,22] Despite no difference in complication rate being identified in the present study, Stillwagon et al. highlights two patients who required greater than 15 oxycodone doses ultimately developed minor complications in the postoperative period.[7] Many authors in the literature have advocated for limiting opioids to only a few doses postoperatively and recommending further evaluation of patients requiring refills or additional analgesia as this may indicate an underlying complication.[7,19,21,22] Irrespective of the decision to prescribe opioids postoperatively, there is no difference in clinical utilization of resources in the form of call ins and emergency room visits, however, providers should take care to evaluate patients with uncontrolled pain in the postoperative period to avoid missing potential complications.

Limitations of this study primarily revolve around its retrospective design. As with all retrospective studies, there is the risk of inaccuracies in data recording, incomplete data, and the inability to establish causal relationships between opioids and outcomes seen in this study due to multiple confounding variables. One potential confounding variable that was not captured in this study was characterizing the type and quantity of non-opioid medications prescribed at discharge or during the perioperative period. It is possible perioperative medication administration such as ketorolac and local anesthetic, as well as discharge medications such as acetaminophen, muscle relaxers, and NSAIDS were not the same between the opioid and non-opioid cohort which may confound the creation of future pain protocols. It is critical to know which, if any, medications are being prescribed to patients in the non-opioid group to achieve comparable analgesia in comparison to those receiving opioids. The possibility of patients seeking care from their primary care provider or outside medical facilities not accounted for in this study may artificially decrease the calls for pain, ED visits, complications and subsequent opioid prescriptions. There was initial concern that the results of this study may also be confounded by the two-part retrospective data, as the change in practice seen in opioid prescribing may have led to changes in pain management counseling for patients and their families, as well as subsequent management such as calling in for pain and presenting to the emergency department for further evaluation. However, the rate of return and phone calls, return to ED, and clinic visits remained consistent in the opioid group both before and after the clinical practice change. This risk still exists for the non-opioid cohort as it is significantly different from the patients who received opioids.

This study is further limited by selection bias given that only closed and isolated supracondylar fractures were included in this study, which may have led to overall low pain needs at baseline in comparison to more heterogenous populations, thus leading to no significant differences in pain control and outcomes between groups. This limits extrapolation of data to patients requiring open reduction, those with neurovascular injury, and polytraumatized patients. While this study does demonstrate clinical equipoise for the more common closed and isolated supracondylar humerus fractures, future studies should be directed at which patients may benefit more from opioid prescriptions. Extensive study has been performed of supracondylar humerus fractures in the pediatric population, which calls for future research to be directed at other common pediatric fractures such isolated diaphyseal femur fractures and other common pediatric injuries faced by on call orthopaedic providers.

This retrospective study demonstrates that non-opioid pain regimens achieve equivalent pain control to opioids postoperatively, while not increasing complications and healthcare utilization in the form of emergency department visits or pain related calls. Based on this institutional review and current literature, the authors advocate for the use of a non-opioid pain regimen following operative management of uncomplicated closed supracondylar humerus fractures. This has led to a practice change at our institution with no opioids being prescribed to patients undergoing operative management of closed supracondylar humerus fractures and five to ten opioid doses being prescribed to more complex patients requiring open reduction or sustaining open supracondylar humerus fractures. Future studies are needed to assess the efficacy of non-opioid analgesia for other common pediatric fractures to help further reduce unnecessary opioid prescribing.

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FUNCTIONAL OUTCOMES AND COMPLICATIONS FOLLOWING GREATER TUBEROSITY RESURFACING FOR COMPENSATED CUFF ARTHROPATHY

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ABSTRACT

Background: Patients with large, irreparable rotator cuff tears may develop a compensated cuff arthropathy (CCA) with persistent shoulder pain from contact between the humeral head and acromion. This study reports shoulder pain relief, functional outcomes, and complications in CCA patients treated with greater tuberosity resurfacing (GTR).

Methods: A retrospective case-series review of patients who underwent GTR between 2014 and 2021 by a single community hospital-based surgeon was conducted. Patients who failed nonoperative treatment underwent diagnostic arthroscopy. If the rotator cuff was deemed irreparable intraoperatively, a metallic implant (HemiCAP) was placed at the supraspinatus insertion via a mini-open deltoid splitting approach. Postoperatively, patients followed a standard physiotherapy regimen. Shoulder range of motion, American Shoulder and Elbow Surgeons (ASES) assessment form, Pennsylvania Shoulder Score (PSS), satisfaction scores were collected, and complications recorded.

Results: Of the 33 shoulders, (32 patients), that had a GTR, 29 shoulders (28 patients) were included in the final analysis (two patients were converted to reverse shoulder arthroplasty, one was lost to follow-up, and one was deceased). Mean age was 69 years. Mean follow-up was 48 months. Mean postoperative ASES and PSS were 79 and 74, respectively. Patients were very satisfied with the procedure in 18 (62%) shoulders and satisfied in five (17%) shoulders. Twenty-four patients (86%) with 25 shoulders (86%) stated they would recommend the procedure.

Conclusion: GTR for CCA showed significant pain relief, acceptable functional outcomes, and low revision rates. GTR reduces pain and maintains function in patients with CCA and minimal glenohumeral arthritis.

Level of Evidence: IV

Keywords: compensated rotator cuff tear; greater tuberosity resurfacing; inlay arthroplasty technique; minimally invasive technique; shoulder arthroplasty

INTRODUCTION

Treating irreparable rotator cuff tears presents a challenge for orthopaedic surgeons as a multitude of factors influence outcomes, including the patient's age, activity level, and extent of disability caused by the tear.[1-3] The loss of rotator cuff function can lead to early- and late-stage cuff arthropathy. Cuff tear arthropathy (CTA) is defined as a combination of both muscular and bony changes resulting from rotator cuff insufficiency and superior migration of the humeral head ultimately resulting in glenohumeral arthritis.[4] In cases of irreparable tears with advanced glenohumeral degenerative changes, reverse total shoulder arthroplasty (RSA) has become the preferred treatment option producing promising clinical results in both reducing pain and increasing function.[5-9]

Some patients functionally adapt to their rotator cuff tear and present with a painful shoulder without glenohumeral degenerative changes, resulting in a "compensated cuff arthropathy" (CCA). CCA is defined as a "functional force coupling of the deltoid and remaining rotator cuff using the glenoid or acromion as a fulcrum for active forward elevation."[10] Pain generators often accompany torn rotator cuffs, including the torn tendon itself, an inflamed subacromial bursa, or a degenerated biceps tendon. Historically, simple tuberoplasty, arthroscopic subacromial decompression, and biceps tenotomy have been used to address these pain generators.[11] More recently, superior capsular reconstruction (SCR), biologic tuberoplasty, and subacromial balloon spacers have also been employed in an attempt to treat the pain associated with massive rotator cuff tears.[12-14] In this investigation, greater tuberosity resurfacing (GTR) with an inlay arthroplasty is utilized to address the pain generated by acromiohumeral articulation in patients with CCA.

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Resurfacing of the greater tuberosity with a surgical implant was described by McKenna and Chandler.[10] Their technique involves using an inlay arthroplasty to replace the greater tuberosity using a small articular resurfacing implant. The procedure eliminates the pain generator secondary to the articulation of the humeral head on the acromion, allowing patients to functionally move their shoulder without pain. As an early-stage intervention, GTR is a less invasive and joint preserving arthroplasty procedure, demonstrating promising benefits including bone preservation, shorter operative time, fast rehabilitation, and pain relief.[10] To the best of our knowledge, no functional outcomes have been reported in the literature. The objective of this case series was to review both clinical and functional outcomes along with patient satisfaction, and post-procedure complications in the treatment of early compensated cuff arthropathy with GTR.

METHODS

A retrospective review of patients who underwent GTR with a HemiCAP (Arthrosurface, Franklin, MA) implant by a single community-based board-certified orthopedic surgeon (GHS) between 2014 and 2021 was approved by the governing institutional review board. All patients provided informed consent before participating in the study.

Patient Selection

Chart review in the senior author's practice identified patients who had undergone GTR with the inlay arthroplasty implant for the diagnosis of massive, irreparable rotator cuff tear with CCA and minimal or no glenohumeral arthritis. All patients in the study were determined to be Hamada grade one or two preoperatively and had at least two years of follow-up. Patients with radiographic or arthroscopic evidence of glenohumeral arthritis were excluded.

Patients with rotator cuff tears most often presented with pain affecting their activities of daily living. The diagnosis of a rotator cuff with CCA and minimal glenohumeral arthritis was provisionally based on history, physical exam, and imaging. Shoulder magnetic resonance imaging (MRI) was obtained to determine the size and severity of the tear, with a specific focus on the integrity of the supraspinatus, infraspinatus, and subscapularis tendons. Only patients who had failed multiple trials of non-operative management with physical therapy, non-steroidal anti-inflammatory medications, and corticosteroid injections were given the option of operative intervention. A shared decision-making process between the primary surgeon and the patient took place in each case. Once surgery was planned, each patient was consented for attempted rotator cuff repair with possible conversion to GTR if the rotator cuff was deemed irreparable intraoperatively. An estimated total of 339 cases were identified with 306 having undergone primary repair of the rotator cuff intraoperatively. A total of 33 cases were deemed to have an irreparable rotator cuff tear and underwent GTR.

Implant Design and Surgical Technique

The HemiCAP is a small resurfacing articular inlay prosthesis. The surgical technique was performed as described in the literature by McKenna and Chandler.[10] In each case, a diagnostic arthroscopy of the affected shoulder was performed, and the rotator cuff tear was inspected and characterized. If the cuff was deemed irreparable, the shoulder was re-prepped, and a mini-deltoid split approach was used to visualize the greater tuberosity and the rotator cuff directly. The rotator cuff was then inspected to evaluate the size of the tear, mobility, and retraction. As described by Hamada et al.,[15] the rotator cuff was pulled distally with the patient's shoulder at 20 degrees of elevation to determine the reparability of the rotator cuff. Other routine procedures including interval slide and releases were attempted as well. If the rotator cuff tear could not be repaired, the surgeon proceeded with GTR.

If the long head of biceps tendon was still intact, a tenotomy was performed. Biceps tenotomy was described as an important step in the surgical description by McKenna and Chandler as the biceps tendon is a commonly recognized secondary pain generator.[10] Attention was then turned to the greater tuberosity for resurfacing (Figure 1). The inlay prosthesis utilizes a central pin and drill to localize the screw implant and ream the surface in one step. The surface implant size is selected based on the area to be covered which is typically 25 or 30 mm. Use of larger implants is limited by the surgical approach. The selected implant is then impacted onto the Morse taper of the screw. The implant is oriented to cover the footprint of the supraspinatus from the edge of the articular surface, extending laterally. Ideally, the implant is placed flush with the surrounding surface.

Postoperative Care

The mini-deltoid splitting approach allows immediate mobilization postoperatively as no deltoid repair is necessary. Therefore, all patients were placed into a simple sling and instructed to wear it until the interscalene block had resolved. There were no specific limitations given once the sling was discontinued. Patients were started on a standardized physiotherapy protocol for both active and passive range of motion as tolerated without restrictions on postoperative day two. Patients were encouraged

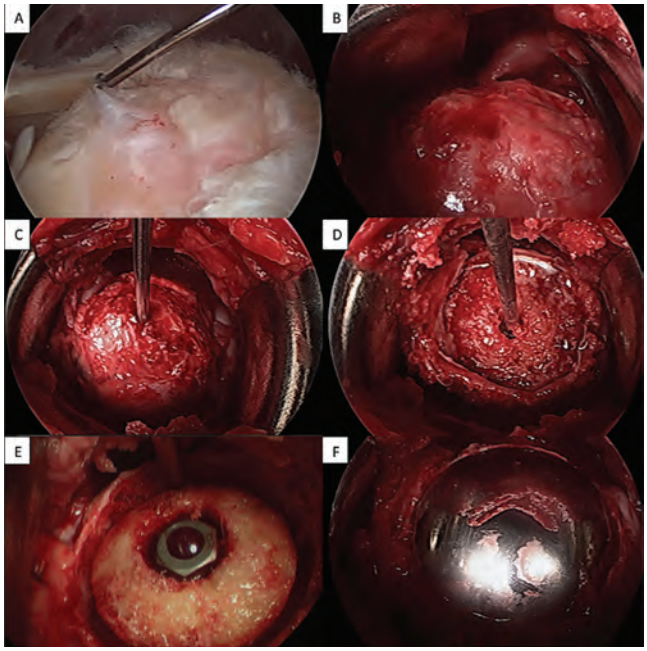

Figure 1A to 1F. Intraoperative progression of greater tuberosity resurfacing procedure with the HemiCAP implant. (1A) Arthroscopic view of greater tuberosity prior to mini-deltoid splitting incision. (1B) Initial exposure of greater tuberosity after mini-deltoid splitting incision and arthroscopic debridement. (1C) Central pin is placed as pilot hole for drill bit guidance to localize the HemiCAP implant over the footprint of the supraspinatus. (1D) Drill bit in place in humeral head following reaming of the greater tuberosity. (1E) Morse taper of screw in the humeral head. (1F) HemiCAP implant tapped onto the Morse taper of the screw to cover the footprint of the supraspinatus.

to resume normal activities immediately as tolerated. Initial follow-up was scheduled for two and six weeks postoperatively. Subsequent follow-up was scheduled as needed and for final functional evaluations.

Demographics and Outcome Measures

Demographic data and co-morbidities were obtained from the medical records of all patients eligible for the study. Duration of shoulder pain, prior shoulder surgeries, and conservative treatments were recorded. Exact numerical preoperative range of motion was not consistently documented in patient charts. Postoperative range of motion measurements were performed by KT with the patient in a seated position using a goniometer. Forward flexion, external rotation, and abduction were assessed. Anteroposterior (AP) and axillary lateral postoperative radiographic views were obtained at the two-week and six-week follow-up appointments. Imaging was reviewed for osteolysis, implant loosening, and periprosthetic fracture.

The American Shoulder and Elbow Surgeons (ASES) assessment form and the Pennsylvania Shoulder Score (PSS) were used to assess patient function postoperatively. The ASES is a validated scale for shoulder surgery consisting of two sections: Pain and activities of daily living (ADL). The pain section is a visual analog scale (VAS) that ranges from zero to 10, where zero represents no pain and 10 represents severe pain. The ADL section contains 10 items coded zero to three, unable to do an activity to no difficulty performing activity, respectively. The raw score is then converted to an interval score which ranges from zero to 100, zero being the worst and 100 being the best.

The PSS has three sections assessing pain, satisfaction, and function. The pain section includes three items with a VAS that ranges from zero to 10, none to worst, respectively. The satisfaction section includes one item with a VAS ranging from zero to 10, zero being least satisfied and 10 being most satisfied. The function section includes 20 items subdivided into five groups coded zero to four, where zero represents no difficulty, three represents cannot perform at all, and four represents patient could not perform before injury. When a patient selects four (could not perform before injury), the item is removed from the final score. The three sections are then added with a range from zero to 100, 100 indicating low pain, high satisfaction, and high function.

Patients also reported their level of satisfaction and whether they would recommend the procedure for one of their family members. Postoperative complications and the need for secondary surgery were recorded. Minor complications included any adverse event that could be treated conservatively with observation or nonoperative management. Major complications were defined as an adverse event resulting in reoperation.

Analysis

Patient characteristics and postoperative scores were summarized using standard descriptive statistics including means, standard deviations, ranges, and percentages.

RESULTS

Between 2014 and 2021, 32 patients (33 shoulders) underwent GTR (Table I). Of the 32 patients, 4 were excluded from the study: two patients underwent conversion to RSA, one patient died, and one patient was lost to follow-up. Thus, 28 patients (29 shoulders) were included in the final analysis. The cohort ranged in age from 52-84 years (mean ± SD: 69 ± 8 years). The average follow-up was 48 months (interquartile range = 26 – 80 months). Table II summarizes additional patient characteristics.

Clinical Outcomes

The mean ASES score was 79 (range 30 – 100) and PSS score was 74 (range 25 – 100). The average subsection scores of the PSS for pain, satisfaction, and function were 24, 7, and 43, respectively. Patients were very

Table I. Magnetic Resonance Imaging Findings of Rotator Cuff Tendon Integrity and Hamada Classification of 33 Shoulders Treated with Greater Tuberosity Resurfacing

Shoulder ID	MRI Interpretation of Rotator Cuff Muscles			Hamada Score	Included in Final Analysis? (Y/N)
	Suprspinatus	Infraspinatus	Subscapularis		
1	Complete tear retracted to glenoid	Complete tear	Intact	1	N
2	Complete tear retracted to glenoid	Intact	Complete tear	2	Y
3	Complete tear retracted to glenoid	Intact	Intact	1	Y
4	Complete tear retracted to glenoid	Intact	Intact	1	Y
5	Complete tear retracted to glenoid	Intact	Intact	1	Y
6	Complete tear retracted to glenoid	Intact	Intact	1	Y
7	Complete tear retracted to glenoid	Intact	Intact	1	Y
8	Complete tear retracted to glenoid	Complete tear	Intact	1	Y
9	Complete tear retracted to glenoid	Intact	Complete tear	1	Y
10	Complete tear retracted to middle of humeral head	Complete tear	Intact	1	Y
11	Complete tear retracted to glenoid	Intact	Intact	1	Y
12	Complete tear retracted to glenoid	Intact	Intact	1	Y
13	Complete tear retracted to middle of humeral head	Intact	Intact	2	Y
14	Complete tear retracted to middle of humeral head	Intact	Complete tear	1	Y
15	Complete tear retracted to glenoid	Intact	Intact	1	Y
16	Complete tear retracted to glenoid	Intact	Intact	1	Y
17	Complete tear retracted to glenoid	Intact	Intact	1	Y
18	Complete tear retracted to glenoid	Intact	Intact	2	Y
19	Complete tear retracted to glenoid	Intact	Complete tear	2	Y
20	Complete tear retracted to glenoid	Complete tear	Intact	2	N
21	Complete tear retracted to glenoid	Intact	Complete tear	2	Y
22	Complete tear retracted to middle of humeral head	Complete tear	Complete tear	1	N
23	Complete tear retracted to glenoid	Intact	Intact	2	Y
24	Complete tear retracted to glenoid	Intact	Intact	1	Y
25	Complete tear retracted to middle of humeral head	Intact	Intact	1	Y
26	Complete tear retracted to middle of humeral head	Intact	Complete tear	1	Y
27	Complete tear retracted to glenoid	Intact	Intact	1	Y
28	Complete tear retracted to glenoid	Intact	Intact	2	Y
29	Complete tear retracted to glenoid	Intact	Intact	1	Y
30	Complete tear retracted to glenoid	Intact	Intact	2	Y
31	Complete tear retracted to glenoid	Intact	Intact	2	N
32	Complete tear retracted to glenoid	Intact	Intact	1	Y
33	Complete tear retracted to glenoid	Complete tear	Intact	2	Y

Table II. Demographics and Preoperative Assessments of 29 Shoulders Included in the Final Analysis

Characteristics	Values
Postoperative follow-up, mo	48 ± 18
Age at index procedure, yr	69 ± 8
Male/Female	20/8
BMI (kg/m2)	30
Tobacco Use (n, %)	6 (21%)
Diabetes (n, %)	7 (25%)
Prior shoulder surgery (Yes/No)	8/20

Data are presented as mean ± standard deviation.

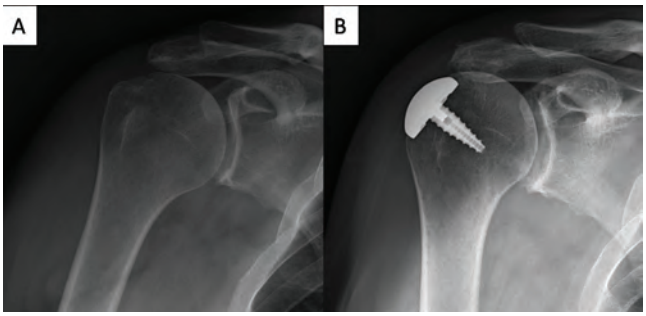

Figure 2A to 2B. Preoperative (2A) and postoperative (2B) radiographs of patient who had HemiCAP implant placed in the right shoulder for compensated rotator cuff arthropathy.

satisfied with the procedure in 18 (62%) shoulders and were satisfied with the procedure in five (17%) shoulders. Patients were unsatisfied with the result in three (10%) shoulders and very unsatisfied with the result in three (10%) shoulders. Twenty-four (86%) patients with 25 (86%) shoulders would recommend the procedure to a friend or family member, while four (14%) patients with four (14%) shoulders would not recommend the procedure.

The average values of postoperative active forward flexion, external rotation, and abduction of the 29 operated shoulders were 119 ± 55 degrees, 50 ± 26 degrees, and 95 ± 39 degrees, respectively. Postoperative passive range of motion in the same shoulders were as follows: 150 ± 33 degrees of forward flexion, 61 ± 23 degrees of external rotation, and 112 ± 31 degrees of abduction.

Radiographic Outcomes

Postoperative radiographs revealed that all resurfacing implants remained stable without evidence of loosening. Comparison of pre- and post-operative AP shoulder radiographs from a typical patient in this study are shown in Figure 2.

Complications

Two of the 33 patients treated with primary GTR underwent reoperation with conversion to RSA. These cases are identified as shoulders 20 and 22 in Table I. The cause for conversion to RSA in both cases was persistent pain after the GTR procedure. Of the 29 shoulders included in the final analysis, there were no complications of infection, wound dehiscence, shoulder dislocation, or further surgical interventions.

DISCUSSION

Massive, irreparable rotator cuff tears present a challenge for orthopedic surgeons and there is continued debate about which treatment option is the best. Given pain is a significant cause of morbidity in irreparable rotator cuff tears, GTR with inlay arthroplasty for patients with CCA without glenohumeral arthritis provides a viable option to improve pain without significant post-surgical limitations. To the best of our knowledge, no studies report GTR functional outcomes in the literature. In this study, GTR improved pain, and 79% of patients were very satisfied or satisfied with the procedure and would recommend it to a family member or friend. Two patients did undergo conversion to RSA; however, among the remaining patients there were no other major or minor complications. The average postoperative functional outcome score using the ASES score was above the patient-acceptable symptom state of 76 described by Chamberlain et al.,[16] and the average PSS score was also favorable.

Several surgical treatment options for CCA exist and determining the best treatment option for each patient typically involves a shared decision-making process between the patient and surgeon. For patients with irreparable tears and advanced glenohumeral arthritis, RSA has become the treatment of choice as it effectively reduces pain and increases function.[5-9] Although RSA has shown promising results, the complication and revision rate remain high. In two meta-analyses, the complication rate ranged from 19% to 24% and the revision rate ranged from 10% to 14%.[17,18] RSA complication rates have been reported as high as 59% to 68%.[6,19]

Long-term survivorship is also a concern for RSA as it becomes more widely used for younger patients with limited long-term studies available to help guide decision-making. Favard et al.,[20] showed implant survivorship to be 89% at 10 years, whereas functional survivorship was only 76%. Guery et al.[21] revealed further concern of long-term functional survivorship as 58% of patients had a Constant score <30. Matthews et al.[22] compared outcomes of RSA in patients less than 65 years of age to patients 70 years of age or older. They showed that RSA in younger

patients improved both pain and function similarly to that of the 70 or older age group. However, the patients less than 65 had significantly worse perceived outcomes, implying that their preoperative expectations may have been unrealistically high.

In patients with intact glenohumeral articular cartilage, irreparable rotator cuff tears present a challenge because, although several joint-preserving surgeries have been developed, there is a paucity of long-term outcome data. Early studies show varying complication and failure rates. One currently available option is SCR which was first described by Mihata et al. in 2012.[12] This technique is achieved by attaching a graft substrate to the superior glenoid and the lateral aspect of the greater tuberosity with the goal of preventing superior migration of the humeral head. This reconstruction also restores the depressor effect of the capsule and improves the rotator cuff concavity compression effect ultimately optimizing the force coupling needed for elevation of the arm.[12,23,24]

Short-term clinical outcomes of the SCR procedure have been promising with improvement in shoulder range of motion, VAS pain scores, and ASES scores.[24,25] However, published studies show failure rates as high as 65%.[26] One factor that correlates strongly with rate of SCR failure is surgeon experience. Woodmass et al.[26] found a failure rate of 77% with surgeon experience less than 10 cases. After performing more than 10 cases, the failure rate decreased to 42%.[26] SCR is a technically challenging procedure, and the results of this study suggest that SCR should only be performed by surgeons who are highly experienced in the reconstruction.

One new technique, biologic tuberoplasty, was developed in response to studies showing torn grafts that remained over the greater tuberosity in SCR procedures still resulted in improved patient-reported outcomes postoperatively.[27] This technique involves suturing an acellular dermal allograft over the greater tuberosity to eliminate bone-on-bone contact between the greater tuberosity and the acromion, effectively eliminating the pain generator.[14] Preliminary outcome studies of this technique show that it results in satisfactory pain reduction and improved patient reported outcomes.[28,29] Additionally, the procedure is less technically challenging than SCR. Biologic tuberoplasty employs the same principle as GTR as both aim to eliminate the pain generator between the greater tuberosity and the acromion, but the longevity of the biologic tuberoplasty has yet to be determined. In the present study, all patients have been followed for at least 2 years, with the longest follow-ups being over six years, with no implant failures. While acellular dermis has shown promise, continued compression between the acromion and the greater tuberosity may lead to graft degradation over time.

Another technique initially described by Savares and Romeo[13] in 2012 involved the placement of a saline filled balloon into the subacromial space. The balloon functions as an interposition spacer with the goal of protecting the acromiohumeral articulation. However, the balloon is absorbed over 12-18 months. The balloon arthroplasty procedure allows for smooth articulation between the acromion and greater tuberosity, while also attempting to prevent proximal migration of the humeral head, limiting subsequent progression of CTA.[13,30] One systematic review evaluated different methods of non-arthroplasty treatments for massive, irreparable rotator cuff tears, and found the balloon spacer improved postoperative external rotation, forward flexion, VAS pain scores, ASES scores, and Constant scores. Revision rates were from 0-8% in five studies, with three studies reporting no revisions. However, the authors acknowledged that many of the patients had only short-term follow-up.[31]

A recent randomized controlled trial compared subacromial space debridement and biceps tenotomy to the same procedure with the addition of subacromial balloon spacer placement. This study reported Oxford shoulder scores statistically favored debridement only. Secondary outcomes of Constant score and multiple planes of shoulder motion also favored debridement only, while there was no difference in participant global impression of change.[32] This study brings into question whether a subacromial balloon spacer provides any benefits compared to arthroscopic debridement for massive, irreparable rotator cuff tears. In addition, data reporting long-term follow-up after degradation of the spacer are sparse.

Like the subacromial balloon spacer and the biologic tuberoplasty, the main purpose of resurfacing the greater tuberosity with inlay arthroplasty is to eliminate the pain generator between the superior articulation of the humeral head on the acromion restoring pain-free shoulder motion. Moreover, the procedure may slow progression to end-stage cuff-tear arthropathy. In the present study, GTR with inlay arthroplasty for patients with CCA resulted in high satisfaction scores and acceptable functional outcome scores. Utilizing a rigid resurfacing implant avoids limitations caused by fixation issues with SCR or resorption of the subacromial balloon spacer or acellular implant, giving the potential for more consistent, longer-term pain relief and improved implant survivorship. In addition, because the procedure is performed through a deltoid-splitting approach, the subscapularis is preserved, minimizing shoulder instability, preserving function, and shortening the rehabilitation period. Finally, the procedure is not technically challenging, and surgeon experience is less likely to result in significant inter-surgeon differences in outcomes.

Only two patients in our series required conversion to RSA secondary to continued shoulder pain and dysfunction. As an early-stage intervention, GTR is a less invasive, joint-preserving, arthroplasty procedure in comparison to RSA. The operative approach when converting the GTR to a RSA is elementary. A primary approach through the deltopectoral interval was used in our two cases. The HemiCAP resurfacing implant was removed with the use of an elevator or osteotome. Minimal bone loss was noted with removal of the HemiCAP and the surgeon was then able to proceed with the RSA via preparation of bony cuts and soft tissue releases in a standard fashion. Gaeremynck et al.[33] recently published results on clinical and radiological outcomes of 17 RSA cases performed after failed humeral head resurfacing. They reported excellent outcomes in all 17 patients with no intraoperative or postoperative complications.[33] On the contrary, revision of failed RSA can be difficult due to glenoid bone loss, frequently requiring bone grafting and possibly a two-stage salvage procedure. Furthermore, revision of RSA has an increased complication rate as high as 69%.[34] GTR preserves valuable bone stock and does not violate the subscapularis, allowing for a straight forward conversion to RSA if needed.

There are several limitations to this study including its retrospective nature, small sample size, and lack of a comparative control group. Patient follow-up is still in the short term. Also, there was a lack of clinical data available preoperatively as PSS and ASES questionnaires were not completed as part of the preoperative assessment nor were exact range of motion measurements recorded. Therefore, direct comparisons of preoperative and postoperative patient-reported outcomes and range of motion measurements were not possible.

CONCLUSION

GTR is a minimally invasive procedure well suited for high-demand patients and those who will not tolerate the postoperative precautions and activity restrictions associated with RSA. GTR is a safe procedure that any well-trained orthopaedic surgeon can easily perform. The procedure provides most patients with satisfactory outcomes, pain reduction, and acceptable function, while maintaining adequate bone stock should a conversion to RSA be necessary. Resurfacing the greater tuberosity may provide a straightforward and reliable construct for long-term pain reduction, comparable to SCR, biologic tuberoplasty, or balloon arthroplasty. Future studies should directly compare SCR, biologic tuberoplasty, balloon arthroplasty, and GTR in a long-term prospective, randomized trial.

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DIFFERENCES BETWEEN SMOKERS AND NON-SMOKERS UNDERGOING SURGERY FOR ANTERIOR SHOULDER INSTABILITY IN THE MULTICENTER ORTHOPAEDIC OUTCOMES NETWORK (MOON) SHOULDER COHORT

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ABSTRACT

Background: The purpose of this study was to better understand the prevalence and implications of smoking status on patients undergoing shoulder stabilization surgery. In particular, we wanted to test the hypothesis that smokers were more likely to undergo glenoid bone augmentation procedures.

Methods: The present study included all patients 12 to 66 years of age undergoing surgery for anterior shoulder instability in the MOON Shoulder Instability cohort. Analysis was done to determine the prevalence of smokers within the cohort and to determine the relationship of smoking with undergoing a glenoid bone augmentation surgery like the Latarjet.

Results: There were 61 smokers (4.8%) among 1267 patients undergoing anterior shoulder instability surgery in our cohort. Smoking was associated with older age, higher BMI, socioeconomic status as determined by DCI score, and minority status. Smokers were more likely to higher number of dislocation events prior to surgery. Although it did not reach significant smokers had a higher percentage of patients with glenoid bone loss. Logistic regression modeling showed that smoking and higher number of dislocation events were statistically associated with undergoing a glenoid bony augmentation surgery such as Latarjet.

Conclusion: The study determined the prevalence of smoking in a large shoulder instability cohort to be 4.8%. Multi-variate analysis demonstrated that smoking and at least 3 dislocation events were statistically associated with undergoing a glenoid bony augmentation surgery.

Level of Evidence: III

Keywords: shoulder instability, latarjet, glenoid bone loss, smoking

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INTRODUCTION

Anterior shoulder instability can have a negative impact on quality of life secondary to pain, loss of function and/or productivity.[1] Unfortunately, it is not an uncommon problem as 21.9 out of 100,000 patients within the population have reported instability.[2] Additionally, instability recurs in up to 67% of shoulder instability patients under 35 years, with younger individuals at a higher risk.[3] Due to the risk of repetitive instability episodes, surgical stabilization is often indicated for either young patients or patients with recurrent instability.

Recurrent instability develops due to numerous factors, one of which can be due to glenoid bone loss. This can be addressed surgically with either soft tissue, or more powerful procedures that offer bony augmentation of the glenoid such as a Latarjet procedure. Historically, the most common indication for glenoid augmentation is presence of 20% bone loss of the anterior glenoid.[4] However, some papers suggest 15% bone loss with recurrent instability may put patients in a borderline category as candidates for anterior glenoid bone augmentation.[5] Latarjet type procedures are becoming more common in the United States,[5] and given the complication rate

of 15-30%,[6] it is important to consider the indications for these procedures and determine potential risk factors for complications among patients.

Recent data suggest that smoking is a significant risk factor for complications. Specifically, a recent NSQIP study noted smoking patients were 2.19 times as likely to have to have complications within 30 days of Latarjet surgery.[7] While smoking prevalence has overall decreased significantly within the United States over the past several decades, it still causes substantial public health and economic issues.[8] With this in mind, smoking has been shown to have a negative effect on health of musculoskeletal tissues.[9] There has been documented association between shoulder pathology and smoking with regards to the rotator cuff.[10] However, there is limited information regarding smoking and patients undergoing surgery for shoulder instability or labrum pathology.

The purpose of this study was to better understand the prevalence and implications of smoking status on patients undergoing shoulder stabilization surgery. In particular, we wanted to test the hypothesis that smokers were more likely to undergo glenoid bone augmentation procedures.

METHODS

This study is a cross sectional analysis of data from the Multicenter Orthopaedic Outcomes Network (MOON) Shoulder Instability study, a prospective multicenter cohort study conducted at 10 institutions throughout the United States of patients undergoing procedures for glenohumeral instability. The MOON Shoulder Instability Study includes all patients undergoing stabilization surgery, including primary and revision surgeries, and excludes nonoperatively managed patients. Details of study methods have been previously described.[11-13] MOON is institutional review board approved, and all patients provided informed consent prior to enrollment. The present study included all patients 12 to 66 years of age undergoing surgery for anterior shoulder instability.

Baseline preoperative data and questionnaires, along with preoperative and post operative forms completed by treating surgeons, were recorded utilizing a REDCap database (REDCap, Nashville, TN). Data obtained from participants included cigarette smoking history, demographic information, previous treatments and longevity/frequency of symptoms. Patient Reported Outcomes Measures (PROMs) administered to participants included the American Shoulder and Elbow Surgeons Standardized Shoulder Assessment (ASES), Western Ontario Shoulder Instability Index (WOSI), SF-36 Physical Component Score (SF36-PCS) and Mental Component Score (SF36-MCS) derived from RAND 36 and the Shoulder Activity Level. Imaging, including both radiographic and advanced, were reviewed at the time of enrollment and intraoperative findings were recorded. This included estimates of glenoid and humeral head bone loss based on surgeon calculations and/or estimates. Glenoid bone loss was categorized as present or absent as well as graded as 0-10%, 11-20%, 21-30% and greater than 30%. Surgical treatment options were left to surgeon discretion, and the treatments provided were recorded.

The 2017 Distressed Community Index (DCI) was utilized to assess for any potential differences in socioeconomic status.[13] (Economic Innovation Group. The Distressed Communities Index. 2017, eig.org/dci. Accessed September 19, 2019). The DCI is a composite score that takes into account the percentage of adults 25 or older without a high school education, percentage of adults living below poverty line, percentage of adults who are unemployed, median household income as a percentage of state's median household income, change in number of jobs, change in number of businesses and percentage of habitable housing that is unoccupied within five-digit zip codes. This score is then normalized to create a DCI score 0-100 with higher numbers revealing higher economic distress. For the present study, the zip code of the home address or primary home address was utilized for all participants or those attending college, respectively. There were 27 non-smokers and 1 smoker without a zip code that allowed for determination of DCI score. Those participants were excluded from analyses that involved DCI score but included in all other analyses.

Statistical Methods

We determined the frequency (percentage) of smokers among MOON participants undergoing shoulder stabilization surgery for anterior instability. Potential differences between smokers and non-smokers were evaluated in the following way. Participants were grouped according to smoking status, and demographic, shoulder injury, and shoulder stabilization surgery characteristics were described by group. Because age, DCI score, and PROM scores were not normally distributed, results were reported as median [inter-quartile range]. Between-group differences were evaluated using the Wilcoxon Rank Sum Tests. Frequencies (percentages) were used to describe categorical variables, and differences between smokers and non-smokers were evaluated with chi-square or exact tests, as appropriate. To determine whether socioeconomic status (DCI score) influenced the relationship between smoking status and odds of Latarjet surgery, logistic regression with adjustment for DCI score, history of dislocations prior to surgery (≥2 vs <2), and, based on prior work from Hettrich CM, et al.,[13] race (white vs minority) was performed. Analyses were completed using SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Demographics

A total of 1267 participants with anterior shoulder stabilization were included in analyses. This involved 1036 primary operations and 231 revision surgeries. There were a small percentage of smokers, which made up only 4.8% (n=61) of the cohort, and 95.2% (n=1206) non-smokers. Tobacco use in the smoking population averaged seven years with 0.5 packs per day. As shown in Table 1, Smokers versus nonsmokers were slightly older (median [IQR]: 26[23-33] vs 22[18-30], p<0.001) and more frequently overweight (60.7% vs 45.5%, p=0.021). However, there were no significant differences in the proportion of female participants among smokers and non-smokers (21.3% vs 20.7%, p=0.901). Our results showed a higher average DCI for smokers versus nonsmokers (39.6[20.3-68.2] vs 25.8[10.1-48.8], p<0.001), indicating smokers had worse economic well-being. Smoking was also associated with race when patients were categorized as white or minority with minorities more likely to smoke (p=0.004). A previous study from this cohort also found small differences in smoking prevalence between different races ranging from 2.9% of white patients to 9.1% of African American patients.[5]

Table 1. Demographics

	Non-smoker (n=1206)		Smoker (n=61)		p-value
	Median	IQR	Median	IQR	
Age (years)	22	18-30	26	23-33	<0.001
Sex (% female)	20.7%		21.3%		0.901
Overweight (% yes)	45.5%		60.7%		0.021
DCI Score	25.8	10.1-48.8	39.6	20.3-68.2	<0.001

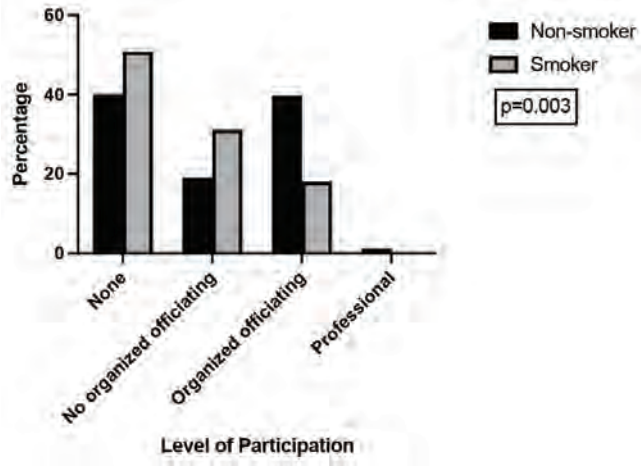

Figure 1. Contact Sport Participation.

PROMs

A greater proportion of non-smokers versus smokers participated in higher level contact sports (p=0.003) and throwing sports (p=0.013) than smokers in our study (Figures 1 & 2). However, Shoulder Activity Levels did not significantly differ between non-smokers (13[10-16]) and smokers (12[10-16], p=0.220, Table 2).

As shown in Table 2, the remaining PROM scores were significantly worse among smokers (SF36-PCS: 42.5 [38.4-48.3], SF36-MCS: 45.1 [35.4-53.4]) versus non-smokers (SF36-PCS 47.7 [41.5-54], SF36-MCS: 52.8 [44.9-57.9], all p<0.001). In particular, shoulder-specific scores were significantly lower among smokers (ASES: 54.2 [42.5-71.7], WOSI: 29.8 [19.9-41.0]) than non-smokers (ASES: 70 [53.3-83.3], 40.4 [28.0-53.6], all p<0.001).

Among participants who underwent Latarjet procedures, between group differences in PROM scores were reduced, with smokers having only significantly lower median ASES (60[39.2-69.2] vs 68.3[51.7-83.3], p=0.049) and PCS scores (44[35-48.4] vs 47.6[41.8-53.4], p=0.031) compared to non-smokers. However, no significant between-group differences in other PROMs were detected (all p>0.05, Table 3).

Table 2. Patient Report Outcomes – Full Shoulder Instability Cohort

PROM	Non-smoker (n=1206)		Smoker (n=61)		p-value
	Median	IQR	Median	IQR	
ASES	70	53.3-83.3	54.2	42.5-71.7	<0.0001
WOSI	40.4	28-53.6	29.8	19.9-41	<0.0001
SF36-PCS	47.7	41.5-54	42.5	38.4-48.3	<0.0001
SF36-MCS	52.8	44.9-57.9	45.1	35.4-53.4	0.0001
Shoulder Activity Score	13	10-16	12	10-16	0.2202

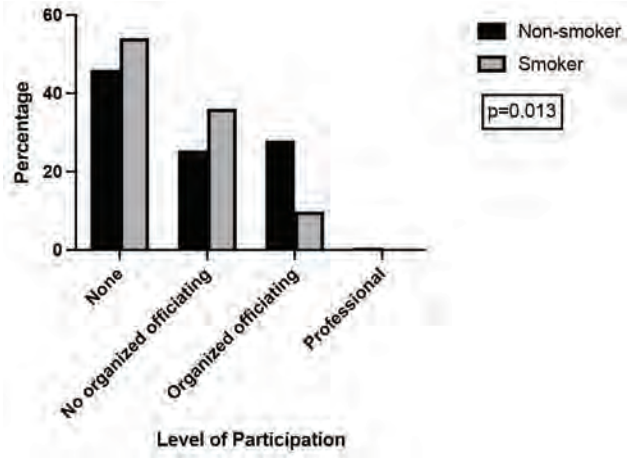

Figure 2. Throwing Sport Participation.

Table 3. Patient Reported Outcomes – Latarjet Cohort

PROM	Non-smoker (n=183)		Smoker (n=17)		p-value
	Median	IQR	Median	IQR	
ASES	68.3	51.7-83.3	60	39.2-69.2	0.0487
WOSI	35.7	24.8-47.6	31.7	17.2-40.1	0.3127
PCS	47.6	41.8-53.4	44	35-48.4	0.0305
MCS	50.8	42.8-57.1	50.3	39.9-55	0.6934
Shoulder Activity Score	13	9-16	12	10-16	0.8635

Table 4. Degree of Glenoid Bone Loss in Non-Smokers vs Smokers

Glenoid Bone Loss	Non-Smokers N(%)	Smokers N(%)
None	847 (71.06%)	36 (62.07%)
<10%	149 (12.50%)	4 (6.90%)
11-20%	130 (10.91%)	12 (20.69%)
21-30%	61 (5.12%)	5 (8.62%)
>30%	5 (0.42%)	1 (1.72%)

Table 5. Relationship Between Latarjet Procedure, Smoking Status, Race, History of 2 or More Dislocations, and Socioeconomic Well-Being

Effect	OR	95% CL		p-value
Smoke: Yes v No	1.89	1.02	3.51	0.0447
Minority: Yes v No	0.95	0.62	1.46	0.8126
Dislocation ≥2 times: Yes v No	4.88	3.13	7.62	<0.0001
DCI	0.98	0.86	1.11	0.7546

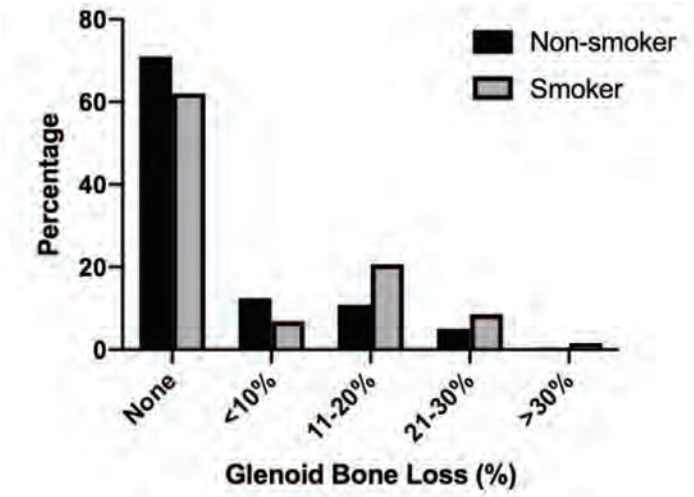

Figure 3. Comparison of Glenoid Bone Loss.

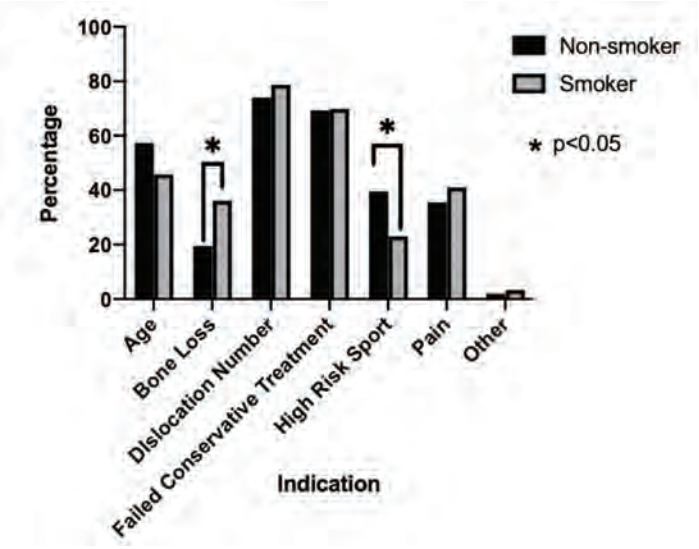

Figure 4. Indications for Surgery.

Injury/Surgery Characteristics

While there was a non-significantly higher proportion of participants with injuries of greater than three month duration among smokers (85.3%) compared to non-smokers (74.5%, p=0.0595), smokers more often had greater than five dislocations prior to surgical intervention compared to non-smokers (36.1% vs 24.6%, p=0.045).

Revision surgeries were not more common among smokers than non-smokers (19.7% vs 18.2%, p=0.765). A greater proportion of smokers (41%) had glenoid bone loss compared to non-smokers (29.8%), though this did not achieve statistical significance (p=0.063). Larger percentages of glenoid bone loss were more common among smokers vs non-smokers (p=0.041, trend=0.017, Table 4, Figure 3). Though, smokers and non-smokers did not differ in the proportion with ≥ 20% bone loss (9.8% vs 5.5%, p=0.153). Despite this, bone loss was a more frequent indication for surgery in smokers (36.1% vs 19.5%, p=0.002) who were also more likely to be indicated for bony glenoid augmentation surgery versus non-smokers (Figure 4).

It was found that significantly more smokers (27.9%) underwent Latarjet or other glenoid augmentation surgery versus non-smokers (15.2%, p=0.008). The odds ratio for glenoid augmentation surgery for smokers vs non-smokers was 2.16 (95% CI=1.21-3.86), p=0.009. Analyses repeated with adjustment for DCI score resulted in similar findings (OR=2.06 (95%CI=1.13-3.75), p=0.018).

Among the 1267 surgeries there were 1036 primary surgeries and 231 revision surgeries. Within the 1036 primary surgeries there were 49 smokers (4.7%). Within the 231 revision surgeries there were 12 smokers (5.2%). There were 207 glenoid bony augmentation surgeries within the cohort, 200 of which were Latarjet procedures, while 7 were distal tibial allografts. Among the 200 Latarjet glenoid augmentation surgeries 119 were revision surgeries and 81 primary surgeries. Of the 81 primary glenoid augmentation surgeries there 10 smokers (12.4%). Among the 119 glenoid augmentation surgeries that were revision surgeries there were 7 smokers (5.9%). Results of logistic regression analyses adjusted for DCI score, history of ≥ 2 dislocations prior to surgery, and race showed greater odds of a Laterjet procedure among smokers vs non-smokers (OR=1.89(95%CI=1.02-3.51), p=0.045, Table 5).

DISCUSSION

Smokers made up 4.8% of this cohort and were more likely to have prolonged symptoms and multiple dislocations prior to shoulder stabilization surgery. Smokers were older, more likely to be overweight and worse off than nonsmokers. They were less likely to participate in high level throwing or overhead sports and had worse baseline shoulder scores than nonsmokers. Finally, they were more likely to be indicated for surgery due to bone loss and more likely to undergo bone augmentation procedures.

The prevalence of smoking in the shoulder instability population has not been well analyzed to date. Tobacco use has been shown to have numerous negative effects on the musculoskeletal system.[9-10,14-16] Specifically with regards to shoulder surgery, numerous studies evaluated outcomes. In the setting of rotator cuff repairs, there are differences within findings of various studies. Lambers Heerspink et al.,[17] found insufficient evidence that smoking impacts functional outcomes after cuff repair whereas Mallon et al.,[15] Naimark et al.,[16] and others found decreased improvement regarding outcomes after surgery. Meta-Analysis by Santiago-Torres et al.,[10] suggests that overall; outcomes following arthroscopic procedures about the shoulder were negatively impacted by tobacco use. With regards to arthroscopic labral repair specifically, there has been limiting and conflicting data. Our finding that the rate of revision surgery was similar between smokers and non-smokers was consistent with Provencher et al.[18] but different from Park et al.,[19] who reported that smokers had a higher rate of revision surgery.

As smoking has a higher prevalence in populations of socioeconomic stress,[20] we sought to distinguish the effects of smoking versus economic status on this cohort. Although smoking status and DCI are correlated, the association between smoking status and undergoing bony augmentation surgery was consistent across DCI quintiles. Furthermore, elevated DCI did not correlate with increased bone loss. And, while smoking was associated with race and DCI, in our modeling race and DCI were not significantly associated with undergoing a Latarjet procedure, while smoking status and increased number of dislocations were statistically significant predictors. These findings suggest that smoking and economic status, despite their known association, have distinct implications in this patient population.

We found that smokers are more likely to undergo glenoid bone augmentation procedures with an odds ratio of 2.16 (p=0.0094). While there was no statistical difference in bone loss between smokers and nonsmokers, this finding could be related to the size of the study, specifically the limited number of patients in the smoking group (n=61). Bone loss was noted in 29.8% of nonsmokers versus 41% of smokers and while statistically insignificant, there does appear to be a trend (p=0.0629). Such a trend would be supported by a previous study by Milano et al.,[21] suggesting that increased occurrences of dislocation is associated with bone loss. Additionally, smoking has been demonstrated to be associated with higher fracture risk as well as decreased bone mineral density.[14] These factors suggest that smoking patients could be at greater risk of having glenoid loss with anterior instability. Given the increased rate of bony glenoid augmentation procedures in smokers, future studies should evaluate how smoking affects the outcomes of these surgeries. Short term data has shown that increased rate of complications in smokers who undergo Latarjet based on analysis of the NSQIP database.[7] This study found that smokers were more likely to have a post-operative deep vein thrombosis, undergo reoperation and to have an unplanned readmission compared to non-smokers.

It was found that smokers had a higher number of dislocations prior to surgery. With this in mind, treating surgeons may have pursued the procedure most powerful to reduce recurrence risk. Such surgical decision making would be supported in literature as Vaswani et al. had noted that a higher number of presurgical dislocations was an independent risk factor for recurrent instability after arthroscopic labral repair.[22] Higher preoperative

instability may have contributed to surgeon preference for Latarjet. Additionally, lower preoperative PROs have been noted to be associated with more substantial soft tissue injury[12] and perhaps that played a role in selecting bone augmentation. Surgeons may have been inclined to offer arthroscopic labral repair in athletes given the findings by Blonna et al., finding a higher return to sport for labral repair than Latarjet.[23]

A strength of this study is the multicenter design and a large cohort of patients. There are likely differing indications amongst surgeons as to when they would opt for glenoid augmentation procedures versus soft tissue repair, especially in the 15-20% glenoid bone loss range, which can be considered borderline.[5] Other patient specific factors such as overall laxity, patient activity level and goals as well as preoperative shoulder scores certainly would play a role in the decision making by surgeons in this borderline area of bone loss. Being multicenter, our data included multiple surgeon and regional preferences and ideally would demonstrate a more generalizable reflection of what procedures are performed within the United States. As a result, we find it interesting that smoking is indeed associated with a higher rate of Latarjet procedures.

There are several limitations of this study. Decisions for which type of stabilization surgery was performed was left to surgeon discretion. This study does not include any postoperative outcomes and therefore the effect of smoking on surgical results cannot be analyzed. Measurement of glenoid bone loss was categorized based on surgeon measurements at the time of indication and there may be inter-observer variability between estimates of glenoid bone loss.

In summary, this study has described the incidence of smoking in a large cohort of shoulder instability patients. Our analysis demonstrates that smoking was, in conjunction with higher number of dislocation events, statistically associated with undergoing a Latarjet type procedure. Future research is necessary to determine the implications of smoking on outcomes of surgery.

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A SYSTEMATIC REVIEW OF LEARNING CURVES IN ORTHOPAEDIC SPORTS SURGERY

Christopher Shultz, MD[1]; Nicole Levine, MD[2]; William Curtis, MD[1]; Robert A. Christian, MD, MBA[3]; Stephanie Hendren, MLIS[2]; Brian C. Lau, MD[2]

ABSTRACT

Background: As surgeons enter practice or senior surgeons embark on new procedures, we must weigh the potential risks to our patients. Despite the concept of a "learning curve" gaining traction, there is limited guidance on the specific learning curves within orthopaedic sports medicine. The purpose of this article is to explore the ways in which learning curves are defined within orthopaedic sports medicine and report the number of cases required to overcome them.

Methods: Pubmed-MEDLINE, Scopus, and Embase databases were queried for "Learning Curves" pertaining to orthopaedic sports medicine procedures according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis guidelines. Abstracts were reviewed by two independent reviewers for inclusion and subdivided into categories including: Shoulder Arthroscopy and Reconstruction, Shoulder Arthroplasty, Hip Arthroscopy, Knee Arthroscopy and Reconstruction, and Knee Osteotomy.

Results: 4,558 articles were reviewed. 14 articles for shoulder arthroscopy and reconstructive procedures, 10 articles for shoulder arthroplasty, 17 articles for hip arthroscopy, 7 articles for knee arthroscopy and reconstructive procedures, and 2 articles for knee osteotomy were ultimately included. The net defined learning curve for each respective surgical sub-category was 22 for shoulder arthroscopy and reconstruction, 28 for shoulder arthroplasty, 71 for hip arthroscopy, 28 for knee arthroscopy and reconstruction, and 32 for knee osteotomy.

Conclusion: Surgeons should consider the synthesis of the described learning curves for shoulder, hip, and knee surgery when incorporating these procedures into their practice.

Level of Evidence: II

Keywords: learning curves, surgical education, medical education, residency, orthopedic surgery, orthopedic residency, surgical training

INTRODUCTION

Every patient encounter is a data point on a surgeon's learning curve. As young surgeons enter practice, or as senior surgeons learn new procedures, we are tasked with making an ethical and pragmatic assessment of our own abilities and weighing the potential risks to our patients. The concept of a "learning curve" was first described by the German psychologist Hermann Ebbinghaus.[1] He described his first attempts at memorization and successful recital on a learning curve, whereby new information resulted in the largest improvement but waned as repetitions continued. Ebbinghaus published his findings in 1885, but since we have come to declare the concept of "steep" learning curves negatively and thus fallaciously.

When considering the morphology of a learning curve, whereby the x-axis represents number of procedures and y-axis represents a favorable surgical outcome, we have come to believe the "steep" learning curve as disparaging. However, a steep learning curve signifies more improvement in fewer number of cases (Figure 1). In this manner surgeons may find themselves frustrated with a "flat" learning curve, in that satisfactory proficiency still has not been achieved even after numerous cases.

Fortunately, learning curves with respect to surgical procedures is not novel to orthopaedic literature.[2-5] However, to date there has been no synthesis and little ethical discussion in the orthopaedic literature as to the number of procedures to overcome a learning curve, maintain the position on that curve, and the patient risk implications of embarking in new procedures. The aim of this article is to review the current knowledge and assessment tools of orthopaedic sports medicine learning curves by surgical procedure, and discuss the implications for education, training, and patient safety.

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METHODS

A literature search of the PubMed-MEDLINE, Scopus, and Embase electronic databases was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines to identify articles pertaining to learning curves in orthopaedic surgical procedures.[6] The databases were searched from inception to August of 2020 to include "learning curve(s)" coupled with a multitude of "orthopaedic procedures" (see appendix).

Two reviewers (C.S, N.L.) reviewed articles and abstracts independently and sorted studies into categories based on general procedural description. Further relevant articles were included upon review of references of selected articles. Studies were selected for inclusion based on 1) report of a prospective or retrospective cohort of patients treated with either shoulder arthroscopy, shoulder arthroplasty, hip arthroscopy, knee osteotomy, or knee arthroscopy and 2) report of a surgical time metric, complications, patient reported outcomes, estimated blood loss, quality of implant placement, or need for revision surgery relative to a quantified number of cases. Studies were excluded if they 1) failed to report data relative to surgeon experience in case volume; 2) if they were written in a language other than English; 3) if they were review articles, technique articles, editorial articles, or case reports; 4) if they reported data on surgical procedures pertaining to cadaveric or simulator models. Disagreement regarding article inclusion was discussed amongst the authors and a consensus was made (Figure 2).

The following data were extracted from the selected studies: level of evidence (LOE), operative time, study design, number of surgeons, number of cases, minimum follow up time, procedure, proposed learning curve by the authors, and number of cases to overcome a learning curve for a given outcome. Outcomes included operative time, implant placement, complications, revision surgery, patient reported outcomes, and quantitative assessment of motor skills.

Quality of evidence of the included studies were quantitatively assessed by three authors (C.S., N.L., R.C.) using the Methodological Index for Non-Randomized Studies (MINORS) criteria.[7] If the LOE was not explicitly stated in the study, it was determined using the criteria described by Spindler et al.[8] As a systematic review, Institutional Review Board (IRB) approval was not required.

Data Analysis

Multiple learning curve data points were extracted when possible. If a study made a conclusion on a singular number of cases reflective of overcoming a learning curve, this was noted in Tables 1-6. For studies that reported on multiple case volumes required to overcome a learning curve, multiple data points were reflected in figures 4-8. When a learning curve was identified between a series of consecutive groups, for example first group of 50 to second group of 50, then the learning curve was presumed to exist in a range within the first group and was reflected as such in figures 4-8. To calculate an average case number to overcome a learning curve for a given outcome, the median of each range was averaged with each outcome and presented in table 6. To calculate a total combined average learning curve, each outcome point was averaged together. When data was presented as a range, the median of the range was used to calculate the average.

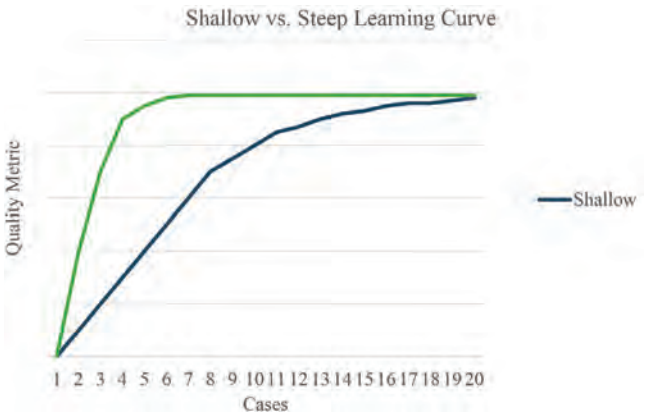

Figure 1. Graphical depiction of a "steep" versus a "shallow" learning curve. A steep learning curve is associated with fewer cases to achieving a steady state of quality, which is preferable to a shallow curve.

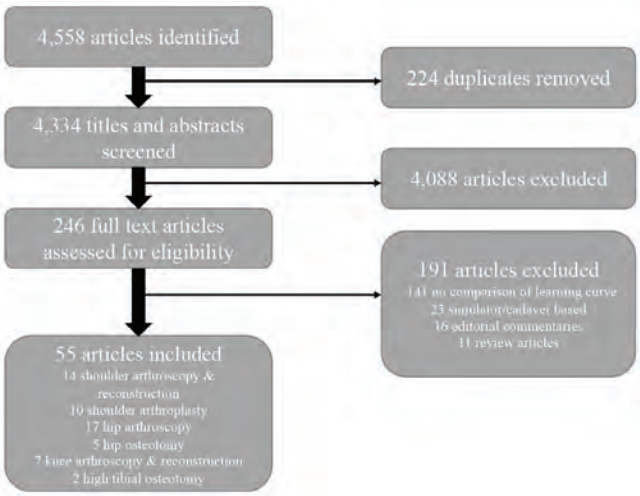

Figure 2. Flowchart of PRIMSA methodology for manuscript review and inclusion.

Table 1. Shoulder Arthroscopy and Reconstruction Study Characteristics

Author	Year	LOE	MINORS	Study Design	Methodology	No. of Surgeons	No. of Cases Followed	Minimum Follow up	Procedure	Proposed Learning Curve
Bonnevialle et al.	2018	II	16	Prospective	Group split, Empirical	4	88	6 mo.	Arthroscopic Latarjet	30
Castricini et al.	2013	II	15	Prospective	Group split	1	30	6 mo.	Arthroscopic Latarjet	20
Castropil et al.	2020	III	15	Retrospective	Empirical	1	30	6 mo.	Arthroscopic Latarjet	20
Cunningham et al.	2015	II	24	Prospective	Group split	1	28	1.5 mo.	Arthroscopic Latarjet	20
Dauzere et al.	2016	IV	15	Retrospective	Time function	1	68	3 mo.	Open Latarjet	Time[A]
Guttmann et al.	2005	IV	14	Prospective	Group split	1	100	Not Reported	Arthroscopic Rotator Cuff Repair	10
Kany et al.	2016	II	16	Prospective	Group split	1	95	Not Reported	Arthroscopic Latarjet	75
Kordasiewicz et al.	2019	III	16	Retrospective	Group split, CUSUM	1	90	13 mo.	Arthroscopic Latarjet	30
Leuzinger et al.	2019	III	15	Retrospective	Group split	5	125	Not Reported	Arthroscopic Latarjet	20
Moga et al.	2018	III	21	Retrospective	Group split	1	27 27	Not Reported	Arthroscopic Latarjet	No Curve
Resch et al.	1997	II	15	Prospective	Empirical	1	100	18 mo.	Arthroscopic Bankart Repair	30
Valsalmis et al.	2020	V	16	Retrospective	Linear Regression (segmental)	12	573	Not Reported	Arthroscopic Latarjet	30-50
Yamakodo et al.	2015	II	16	Prospective	Group split, Correlation coefficient, learning rate	1	300	Not Reported	Arthroscopic Suprascapular Nerve Decompression	50
Yamakodo et al.	2017	IV	16	Prospective	Correlation coefficient, learning rate	1	30	24 mo.	Arthroscopic Latissimus Dorsi Transfer	Not Defined[B]

[A]Surgical time and complications correlated with surgeon experience over 5 years, but not defined by number of cases.
[B]Learning rate of 84% was found after linear correlation, rather than defining a discrete point in case volume.

Table 2. Shoulder Arthroplasty Study Characteristics

Author	Year	LOE	MINORS	Study Design	Methodology	No. of Surgeons	No. of Cases Followed	Minimum Follow up	Procedure	Proposed Learning Curve
Beazley et al.	2018	III	17	Retrospective	CUSUM	1	100 100	12 mo. 12 mo.	TSA RTSA	16 No Curve
Choi et al.	2019	IV	16	Retrospective	Empirical	1	38	12 mo.	RSA	15-20
Groh et al.	2014	IV	10	Retrospective	Group split	1	114	12 mo.	RSA	No Curve
Hasan et al.	2014	IV	15	Retrospective	Empirical	1	60	24 mo.	RSA	15
Kempton et al.	2011	IV	17	Prospective	Empirical	1	192	6 mo.	RSA	40
Levy et al.	2011	IV	10	Retrospective	Group split	1	40	18 mo.	RSA	No Curve
Riedel et al.	2010	IV	12	Retrospective	Slope plateau, Group split	1	62	NR	RSA	18
Walch et al.	2012	III	17	Retrospective	Group split	2	480	24 mo.	RSA	240
Wang et al.	2020	III	17	Prospective	Slope plateau	1	48	NR	RSA	8
Wierks et al.	2009	II	14	Retrospective	Group split	1	24	3 mo.	RSA	7

Table 3. Hip Arthroscopy Study Characteristics

Author	Year	LOE	MINORS	Study Design	Methodology	No. of Surgeons	No. of Cases Followed	Minimum Follow up	Procedure	Proposed Learning Curve
Boden et al.	2014	II	12	Prospective	Group split	1	120	12 mo.	FAI	40-80
Byrd et al.	2018	IV	10	Retrospective	Time function	1	434	Not Reported	Labral Repair	No Curve
Contreras et al.	2010	IV	9	Retrospective	Group split	1	150	Not Reported	Not Specified	No Curve
Dietrich et al.	2014	III	12	Retrospective	Group split	2	317	Not Reported	FAI	85-170
Dumont et al.	2019	IV	12	Retrospective	Group split	1	225	Not Reported	FAI & Labral Repair	75
Flores et al.	2018	II	16	Prospective	Group split	1	60	Not Reported	FAI	30
Kautzner et al.	2018	IV	14	Prospective	Group split	1	150	24 mo.	FAI	100
Kern et al.	2018	IV	13	Prospective	Group split	1	100	Not Reported	Not Specified	50
Konan et al.	2011	IV	14	Retrospective	Group split	1	100	24 mo.	FAI	30
Lee et al.	2013	IV	12	Retrospective	CUSUM	1	40	6 mo.	Not Specified	20
Mehta et al.	2018	III	14	Retrospective	Group split	251	8041	Not Reported	Not Specified	519
Nossa et al.	2014	IV	12	Prospective	Empirical, Group split	4	362	6 mo.	FAI	50
Park et.al.	2014	IV	11	Retrospective	Group split	1	243	19 mo.	FAI	Not Defined
Domb et al.	2020	III	16	Retrospective	Group split	1	400	24 mo.	Not Specified	200
Schuttler et al.	2018	IV	11	Retrospective	Empirical	3	529	6 weeks	Not Specified	60
Smith et al.	2017	IV	13	Retrospective	Group split	1	100	Not Specified	FAI & Labral Repair	25
Souza et al.	2010	IV	12	Retrospective	Group split, time function	1	194	4 mo.	Not Specified	No Curve

Table 4. Knee Arthroscopy and Reconstructive Procedures Study Characteristics

Author	Year	LOE	MINORS	Study Design	Methodology	No. of Surgeons	No. of Cases Followed	Minimum Follow up	Procedure	Proposed Learning Curve
Hiemstra et al.	2017	IV	12	Retrospective	Group split	1	73	Not Reported	MPFL Reconstruction	19
Hohmann et al.	2010	IV	11	Retrospective	Group split	1 1	200 200	6 weeks 6 weeks	ACL Femoral Tunnel ACL Tibial Tunnel	100 100
Hodgins et al.	2014	IV	13	Retrospective	CUSUM	20*	340	Not Reported	Diagnostic Arthroscopy	14-16
Luthringer et al.	2016	IV	11	Retrospective	Group split	1 1	161 161	Not Reported Not Reported	ACL Femoral Tunnel ACL Tibial Tunnel	32-64 No Curve
Masferrer-Pino et al.	2018	II	24	Prospective	Empirical	1	29	12 mo.	Lateral Meniscal Allograft Transplant	4
Sirleo et al.	2017	IV	15	Prospective	Group split	1	60	Not Reported	ACL Femoral Tunnel	50
Snow et al.	2010	IV	12	Retrospective	Empirical	1	10	Not Reported	Double Bundle ACL Reconstruction	>10

*Orthopedic trainee competency measured by task specific checklist and global rating scale.

Table 5. Knee Osteotomy Study Characteristics

Author	Year	LOE	MINORS	Study Design	Methodology	No. of Surgeons	No. of Cases Followed	Minimum Follow up	Procedure	Proposed Learning Curve
Jaquet et al.	2020	II	16	Prospective	CUSUM	3	71	1 year	HTO	10
Lee et al.	2018	IV	16	Retrospective	CUSUM, Group split	1	100	Not Reported	HTO	27, 47, 42*

*27, 47, and 42 cases required for competency in preventing coronal under-correction, excessive posterior slope correction, and rate of lateral hinge fracture, respectively.

Table 6. Mean Learning Curve by Surgical Domain

Procedure	Mean Case Learning Curve (+/- SD)	
Shoulder Arthroscopy and Reconstruction	Total	22 (14)
	Operative time	18 (12)
	Complication rate	20 (16)
	Implant Placement	43 (25)
Shoulder Arthroplasty	Total	28 (34)
	Operative time	14 (5)
	Complication rate	36 (43)
	Implant placement	18
Hip Arthroscopy	Total	71 (57)
	Operative time	45 (34)
	Complication rate	71 (42)
	Revision surgery	112 (102)
	PROMS	78 (20)
Hip Osteotomy	Total	19 (18)
	Operative time	13 (6)
	Complication rate	22 (7)
	Revision surgery	25
Knee Arthroscopy and Reconstruction	Total	28 (32)
	Operative time	10
	PROMS	4
	Implant placement	41 (36)
	Motor skill	15
Knee Osteotomy	Total	32 (17)
	Operative time	10
	Implant Placement	39

Parenthesis represent standard deviation.

RESULTS

The query resulted in 4,558 abstracts and titles to review. After screening of titles and abstracts, 246 articles were assessed for eligibility. Ultimately 55 articles met inclusion criteria and were subdivided into practical anatomic and procedural categories.

Quantification of Learning Curves

The quantification and definition of a learning curve varied in the literature. The various methodologies for defining a learning curve can be subdivided into the following (figure 3):

1. Group Splitting: Method authors chose to split a series of patients into multiple arbitrary groups (figure 3A). Groups could be split into two, three, or four. Cases were often reported consecutively. However, some studies chose to report and analyze cases non-consecutively by first 200 to last 200, with up to 2000 cases in between. For studies that utilized a group splitting method, the learning curve was therefore surmised to exist in a range between the early and late group and was reported as such.

2. Cumulative Sum Analysis (CUSUM): for a given case number on the x-axis the outcome on the y-axis is reported as a difference from the mean of the prior case outcomes up to that point (figure 3B). A change in the slope or "inflection point" reflects the case at which further improvement diminishes. When a CUSUM curve has multiple inflection points the outcome associated with that procedure is considered to not have a definable learning curve.

3. Slope Plateau: Slope plateau method employs identifying a point along the learning curve at which the slope begins to flatten (Figure 3C). This can be done empirically or utilizing linear regression.

4. Linear regression and correlation coefficient: An extension of slope plateau method, linear regression can be utilized on both the flat aspect of the learning curve as well as the "learning phase" of the curve (Figure 3D). Additional regression lines can be used to quantify multiple phases of learning, called "Segmented Linear Regression". When linear regression is applied to the learning phase(s) of the curve a correlation coefficient can also be calculated. This coefficient can be used to express a strength of relationship of a learning curve to a given outcome. Linear regression is often considered the most precise in determining a learning curve.

5. Learning rate: Expressed as a percentage describes the expected outcome of the next subsequent cases after cumulative doubling of the previous cases. In Yamakodo's report of the learning rate associated with arthroscopic latissimus dorsi transfer, he reported a learning rate of 84%.[9] Thus, if a surgeon were to apply that rate to their first 10 cases averaging 100 minutes per case, the next 10 would expect to take 84 minutes. A learning rate that approaches 100% is associated with substantial difficulty and time in improving.

6. Empirical analysis: Picking a point along the curve or data set at which an outcome seems to improve. For example, a surgeon may observe that 3 complications occurred within the first 10 cases but thereafter only 1 occurred in the subsequent 50. They would then conclude that the learning curve is 10 cases.

7. Time function: Learning curves are typically reported as a function of case volume on the x-axis, they can also be reported as a function of time span over a surgeons career.

Shoulder Arthroscopy and Reconstruction

Fourteen papers were included in this review.[9-22] The majority of studies focused on the learning curve of the arthroscopic Latarjet procedure. The median MINORs criteria was 16 (range 15-24) (Table 1). The relative learning curves for a given outcome for shoulder arthroscopy and reconstructive procedures are summarized in figure 4.

Shoulder Arthroplasty

Ten total papers were included in the final review (Table 2).[23-32] Most studies were of level IV evidence. The median score of MINORs criteria was 15.5 (range 10-17). Most studies reported on the learning curve of a complication rate. The relative learning curves for a given outcome for shoulder arthroplasty are summarized in figure 5.

Hip Arthroscopy

Seventeen papers were included for final analysis.[33-49] The majority of studies were of level II evidence (Table 3). The median MINORs score was 12 (range 9-16). The indication for hip arthroscopy was most commonly for CAM impingement and labral repair, though many studies did not specify this. The most frequently reported learning curve outcome was time, followed by PROM and complication rate, and lastly need for revision surgery. These results are presented in figure 6. Four studies found no learning curve associated with hip arthroscopy, 3 of which were based on case volume, and one was based on function of time. Interestingly, all four of these studies included over 150 cases.

Knee Arthroscopy

Seven papers were included in this review (Table 4).[50-56] The median MINORs criteria was 12 (range 11-24). Overall, most of these studies focused on different aspects of ACL reconstruction (ACLR). The relative learning curves for a given outcome for arthroscopic knee procedures are summarized in figure 7.

High Tibial Osteotomy

Two papers reporting on medial opening wedge high tibial osteotomy were included in our analysis (Table 5).[34,57] The two included studies were of level II and IV evidence. The MINORs criteria score was 16. Both papers utilized a CUSUM method for analysis of the learning curve (Figure 8).

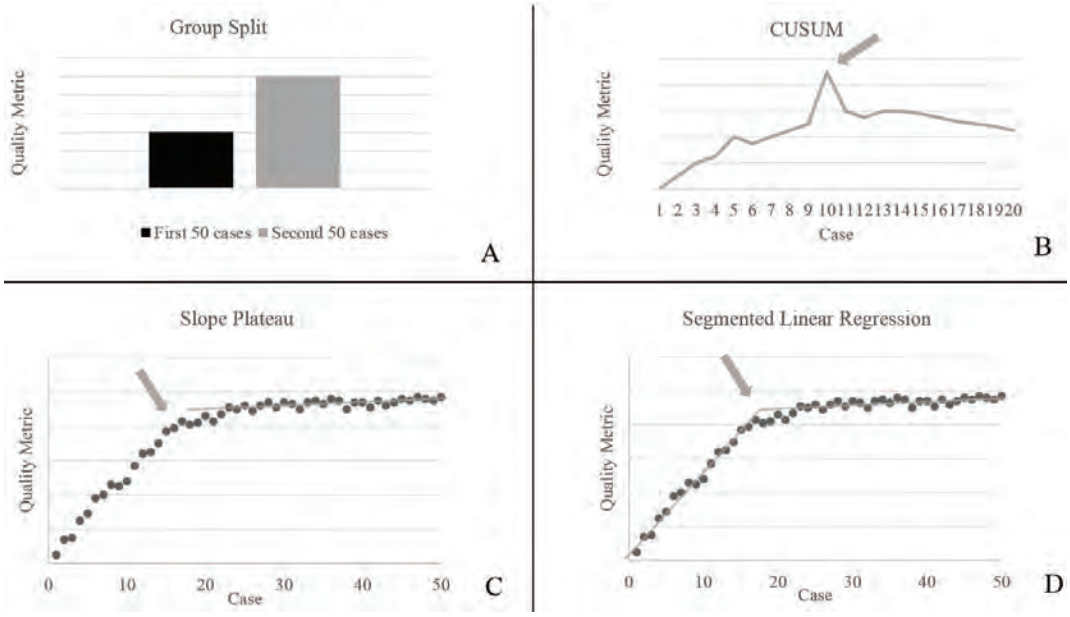

Figure 3A to 3D. Graphical depiction of multiple methodologies for measuring a learning curve. (1A) group split method, (1B) Cumulative Sum (CUSUM) analysis, (1C) Slope plateau, (1D) Segmented Linear Regression. Arrow denotes case at which a learning curve is overcome.

Figure 4. Number of cases described to overcome the learning curve with respect to various outcomes in shoulder arthroscopy and reconstructive procedures. A single point is reported when studies identified a point at which a learning curve plateaued. A range is reported when a study identified a learning curve between a series of consecutive groups. For example, if a difference was found between the first 30 and second 30 cases, the curve is surmised to fall in a range between 0 and 30 cases.

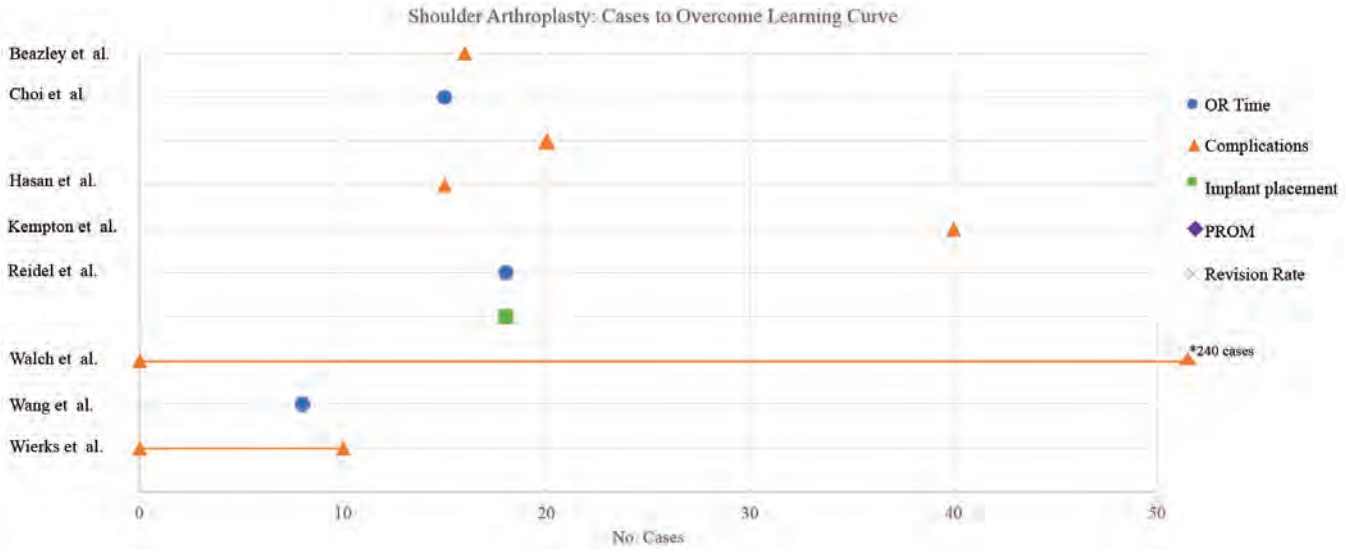

Figure 5. Number of cases described to overcome the learning curve with respect to various outcomes in shoulder arthroplasty. A single point is reported when studies identified a point at which a learning curve plateaued. A range is reported when a study identified a learning curve between a series of consecutive groups. For example, if a difference was found between the first 30 and second 30 cases, the curve is surmised to fall in a range between 0 and 30 cases.

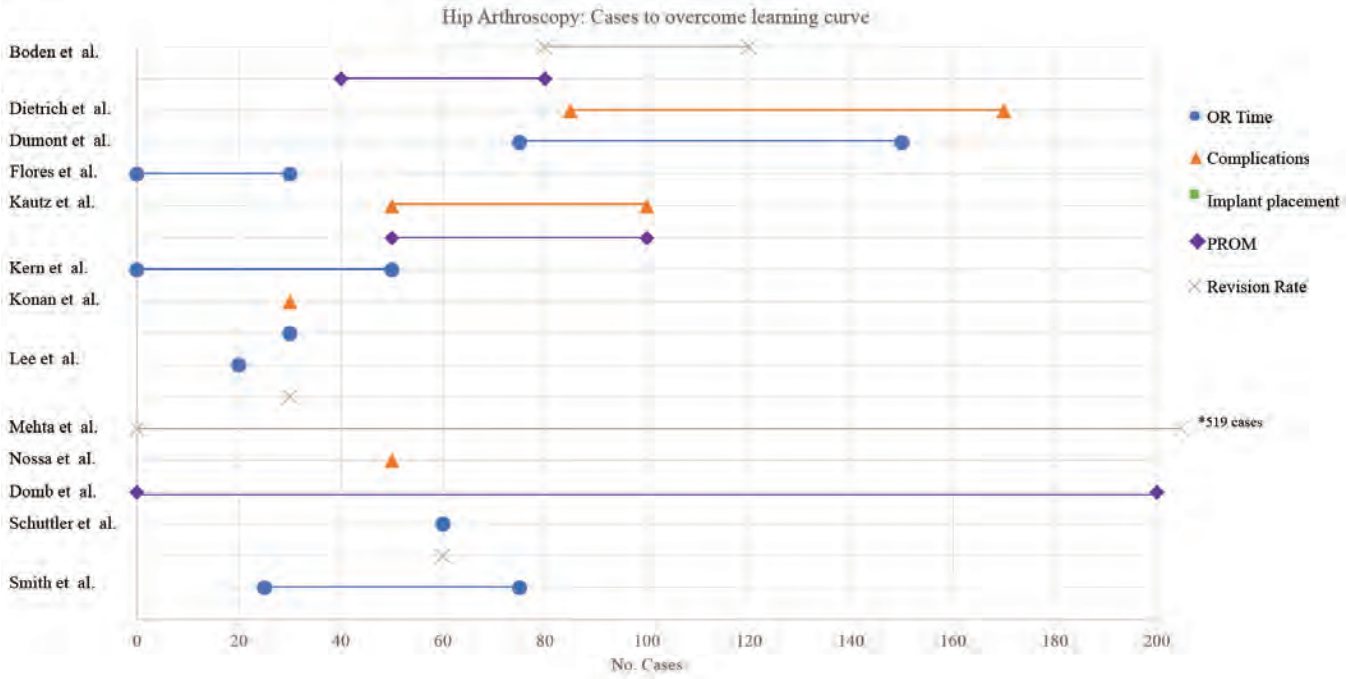

Figure 6. Number of cases described to overcome the learning curve with respect to various outcomes in hip arthroscopy. A single point is reported when studies identified a point at which a learning curve plateaued. A range is reported when a study identified a learning curve between a series of consecutive groups. For example, if a difference was found between the first 30 and second 30 cases, the curve is surmised to fall in a range between 0 and 30 cases.

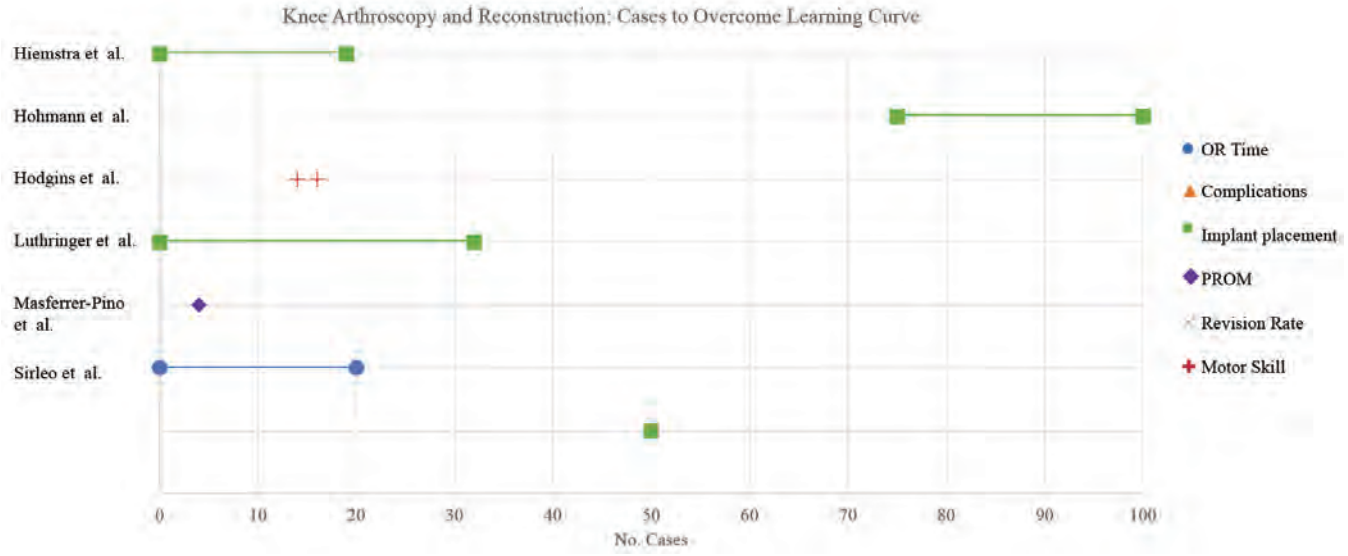

Figure 7. Number of cases described to overcome the learning curve with respect to various outcomes in knee arthroscopy and reconstructive procedures. A single point is reported when studies identified a point at which a learning curve plateaued. A range is reported when a study identified a learning curve between a series of consecutive groups. For example, if a difference was found between the first 30 and second 30 cases, the curve is surmised to fall in a range between 0 and 30 cases.

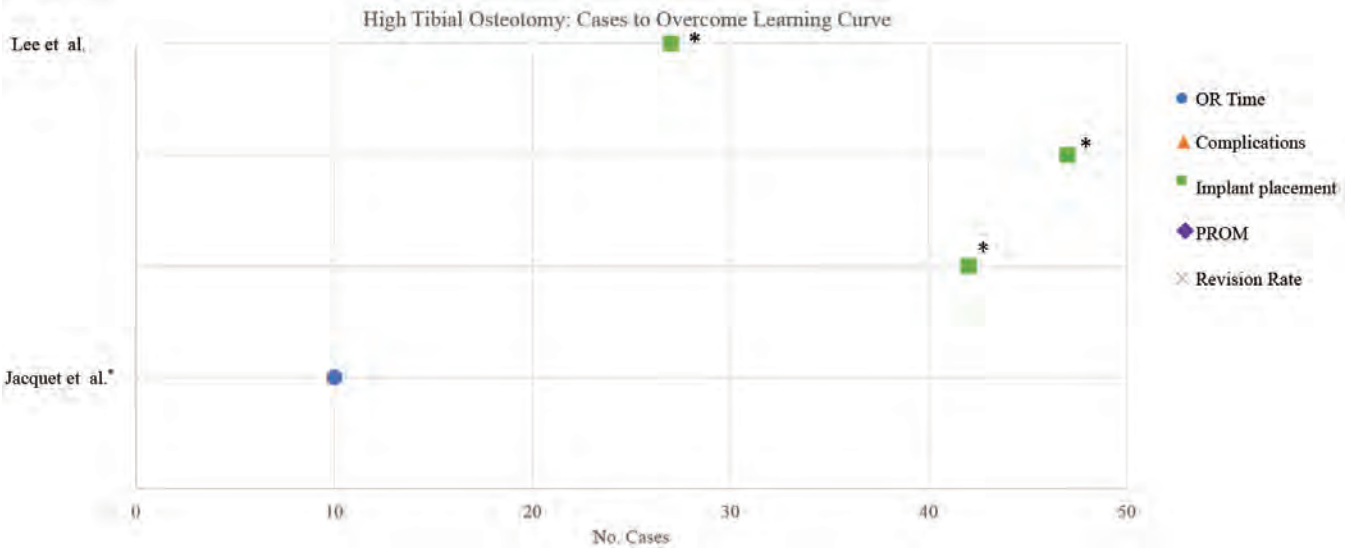

Figure 8. Number of cases described to overcome the learning curve with respect to various outcomes in osteotomies about the knee. A single point is reported when studies identified a point at which a learning curve plateaued. A range is reported when a study identified a learning curve between a series of consecutive groups. For example, if a difference was found between the first 30 and second 30 cases, the curve is surmised to fall in a range between 0 and 30 cases. *Denotes number of cases for overcoming learning curve for coronal correction (27), slope correction (47), and lateral hinge fracture (42).

DISCUSSION

The concept of learning curves have been well established,[4] described in various fields[2,3] and here to stay in medicine. The aim of this review was to provide a contemporary evaluation and summary of learning curve theory to common procedures within an orthopaedic sports surgeon's domain (Table 6).

The application of learning curve models to surgical procedures remains challenging due to several factors. In this review we identified seven different methodologies for quantifying a learning curve. The majority of the manuscripts measured learning curves as a function of case volume, though some authors chose to measure learning curve outcomes as a function of time.[18,49] Analysis by time function is thoughtful, though whether five cases over a five-week span is more conducive to learning over five cases all in one week remains unknown. The temporal relationship to motor skill acquisition has been studied in the past. In a review of adult learning of motor skill tasks, Doyon et al. identified multiple phases of motor learning.[58] These phases generally follow an order of fast learning, slow learning, a consolidation period, and finally an autonomic/retention phase, whereby a motor task can be performed with minimal cognitive resources. Phases of learning are crucial for both educators and learners to appreciate the time dependency of consolidation as well as the cognitive load associated with performing motor tasks that are not yet in the automotive phase.

Most studies included in our review measured learning curves by function of case volume. This method allows for more precise assessment of a learning curve without the convolution of case frequency in a given time period. Group splitting was the most common technique employed despite being nearly the most imprecise, second only to empirical assessment. Group splitting offers the advantage of being easily performed without an advanced statistical background but does not provide detailed characterization of a curve. In some cases, when studies used group splitting and CUSUM, significant differences were found using CUSUM analysis but not group split.[34] Analysis of a learning curve became particularly challenging when groups were split binarily over an extended case volume. For example, Walch et al. reported on their first 240 and second 240 reverse total shoulder arthroplasty cases.[31] One can surmise that some improvement occurs over the first 240 cases, but at what point along the first 240 was not reported. A minimum of 240 cases to approach a learning curve plateau seems inconsistent with the remaining shoulder arthroplasty literature. Despite the limitations of group splitting methodology, it can be a useful method for evaluating rare, non-continuous outcomes such as complications, whereby a continuous curve may be difficult to generate.

CUSUM, slope plateau, and linear regression analysis all offer precise quantification and characterization of a learning curve and are particularly useful for continuous variable outcomes such as surgical time and PROMs. CUSUM provides a graphical depiction of the difference of each data point from the mean to the prior. This dynamic representation of the learning curve allows for identification of an inflection point to define a case

number in the learning curve but is challenging when multiple inflection points exist. Slope plateau is more conceptually simple but falls short when a learning curve morphologically doesn't fit a clean curve. Linear regression can be helpful to establish a correlation between case volume and quality outcome if a defined learning curve does not exist. In a review of the learning curve associated with the arthroscopic Latarjet procedure, Valsamis et al. provided a more contemporary analysis of learning curves by adding multiple linear regression lines, termed "segmented linear regression".[16] The authors examined the learning curve of the first 25 cases amongst 12 different surgeons and found that surgeons performing less than 14 cases were unable to demonstrate a reduction in operative time, concluding that the average case volume to achieving a steady state of operative time was 30 to 50 cases. They also found a volume of 50 cases to plateau in bone block positioning. Perhaps more intriguing, as one of the few studies exploring the curves amongst different surgeons, the authors found that the 12 surgeons all demonstrated different learning curve morphologies. This brings into question the applicability of studies that have examined the learning curve of a single surgeon. It is the authors' opinion that segmented linear regression allows for the most precise assessment of a learning curve, particularly when a given procedure doesn't follow a classic Ebbinghaus curve morphology.

There are many benefits to characterizing a learning curve. First, a learning curve should serve as a guide for young surgeons or senior surgeons adding a skill set to their practice. When embarking on a surgical procedure with a known learning curve we risk inferior outcomes and potentially higher complication rates for a finite number of cases. The ethical implications of the relative risk of surgical treatment early in a surgeon's learning curve is seldom discussed, yet patients sensibly ask, "How many of these have you done, doctor?".

The second benefit of characterizing learning curves is to serve as a guide in training. According to the 2018-2019 ACGME guidelines, orthopedic surgery graduates must log a minimum of 10 ACL cases.[59] The national average number of ACL cases logged for 2018-2019 was 31.3.[59] While this average fits nicely with this present study's findings, future case log volume may benefit from data driven by learning curves and serve as a reference for residency and fellowship program directors.

The ultimate goal of characterizing a learning curve is to devise strategies to overcome the learning curve more quickly. Multiple strategies have been described to try and overcome a learning curve over fewer cases. Howie et al. described close mentorship with a senior surgeon to include site visits and observation in the OR, cadaveric sessions, and preoperative discussion of cases, all of which lead to a series of hip osteotomies performed with limited complication and re-operation rate.[60] The role subspecialty fellowship plays on overcoming a learning curve also remains largely uncharted. Simulation and virtual reality training augments have also been described and are currently underway.[61] The expanding literature of virtual reality and surgical simulation represent an exciting era of orthopedic education.

Lastly, the prospect of being early in a surgical learning curve should not be confused with competency. Defining competency is a complex topic beyond the scope of this review. The most common metric by which surgical learning curves were measured in this review was time. Time may be associated in some cases with higher complications but should not be interpreted as a surrogate for surgical quality. In multiple cases in this review a learning curve was established for time, but not for arguably more clinically meaningful outcomes such as complication rate or PROM.[10,11,15,16] It is also worth noting that progress along a learning curve may not reflect a change in technical skill, but a change in patient selection. In studies where a learning curve was not found to exist this may in fact indicate sufficient training such that improvements in subsequent cases are marginal. Finally, it should be noted that while some learning curves relate to relatively benign issues (i.e. surgical time), others may be more consequential (i.e. implant or tunnel placement). We would therefore expect trainees to progress more slowly along learning curves for more consequential procedures.

This review not without limitations. First, the heterogeneity of methodology for defining a learning curve resulted in a large range of cases required to establish a learning curve. Many of the studies reported were single surgeon, which may not be externally valid to a population of surgeons. Furthermore, the procedures reported were heterogeneous and in some cases complex, and may not represent the learning curves associated with less complex arthroscopic procedures. All but one study[52] reported on the learning curves of graduated surgeons, and therefore may not be applicable to trainees.

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APPENDIX. Final Search Strategies

Librarian: Steph Hendren, MLIS; Duke University Medical Center Library & Archives, Duke University School of Medicine
Date of conducted searches: 2/2/2021
Total number of articles (before de-duplication): 9994

Database: MEDLINE (via PubMed)

1. Orthopedic procedure terms	"Acetabuloplasty"[Mesh] OR "Alveolar Bone Grafting"[Mesh] OR "Amputation"[Mesh] OR "Arthrodesis"[Mesh] OR "Anterior Cruciate Ligament Reconstruction"[Mesh] OR "Arthroplasty"[Mesh] OR "Arthroplasty, Replacement"[Mesh] OR "Arthroplasty, Subchondral"[Mesh] OR "Arthroscopy"[Mesh] OR "Bone lengthening"[Mesh] OR "Bone-Patellar Tendon-Bone Grafting"[Mesh] OR "Bone Transplantation"[Mesh] OR "Cementoplasty"[Mesh] OR "Closed fracture reduction"[Mesh] OR "Decompression, Surgical"[Mesh] OR "Disarticulation"[Mesh] OR "Diskectomy"[Mesh] OR "Fracture Fixation"[Mesh] OR "Fracture Fixation, Internal"[Mesh] OR "Hemipelvectomy"[Mesh] OR "Ilizarov Technique"[Mesh] OR "Intervertebral Disc Chemolysis"[Mesh] OR "Joint Capsule Release"[Mesh] OR "Kyphoplasty"[Mesh] OR "Laminectomy"[Mesh] OR "Laminoplasty"[Mesh] OR "Limb salvage"[Mesh] OR "Manipulation, Orthopedic"[Mesh] OR "Meniscectomy"[Mesh] OR "Orthognathic Surgical Procedures"[Mesh] OR "Open fracture reduction"[Mesh] OR "Orthopedic Procedures"[Mesh] OR "Osteotomy"[Mesh] OR "Osteotomy, Le Fort"[Mesh] OR "Osteotomy, Sagittal Split Ramus"[Mesh] OR "Osteogenesis, Distraction"[Mesh] OR "Posterior Cruciate Ligament Reconstruction"[Mesh] OR "Sinus floor augmentation"[Mesh] OR "Spinal Fusion"[Mesh] OR "Synovectomy"[Mesh] OR "Tendon Transfer"[Mesh] OR "Tenodesis"[Mesh] OR "Tenotomy"[Mesh] OR "Traction"[Mesh] OR "Ulnar Collateral Ligament Reconstruction"[Mesh] OR "Vertebroplasty"[Mesh] OR "Viscosupplementation"[Mesh] OR acetabuloplasty[tiab] OR acetabuloplasties[tiab] OR "ACL reconstruction"[tiab] OR "ACL reconstructions"[tiab] OR "anterior cruciate ligament reconstruction"[tiab] OR "anterior cruciate ligament reconstructions"[tiab] OR amputation[tiab] OR amputations[tiab] OR amputate[tiab] OR amputates[tiab] OR amputated[tiab] OR amputating[tiab] OR arthrodesis[tiab] OR arthrodeses[tiab] OR arthroplasty[tiab] OR arthroplasties[tiab] OR arthroscopy[tiab] OR arthroscopies[tiab] OR arthroscopic[tiab] OR "bone grafting"[tiab] OR "bone graft"[tiab] OR "bone grafts"[tiab] OR "bone lengthening"[tiab] OR "bone transplantation"[tiab] OR "bone transplantations"[tiab] OR "bone transplant"[tiab] OR "bone transplants"[tiab] OR cementoplasty[tiab] OR cementoplasties[tiab] OR corpectomy[tiab] OR corpectomies[tiab] OR diskectomy[tiab] OR diskectomies[tiab] OR discectomy[tiab] OR discectomies[tiab] OR "distraction osteogenesis"[tiab] OR "foraminal decompression"[tiab] OR foraminotomy[tiab] OR foraminotomies[tiab] OR "fracture reduction"[tiab] OR "fracture reductions"[tiab] OR "heel cord release"[tiab] OR hemiarthroplasty[tiab] OR hemiarthroplasties[tiab] OR hemipelvectomy[tiab] OR hemipelvectomies[tiab] OR "intervertebral disc chemolysis"[tiab] OR "Ilizarov Technique"[tiab] OR "Ilizarov Method"[tiab] OR "joint capsule release"[tiab] OR kyphoplasty[tiab] OR kyphoplasties[tiab] OR laminectomy[tiab] OR laminectomies[tiab] OR laminotomy[tiab] OR laminotomies[tiab] OR laminoplasty[tiab] OR laminoplasties[tiab] OR "Le Fort"[tiab] OR microdiscectomy[tiab] OR microdiscectomies[tiab] OR microdiskectomy[tiab] OR microdiskectomies[tiab] OR meniscectomy[tiab] OR meniscectomies[tiab] OR orthopedic[tiab] OR orthopedics[tiab] OR orthopaedic[tiab] OR orthopaedics[tiab] OR osteotomy[tiab] OR osteotomies[tiab] OR osteosynthesis[tiab] OR "percutaneous osteoplasty"[tiab] OR "percutaneous osteoplasties"[tiab] OR "posterior cruciate ligament reconstruction"[tiab] OR "posterior cruciate ligament reconstructions"[tiab] OR "sinus floor augmentation"[tiab] OR "sinus floor augmentations"[tiab] OR "spinal fusion"[tiab] OR "spinal fusions"[tiab] OR spondylodesis[tiab] OR spondylodeses[tiab] OR spondylosyndesis[tiab] OR synovectomy[tiab] OR synovectomies[tiab] OR "synovium resection"[tiab] OR "synovium resections"[tiab] OR "tendon transfer"[tiab] OR "tendon transfers"[tiab] OR tenodesis[tiab] OR tenodeses[tiab] OR tenotomy[tiab] OR tenotomies[tiab] OR "tendon release"[tiab] OR "tendon lengthening"[tiab] OR "Tommy Johns surgery"[tiab] OR "Tommy John surgery"[tiab] OR "Tommy John's surgery"[tiab] OR "total disc replacement"[tiab] OR "total disc replacements"[tiab] OR "ulnar collateral ligament reconstruction"[tiab] OR "ulnar collateral ligament reconstructions"[tiab] OR vertebroplasty[tiab] OR vertebroplasties[tiab] OR viscosupplementation[tiab] OR viscosupplementations[tiab] OR vertebrectomy[tiab] OR vertebrectomies[tiab]	486927

2. Musculoskeletal regional terms	"Skeleton"[Mesh] OR "Bone and Bones"[Mesh] OR "Joints"[Mesh] OR "Tendons"[Mesh] OR "Ligaments"[Mesh] OR "Cartilage"[Mesh] OR cranial[tiab] OR cranium[tiab] OR jaw[tiab] OR mandible[tiab] OR maxillofacial[tiab] OR maxilla-mandibular[tiab] OR orthognathic[tiab] OR spine[tiab] OR spines[tiab] OR spinal[tiab] OR vertebrae[tiab] OR vertebral[tiab] OR lumbar[tiab] OR thoracic[tiab] OR cervical[tiab] OR ilium[tiab] OR ilial[tiab] OR ischial[tiab] OR ischium[tiab] OR pelvic[tiab] OR pelvis[tiab] OR pubis[tiab] OR symphysis[tiab] OR acetabulum[tiab] OR acetabular[tiab] OR ankle[tiab] OR ankles[tiab] OR femur[tiab] OR femurs[tiab] OR femoral[tiab] OR tibia[tiab] OR tibias[tiab] OR fibula[tiab] OR fibulas[tiab] OR tibial[tiab] OR knee[tiab] OR knees[tiab] OR patella[tiab] OR patellar[tiab] OR hip[tiab] OR hips[tiab] OR intervertebral[tiab] OR atlanto-axial[tiab] OR gleno-humeral[tiab] OR glenohumeral[tiab] OR shoulder[tiab] OR shoulders[tiab] OR humerus[tiab] OR humeral[tiab] OR ulnar[tiab] OR ulna[tiab] OR radius[tiab] OR radial[tiab] OR scapula[tiab] OR scapulas[tiab] OR scapular[tiab] OR costal[tiab] OR intracostal[tiab] OR intercostal[tiab] OR clavicle[tiab] OR clavicles[tiab] OR clavicular[tiab] OR sternum[tiab] OR sternums[tiab] OR sternal[tiab] OR elbow[tiab] OR elbows[tiab] OR wrist[tiab] OR wrists[tiab] OR interphalangeal[tiab] OR inter-phalangeal[tiab] OR tarsal[tiab] OR tarsals[tiab] OR metatarsal[tiab] OR metatarsals[tiab] OR carpal[tiab] OR phalanges[tiab] OR bone[tiab] OR bones[tiab] OR skeletal[tiab] OR skeleton[tiab] OR skeletons[tiab] OR fracture[tiab] OR fractures[tiab] OR intramedullary[tiab] OR joint[tiab] OR joints[tiab] OR limb[tiab] OR limbs[tiab] OR costochondral[tiab] OR cartilage[tiab] OR rib[tiab] OR ribs[tiab] OR talus[tiab] OR talar[tiab] OR metacarpal[tiab] OR carpal[tiab] OR tendon[tiab] OR tendons[tiab] OR ligament[tiab] OR ligaments[tiab] OR muscle[tiab] OR muscles[tiab] OR ACL[tiab] OR meniscus[tiab] OR meniscal[tiab] OR intraarticular[tiab] OR intra-articular[tiab] OR synovial[tiab] OR synovium[tiab]	3490279
3. Surgical terms	"Surgical Procedures, Operative"[Mesh] OR "surgery" [Subheading] OR electrosurgery[tiab] OR electrosurgeries[tiab] OR electrosurgical[tiab] OR radiosurgery[tiab] OR radiosurgeries[tiab] OR radiosurgical[tiab] OR surgery[tiab] OR surgeries[tiab] OR surgical[tiab] OR operative[tiab] OR operation[tiab] OR operations[tiab] OR dissect[tiab] OR dissected[tiab] OR dissection[tiab] OR dissections[tiab] OR dissecting[tiab] OR microdissect[tiab] OR microdissected[tiab] OR microdissection[tiab] OR microdissections[tiab] OR microdissecting[tiab] OR cauter[tiab] OR cauterization[tiab] OR cauterizations[tiab] OR cauterize[tiab] OR cauterizes[tiab] OR cauterized[tiab] OR transplant[tiab] OR transplants[tiab] OR transplanting[tiab] OR transplanted[tiab] OR transplantation[tiab] OR implant[tiab] OR implants[tiab] OR implanted[tiab] OR implanting[tiab] OR implantation[tiab] OR implantations[tiab] OR graft[tiab] OR grafted[tiab] OR grafts[tiab] OR grafting[tiab] OR homograft[tiab] OR homografted[tiab] OR homografts[tiab] OR homografting[tiab] OR allograft[tiab] OR allografts[tiab] OR allografting[tiab] OR allografted[tiab] OR xenograft[tiab] OR xenografts[tiab] OR xenografted[tiab] OR xenografting[tiab] OR autograft[tiab] OR autografts[tiab] OR autografted[tiab] OR autografting[tiab] OR prostheses[tiab] OR prosthesis[tiab] OR prosthetic[tiab] OR bypass[tiab] OR rod[tiab] OR rods[tiab] OR screw[tiab] OR screws[tiab] OR pin[tiab] OR pins[tiab] OR cage[tiab] OR cages[tiab] OR diversion[tiab] OR drainage[tiab] OR drain[tiab] OR drained[tiab] OR draining[tiab] OR drains[tiab] OR debride[tiab] OR debrides[tiab] OR debridement[tiab] OR fuse[tiab] OR fused[tiab] OR fusing[tiab] OR fusion[tiab] OR fusions[tiab] OR traction[tiab] OR tractions[tiab] OR mobilization[tiab] OR mobilisation[tiab] OR manipulation[tiab] OR manipulations[tiab] OR revascularize[tiab] OR revascularized[tiab] OR revascularization[tiab] OR revascularizations[tiab] OR revascularizes[tiab] OR replacement[tiab] OR replacements[tiab] OR lengthen[tiab] OR lengthens[tiab] OR lengthening[tiab] OR distraction[tiab] OR fixation[tiab] OR fixations[tiab] OR fixate[tiab] OR fixated[tiab] OR fixating[tiab] OR salvage[tiab] OR salvages[tiab] OR salvaging[tiab] OR reconstruct[tiab] OR reconstructs[tiab] OR reconstruction[tiab] OR reconstructions[tiab] OR reconstructed[tiab] OR harvest[tiab] OR harvests[tiab] OR harvested[tiab] OR harvesting[tiab]	6204189
4.	2 AND 3	1417302
5.	1 OR 4	1518201
6. Learning curve terms	("Learning Curve"[Mesh] OR "learning curve"[tiab] OR "learning curves"[tiab] OR "learning phase"[tiab] OR "learning phases"[tiab])	14445
7.	5 AND 6	3319

Database: Embase (via Elsevier)
Note: all searches were conducted in the "results" tab

1. Orthopedic procedure terms	'acetabuloplasty'/exp OR 'alveolar bone grafting'/exp OR 'amputation'/exp OR 'arthrodesis'/exp OR 'anterior cruciate ligament reconstruction'/exp OR 'arthroplasty'/exp OR 'arthroscopy'/exp OR 'leg lengthening'/exp OR 'bone transplantation'/exp OR 'cementoplasty'/exp OR 'closed fracture reduction'/exp OR 'closed fracture reduction'/exp OR 'disarticulation'/exp OR 'discectomy'/exp OR 'fracture fixation'/exp OR 'joint surgery'/exp OR 'hemipelvectomy'/exp OR 'orthognathic surgery'/exp OR 'Ilizarov technique'/exp OR 'chemonucleolysis'/exp OR 'capsular release'/exp OR 'kyphoplasty'/exp OR 'laminectomy'/exp OR 'laminoplasty'/exp OR 'limb salvage'/exp OR 'meniscectomy'/exp OR 'orthopedic manipulation'/exp OR 'open fracture reduction'/exp OR 'osteosynthesis'/exp OR 'orthopedic surgery'/exp OR 'osteotomy'/exp OR 'Le Fort osteotomy'/exp OR 'sagittal split ramal osteotomy'/exp OR 'distraction osteogenesis'/exp OR 'posterior cruciate ligament reconstruction'/exp OR 'sinus floor augmentation'/exp OR 'spine fusion'/exp OR 'synovectomy'/exp OR 'tendon transfer'/exp OR 'tenodesis'/exp OR 'traction therapy'/exp OR 'ulnar collateral ligament reconstruction'/exp OR 'percutaneous vertebroplasty'/exp OR 'viscosupplementation'/exp OR (acetabuloplasty OR acetabuloplasties OR 'ACL reconstruction' OR 'ACL reconstructions' OR 'anterior cruciate ligament reconstruction' OR 'anterior cruciate ligament reconstructions' OR amputation OR amputations OR amputate OR amputates OR amputated OR amputating OR arthrodesis OR arthrodeses OR arthroplasty OR arthroplasties OR arthroscopy OR arthroscopies OR arthroscopic OR 'bone grafting' OR 'bone graft' OR 'bone grafts' OR 'bone lengthening' OR 'bone transplantation' OR 'bone transplantations' OR 'bone transplant' OR 'bone transplants' OR cementoplasty OR cementoplasties OR corpectomy OR corpectomies OR diskectomy OR diskectomies OR discectomy OR discectomies OR 'distraction osteogenesis' OR 'foraminal decompression' OR foraminotomy OR foraminotomies OR 'fracture reduction' OR 'fracture reductions' OR 'heel cord release' OR hemiarthroplasty OR hemiarthroplasties OR hemipelvectomy OR hemipelvectomies OR 'intervertebral disc chemolysis' OR 'Ilizarov Technique' OR 'Ilizarov Method' OR 'joint capsule release' OR kyphoplasty OR kyphoplasties OR laminectomy OR laminectomies OR laminotomy OR laminotomies OR laminoplasty OR laminoplasties OR 'Le Fort' OR microdiscectomy OR microdiscectomies OR microdiskectomy OR microdiskectomies OR meniscectomy OR meniscectomies OR orthopedic OR orthopedics OR orthopaedic OR orthopaedics OR osteotomy OR osteotomies OR osteosynthesis OR 'percutaneous osteoplasty' OR 'percutaneous osteoplasties' OR 'posterior cruciate ligament reconstruction' OR 'posterior cruciate ligament reconstructions' OR 'sinus floor augmentation' OR 'sinus floor augmentations' OR 'spinal fusion' OR 'spinal fusions' OR spondylodesis OR spondylodeses OR spondylosyndesis OR synovectomy OR synovectomies OR 'synovium resection' OR 'synovium resections' OR 'tendon transfer' OR 'tendon transfers' OR tenodesis OR tenodeses OR tenotomy OR tenotomies OR 'tendon release' OR 'tendon lengthening' OR 'Tommy Johns surgery' OR 'Tommy John surgery' OR 'total disc replacement' OR 'total disc replacements' OR 'ulnar collateral ligament reconstruction' OR 'ulnar collateral ligament reconstructions' OR vertebroplasty OR vertebroplasties OR viscosupplementation OR viscosupplementations OR vertebrectomy OR vertebrectomies):ti,ab	703722
2. Musculoskeletal regional terms	'musculoskeletal system'/exp OR 'bone'/exp OR 'cartilage'/exp OR 'joint'/exp OR 'ligament'/exp OR 'tendon'/exp OR (cranial OR cranium OR jaw OR mandible OR maxillofacial OR maxilla-mandibular OR orthognathic OR spine OR spines OR spinal OR vertebrae OR vertebral OR lumbar OR thoracic OR cervical OR ilium OR ilial OR ischial OR ischium OR pelvic OR pelvis OR pubis OR symphysis OR acetabulum OR acetabular OR ankle OR ankles OR femur OR femurs OR femoral OR tibia OR tibias OR fibula OR fibulas OR tibial OR knee OR knees OR patella OR patellar OR hip OR hips OR intervertebral OR atlanto-axial OR gleno-humeral OR glenohumeral OR shoulder OR shoulders OR humerus OR humeral OR ulnar OR ulna OR radius OR radial OR scapula OR scapulas OR scapular OR costal OR intracostal OR intercostal OR clavicle OR clavicles OR clavicular OR sternum OR sternums OR sternal OR elbow OR elbows OR wrist OR wrists OR interphalangeal OR inter-phalangeal OR tarsal OR tarsals OR metatarsal OR metatarsals OR carpal OR phalanges OR bone OR bones OR skeletal OR skeleton OR skeletons OR fracture OR fractures OR intramedullary OR joint OR joints OR limb OR limbs OR costochondral OR cartilage OR rib OR ribs OR talus OR talar OR metacarpal OR carpal OR tendon OR tendons OR ligament OR ligaments OR muscle OR muscles OR ACL OR meniscus OR meniscal OR intraarticular OR intra-articular OR synovial OR synovium):ti,ab	5159117
3. Surgical terms	'surgery'/exp OR su.fs OR (electrosurgery OR electrosurgeries OR electrosurgical OR radiosurgery OR radiosurgeries OR radiosurgical OR surgery OR surgeries OR surgical OR operative OR operation OR operations OR dissect OR dissected OR dissection OR dissections OR dissecting OR microdissect OR microdissected OR microdissection OR microdissections OR microdissecting OR cauter OR cauterization OR cauterizations OR cauterize OR cauterizes OR cauterized OR transplant OR transplants OR transplanting OR transplanted OR transplantation OR implant OR implants OR implanted OR implanting OR implantation OR implantations OR graft OR grafted OR grafts OR grafting OR homograft OR homografted OR homografts OR homografting OR allograft OR allografts OR allografting OR allografted OR xenograft OR xenografts OR xenografted OR xenografting OR autograft OR autografts OR autografted OR autografting OR prostheses OR prosthesis OR prosthetic OR bypass OR rod OR rods OR screw OR screws OR pin OR pins OR cage OR cages OR diversion OR drainage OR drain OR drained OR draining OR drains OR debride OR debrides OR debridement OR fuse OR fused OR fusing OR fusion OR fusions OR traction OR tractions OR mobilization OR mobilisation OR manipulation OR manipulations OR revascularize OR revascularized OR revascularization OR revascularizations OR revascularizes OR replacement OR replacements OR lengthen OR lengthens OR lengthening OR distraction OR fixation OR fixations OR fixate OR fixated OR fixating OR salvage OR salvages OR salvaging OR reconstruct OR reconstructs OR reconstruction OR reconstructions OR reconstructed OR harvest OR harvests OR harvested OR harvesting):ti,ab	8140243

4.	2 AND 3	2051976
5.	1 OR 4	2205719
6. Learning curve terms	'learning curve'/exp OR ('learning curve' OR 'learning curves' OR 'learning phase' OR 'learning phases'):ti,ab	24374
7.	5 AND 6	5666
8.	7 NOT ([conference abstract]/lim OR 'conference abstract'/exp OR 'conference abstract'/it)	3632

Database: Scopus (via Elsevier)

1. Orthopedic procedure terms	TITLE-ABS(acetabuloplasty OR acetabuloplasties OR {ACL reconstruction} OR {ACL reconstructions} OR {anterior cruciate ligament reconstruction} OR {anterior cruciate ligament reconstructions} OR amputation OR amputations OR amputate OR amputates OR amputated OR amputating OR arthrodesis OR arthrodeses OR arthroplasty OR arthroplasties OR arthroscopy OR arthroscopies OR arthroscopic OR {bone grafting} OR {bone graft} OR {bone grafts} OR {bone lengthening} OR {bone transplantation} OR {bone transplantations} OR {bone transplant} OR {bone transplants} OR cementoplasty OR cementoplasties OR corpectomy OR corpectomies OR diskectomy OR diskectomies OR discectomy OR discectomies OR {distraction osteogenesis} OR {foraminal decompression} OR foraminotomy OR foraminotomies OR {fracture reduction} OR {fracture reductions} OR {heel cord release} OR hemiarthroplasty OR hemiarthroplasties OR hemipelvectomy OR hemipelvectomies OR {intervertebral disc chemolysis} OR {Ilizarov Technique} OR {Ilizarov Method} OR {joint capsule release} OR kyphoplasty OR kyphoplasties OR laminectomy OR laminectomies OR laminotomy OR laminotomies OR laminoplasty OR laminoplasties OR {Le Fort} OR microdiscectomy OR microdiscectomies OR microdiskectomy OR microdiskectomies OR meniscectomy OR meniscectomies OR orthopedic OR orthopedics OR orthopaedic OR orthopaedics OR osteotomy OR osteotomies OR osteosynthesis OR {percutaneous osteoplasty} OR {percutaneous osteoplasties} OR {posterior cruciate ligament reconstruction} OR {posterior cruciate ligament reconstructions} OR {sinus floor augmentation} OR {sinus floor augmentations} OR {spinal fusion} OR {spinal fusions} OR spondylodesis OR spondylodeses OR spondylosyndesis OR synovectomy OR synovectomies OR {synovium resection} OR {synovium resections} OR {tendon transfer} OR {tendon transfers} OR tenodesis OR tenodeses OR tenotomy OR tenotomies OR {tendon release} OR {tendon lengthening} OR {Tommy Johns surgery} OR {Tommy John surgery} OR {Tommy John's surgery} OR {total disc replacement} OR {total disc replacements} OR {ulnar collateral ligament reconstruction} OR {ulnar collateral ligament reconstructions} OR vertebroplasty OR vertebroplasties OR viscosupplementation OR viscosupplementations OR vertebrectomy OR vertebrectomies)	413860
2. Musculoskeletal regional terms	TITLE-ABS(cranial OR cranium OR jaw OR mandible OR maxillofacial OR maxilla-mandibular OR orthognathic OR spine OR spines OR spinal OR vertebrae OR vertebral OR lumbar OR thoracic OR cervical OR ilium OR ilial OR ischial OR ischium OR pelvic OR pelvis OR pubis OR symphysis OR acetabulum OR acetabular OR ankle OR ankles OR femur OR femurs OR femoral OR tibia OR tibias OR fibula OR fibulas OR tibial OR knee OR knees OR patella OR patellar OR hip OR hips OR intervertebral OR atlanto-axial OR gleno-humeral OR glenohumeral OR shoulder OR shoulders OR humerus OR humeral OR ulnar OR ulna OR radius OR radial OR scapula OR scapulas OR scapular OR costal OR intracostal OR intercostal OR clavicle OR clavicles OR clavicular OR sternum OR sternums OR sternal OR elbow OR elbows OR wrist OR wrists OR interphalangeal OR inter-phalangeal OR tarsal OR tarsals OR metatarsal OR metatarsals OR carpal OR phalanges OR bone OR bones OR skeletal OR skeleton OR skeletons OR fracture OR fractures OR intramedullary OR joint OR joints OR limb OR limbs OR costochondral OR cartilage OR rib OR ribs OR talus OR talar OR metacarpal OR carpal OR tendon OR tendons OR ligament OR ligaments OR muscle OR muscles OR ACL OR meniscus OR meniscal OR intraarticular OR intra-articular OR synovial OR synovium)	5539044
3. Surgical terms	TITLE-ABS(electrosurgery OR electrosurgeries OR electrosurgical OR radiosurgery OR radiosurgeries OR radiosurgical OR surgery OR surgeries OR surgical OR operative OR operation OR operations OR dissect OR dissected OR dissection OR dissections OR dissecting OR microdissect OR microdissected OR microdissection OR microdissections OR microdissecting OR cauter OR cauterization OR cauterizations OR cauterize OR cauterizes OR cauterized OR transplant OR transplants OR transplanting OR transplanted OR transplantation OR implant OR implants OR implanted OR implanting OR implantation OR implantations OR graft OR grafted OR grafts OR grafting OR homograft OR homografted OR homografts OR homografting OR allograft OR allografts OR allografting OR allografted OR xenograft OR xenografts OR xenografted OR xenografting OR autograft OR autografts OR autografted OR autografting OR prostheses OR prosthesis OR prosthetic OR bypass OR rod OR rods OR screw OR screws OR pin OR pins OR cage OR cages OR diversion OR drainage OR drain OR drained OR draining OR drains OR debride OR debrides OR debridement OR fuse OR fused OR fusing OR fusion OR fusions OR traction OR tractions OR mobilization OR mobilisation OR manipulation OR manipulations OR revascularize OR revascularized OR revascularization OR revascularizations OR revascularizes OR replacement OR replacements OR lengthen OR lengthens OR lengthening OR distraction OR fixation OR fixations OR fixate OR fixated OR fixating OR salvage OR salvages OR salvaging OR reconstruct OR reconstructs OR reconstruction OR reconstructions OR reconstructed OR harvest OR harvests OR harvested OR harvesting)	8769580

4.	2 AND 3	1488220
5.	1 OR 4	1638202
6. Learning curve terms	TITLE-ABS({learning curve} OR {learning curves} OR {learning phase} OR {learning phases})	23248
7.	5 AND 6	3388
8.	7 AND selected document types: article, review	3043

PERIOPERATIVE MANAGEMENT OF HIP ARTHROSCOPY

Christian E. Athanasian, AB[1]; Abed Abdelaziz, MD[1]; Christopher L. Shultz, MD[2]; Robert A. Christian, MD, MBA[1]

ABSTRACT

Hip arthroscopy is a surgical procedure commonly used for hip pathologies including femoroacetabular impingement (FAI). Perioperative considerations in hip arthroscopy have not been explored as thoroughly as more common orthopedic procedures. Preferences vary between surgeons, and there is no current consensus regarding various aspects of perioperative management. Utilization of traction, patient positioning, type of anesthesia, regional nerve blocks, as well as the use of antibiotic prophylaxis and tranexamic acid must be considered. This review will summarize the current literature on this topic, identify recent techniques that have demonstrated promise, and provide suggested direction for future research.

Level of Evidence: IV

Keywords: hip arthroscopy, perioperative management, anesthesia, femoroacetabular impingement

INTRODUCTION

The utilization of arthroscopic hip procedures has been growing rapidly in the US, increasing 85% between 2011 and 2018.[1] The development of hip arthroscopy has enabled effective care for patients with pre-arthritic hip pathologies including femoroacetabular impingement (FAI),[2] though indications are currently expanding to include labral pathology in the setting of borderline hip dysplasia, loose body removal, septic arthritis, traumatic labral tears, and hip instability.[3] Untreated FAI has been identified as a risk factor leading to the early development of hip osteoarthritis,[4] and recent research suggests that correction of FAI may slow progression of arthritis and prolong the lifespan of the native hip joint.[2,5,6] Randomized controlled trials have demonstrated significant improvements in outcomes in patients undergoing hip arthroscopy compared to patients receiving conservative care for FAI syndrome.[7,8] Patient-selection is critical to the success and efficacy of arthroscopic hip procedures, as patients already demonstrating degenerative changes are at an elevated risk of conversion to total hip arthroplasty.[9]

Perioperative management of patients undergoing hip arthroscopy is complex. Factors such as the use and management of traction, patient positioning, types of anesthesia, regional nerve blocks as well as the use of antibiotic prophylaxis or tranexamic acid must be considered in order to provide the highest quality care and minimize complication rates. Given the rapidly increasing utilization of hip arthroscopy, perioperative management of this procedure has not been explored as broadly standardized as more long-standing orthopedic procedures. The goal of this review is to identify recent advances in the perioperative management in hip arthroscopy.

INTRA-OPERATIVE TRACTION

Hip arthroscopy utilizes traction to distract the hip joint in order to gain safe access to the central compartment. Insufficient joint distraction intraoperatively can lead to poor visualization and iatrogenic intra-articular damage.[10] While traction plays a critical role in the procedure, traction-related complications are common, with Frandsen et al. finding 74% of patients reporting traction-related problems after surgery.[11] A 2023 systematic review by Arriaza et al. found a traction-related complication rate of 36%, including sciatic nerve injury, peroneal nerve injury, and numbness or pain in the ankle or foot.[12]

One such complication related to traction use is postoperative nerve palsy, or neuropraxia, which can manifest as numbness or weakness in the operative extremity following the procedure. A 2017 systematic review of 36,761 hip arthroscopy cases found the most commonly affected nerves to be the pudendal nerve (9.0% of all complications), lateral femoral cutaneous nerve (7.8% of all complications), sciatic nerve (4.6% of all complications), common peroneal nerve (1.6% of all complications), and the femoral nerve (0.6% of all complications), all of which were temporary injuries.[13] There was only one case of

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permanent nerve injury reported.[13] It appears that these neurapraxias almost always resolve, with a review of postoperative pudendal nerve neurapraxias in patients undergoing hip arthroscopy also demonstrating that all neurapraxias resolved between 6 weeks and 3 months.[14] The advent of post-less techniques for patient positioning in hip arthroscopy has addressed these elevated rates of groin-related complications. The goal of the post-less technique is to apply counter-traction through friction of the patient on the table rather than a perineal post, thereby decreasing the risk of pudendal nerve palsy.

While numerous studies have demonstrated a relationship between traction and neuropraxias, the exact cause remains unclear. Current theories include the amount of traction forced used and the length of traction time. Telleria et al. performed a study measuring sciatic nerve dysfunction intraoperatively and found that maximum traction weight, and not traction time, was the greatest risk factor[15] for sciatic nerve neuropraxia. It should be noted this study was performed with the patient in the lateral position, which is associated with a higher rate of sciatic nerve injury while the supine position is associated with a higher rate of pudendal nerve injury[14,16] Additionally, cadaveric models have demonstrated that increased traction force with the patient in the supine position with the use of a perineal post increases pudendal nerve compression.[17]

The literature regarding traction time and its relation to neuropraxia is limited. It is commonly recommended that surgeons limit traction time to 2 hours, based on tourniquet times of greater than 2 hours resulting in myelin sheath destruction and permanent nerve damage.[18] As was previously mentioned, Telleria et al. did not find an association between traction time and sciatic nerve dysfunction in patients undergoing hip arthroscopy in the lateral position.[15]

Several techniques have been reported to reduce the risk of traction-related complications. Overall, reducing traction time and force of traction are believed to decrease the risk of post-operative neuropraxias. As a result, the minimum necessary traction force to gain adequate access to the hip joint should be utilized and the surgeon should work efficiently to minimize traction time. Venting the hip joint in the initial stages of the procedure can be utilized to break the labral suction seal and reduce the force needed to distract the hip joint.[19] The use of Trendelenburg positioning for patients undergoing hip arthroscopy in the supine position with the use of a perineal post has also been demonstrated to reduce perineal pressure.[20] Additionally, there is a well-documented learning curve in reducing traction, and overall operative, times in hip arthroscopy, with 30 cases being the most commonly cited number for the development of proficiency.[21,22] Traction times may continue to improve well beyond that number, with a single-surgeon study finding that total traction time plateaued at 374 cases and traction time per anchors placed plateauing after 487 cases.[23] The introduction of the post-less technique has provided another option in the prevention of complications related to traction in hip arthroscopy.

Post-less Positioning

Traditionally, a perineal post was used to stabilize the patient during the procedure and facilitate the safe use of traction on the operative extremity. Hip arthroscopy without the use of a perineal post, a post-less setup, has recently become increasingly popular to avoid compression of the pudendal nerve. According to a 2023 systematic review, utilization of a perineal post during hip arthroscopy accounts for 23% of complications, including both pudendal nerve injury and soft tissue injury of the groin area.[12] Pudendal nerve injury occurs at a 1.8% rate.[14] In a series of 1000 patients undergoing hip arthroscopy using a post-less setup, Mei-Dan et al. reported no groin related complications.[24] Recently, Kraeutler et al. performed the first study prospectively comparing complications in patients undergoing hip arthroscopy with a post to patients undergoing post-less hip arthroscopy. This study showed reduced groin-related complications in the post-less group compared to the post group, including no instances of postoperative perineal numbness.[25] The post-less technique does not come at the cost of reduced joint distraction.[24] The addition of Trendelenburg positioning may also be used to facilitate increased traction force across the hip joint using a post-less technique, or to decrease the perineal pressure if a posted setup is utilized.[20,26] In addition to the reduction in neurapraxias, Schaver et al. also found reduced times to discharge when hip arthroscopy was done with a post-less technique when compared to hip arthroscopy with the use of a perineal post.[27]

It should be noted that underreporting of complications due to utilization of perineal posts has been suggested.[28,29] In 2013, Pailhé et al. performed a retrospective review of the literature on pudendal nerve neuralgia after hip arthroscopy and discussed the possibility of bias towards decreased reporting of these instances.[29] These complications may be overlooked as patients may be modest in reporting groin-related symptoms, and surgeons may not directly ask about or evaluate for these complications.[22,29] Wininger et al. performed a 2022 systematic review of post-related complications in hip arthroscopy, and found that the incidence of these complications was 5 times greater in prospective studies than retrospective studies.[30] This further validates the idea that neurapraxias due to utilization of perineal posts may indeed be underreported.

A 2022 survey study by the International Society for Hip Arthroscopy found that 61% of its members utilize a perineal post, while 33% use the post-less technique. Of the respondents that changed their technique, 59% reported changing to reduce pudendal nerve and/or soft tissue complications, and 71% reported they have noticed a decrease in these complications.[31] Multiple techniques on various surgical tables have been described to allow for safe, post-less distraction in hip arthroscopy. All of these techniques utilize a foam traction pad to provide counter-traction via increased friction between the patient and the table.[32]

ANESTHESIA-RELATED CONSIDERATIONS

General Versus Neuraxial Anesthesia

The literature regarding hip arthroscopy and primary anesthetic considerations between general and neuraxial anesthesia is limited.[33] To our knowledge, just one study has been published directly comparing the two. Turner et al. found that neuraxial anesthesia use was associated with lower post-operative pain scores, and both lower intraoperative and immediate postoperative opioid requirements. They also noted no adverse events when compared to general anesthesia.[34] Ellenrieder et al. found that general versus spinal anesthesia did not influence utilization of traction forces.[35] Survey results from an international hip course found that general anesthesia was used by 64% of surgeons while a combination of spinal and general anesthesia was used by 34%.[36]

Neuromuscular Blockade

Of particular interest to the authors is the use of general anesthesia with neuromuscular blockade intraoperatively. Neuromuscular blockade, or paralysis, can be utilized during hip arthroscopy to decrease the amount of traction force needed to gain a similar amount of joint distraction. In a randomized controlled trial, Ledowski et al. explored perineal post pressures during hip arthroscopy with and without deep neuromuscular paralysis.[37] They demonstrated that neuromuscular paralysis reduced perineal pressure and increased joint width with traction. However, the use of muscular paralysis without the use of a perineal post has not yet been explored. The authors hypothesize that neuromuscular paralysis may reduce the protective effect of baseline neuromuscular function and increase the traction force seen by nerves, which could have implications for the incidence of postoperative neuropraxias. Further research in this area is recommended.

Regional Nerve Blocks

In addition to the primary anesthetic options discussed above, regional nerve blocks can be utilized for post-operative analgesia. Commonly considered regional blocks for hip arthroscopy include femoral nerve blocks,[38,39,40] fascia iliaca blocks,[41,42,43] lumbar plexus blocks,[44,45] and pericapsular nerve group (PENG) blocks.[46-50]

Femoral nerve blocks target the femoral nerve, which has both sensory and motor function, notably powering the anterior compartment musculature of the thigh. Randomized controlled trials have demonstrated that femoral nerve blocks are effective for postoperative pain following hip arthroscopy.[39,40] However, they are also associated with increased postoperative falls due to decreased quadriceps function, and therefore may be problematic if used in the ambulatory setting.[40]

Lumbar plexus blocks anesthetize the iliohypogastric, ilioinguinal, genitofemoral, lateral femoral cutaneous, femoral, and obturator nerves.[51] They have also been shown to be effective for postoperative pain in a 2012 randomized controlled trial.[44] However, a 2013 systematic review demonstrated that lumbar plexus blocks can also be associated with increased postoperative falls, posing the same issues as the femoral nerve block with regard to ambulatory settings.[52] Additionally, lumbar plexus blocks are noted for their technical complexity, which may be another factor limiting their use.

Fascia iliaca blocks anesthetize the femoral nerve and lateral femoral cutaneous nerve.[51] Recent literature has not been supportive of the use of fascia iliaca blocks in hip arthroscopy. A 2021 systematic review of randomized controlled trials by Smith et al. comparing fascia iliaca block to other modes of analgesic modalities and found that post-anesthesia care unit (PACU) pain scores were not significantly different between fascia iliaca blocks and lumbar plexus blocks, intra-articular ropivacaine, control groups receiving no blocks, or a saline placebo.[41] Two other randomized control trials found higher 1 hour postoperative pain scores in patients receiving a fascia iliaca block compared to local anesthetic infiltrate, and fascia iliaca blocks had greater total analgesic consumption in morphine equivalent dosing in the PACU compared to lumbar plexus blocks.[43] Additionally, fascia iliaca blocks have also been associated with postoperative quadriceps weakness and increased fall risk.[53] At the conclusion of their systematic review, Smith et al. recommended against the routine use of fascia iliaca blocks for pain control in patients undergoing hip arthroscopy.

The use of PENG blocks in surgeries for hip fracture was demonstrated in 2018 by Girón-Arango et al.[54] The anterior hip capsule is innervated primarily by the femoral nerve, obturator nerve, and accessory obturator nerve.[55-57] The PENG block technique targets the high articular branches of both the accessory obturator nerve and femoral nerve.[54] It has also been shown to spare postoperative quadriceps function when com-

pared to femoral nerve blocks in patients undergoing hip fracture surgery,[58] which may lead to reduced falls postoperatively[40] and thus make it an excellent option for ambulatory hip arthroscopy patients.

Orozco et al. was among the first to report the utilization of PENG blocks in hip arthroscopy in a case series of five patients, where they reported successful management of postoperative pain.[46] Recent studies exploring the utilization of PENG blocks in hip arthroscopy have yielded mixed results. The retrospective review by Kollmorgen et al. comparing patients who received a PENG block to patients who received no block demonstrated reduced initial PACU pain, PACU narcotic consumption, intraoperative fentanyl usage, and quicker times to discharge in the group that received the PENG block.[47] A 2023 retrospective review by Yusupov et al. also had similar results, with patients receiving a PENG block demonstrating decreased postoperative pain, opioid consumption, time to discharge, antiemetic requirements, and benzodiazepine requirements compared to patients who did not.[48] Likewise, a 2024 randomized controlled comparing the PENG block to a sham block also demonstrated decreased postoperative pain between the 18th and 24th postoperative hours, though improvements were small.[59] In a randomized controlled trial comparing PENG blocks and lumbar plexus blocks including 64 patients, Scanaliato et al. found the two to provide equivalent analgesia.[49] Patients in this study receiving the PENG block trended lower in pain scores than those receiving the lumbar plexus block, however these results were not significant.[49] In contrast to these previous results, a 2022 randomized controlled trial by Amato et al. including 68 patients that compared preoperative PENG blocks to a sham block demonstrated no significant difference in postoperative pain scores.[50] In the setting of combined hip arthroscopy and periacetabular osteotomy, the PENG block has also been demonstrated to reduce narcotic utilization when administered in conjunction with transversus abdominal plane blocks.[60]

TRANEXAMIC ACID

The utilization of tranexamic acid (TXA) to reduce peri-operative bleeding has become commonplace in many orthopedic procedures[61] through various routes of administration, and now is considered standard for elective hip and knee arthroplasty as well as geriatric hip fracture care (ortho clinical practice guidelines). Multiple studies have demonstrated decreased hemarthrosis and improved pain scores with utilization of TXA in shoulder and knee arthroscopy, with a very minimal thromboembolic complication profile.[62,63] In a systematic review of level I and level II evidence, Zhao et al. found that intra-operative TXA significantly improved visualization and decreased operative time by 13 minutes in rotator cuff repair.[64] The use of TXA in hip arthroscopy also offers the theoretical advantage of improved visualization and decreased hemarthrosis to offload capsular repair, though studies demonstrating this efficacy remain lacking and are an avenue for future research. Surgeons utilizing TXA in hip arthroscopy could likely extrapolate the opportune safety profile from shoulder and knee arthroscopy, though the benefits have yet to be determined. The senior author does not routinely use TXA for arthroscopic hip procedures due to limited supporting evidence.

ANTIBIOTICS

The use of antibiotic prophylaxis in hip arthroscopy has not been explored extensively. There are no current-evidence based guidelines for its use.[65] A 2018 systematic review by Ekhtiari et al. found that only 9 studies included information about the use of antibiotic prophylaxis. Of the 652 operations included in this review, only three infections were reported, all of which occurred in patients receiving antibiotic prophylaxis. When surveying 21 high-volume hip arthroscopists, 81% routinely used antibiotic prophylaxis, the most common of which was preoperative cefazolin (66.7%).[66] Traditionally, pre-operative prophylactic antibiotics are used in elective orthopaedic surgical procedures and the authors recommend use during arthroscopic hip procedures.

CONCLUSION

Perioperative management of hip arthroscopy is complex. The use of traction, patient positioning, anesthesia techniques, regional nerve blocks, perioperative antibiotic prophylaxis, and TXA use must be considered to improve the quality of patient care and reduce postoperative complication rates. When positioning the patient during hip arthroscopy, the senior author favors the utilization of a supine, post-less technique, and occasionally the addition of Trendelenburg positioning to increase traction. General anesthesia with the addition of a PENG block for post-operative pain control is also preferred by the senior author. The author uses routine pre-operative antibiotic prophylaxis for all procedures, but does not routinely use TXA. Further research in perioperative management is recommended to improve outcomes in patients undergoing hip arthroscopy.

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PRE-OPERATIVE MRA ACCURATELY PREDICTS CAPSULOLABRAL ADHESIONS AT REVISION HIP ARTHROSCOPY

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ABSTRACT

Background: To determine the accuracy of pre-operative magnetic resonance arthrogram (MRA) in detecting capsulolabral adhesions in patients undergoing revision hip arthroscopy.

Methods: We retrospectively reviewed revision hip arthroscopies performed by a single surgeon between 2019 and 2022. Patients without pre-operative MRA were excluded. Musculoskeletal radiologists blinded to surgical variables assessed pre-operative axial T1 FS MRA for adhesions and graded adhesions as mild (length <5 mm), moderate (5-10 mm), or severe (> 10mm). Paralabral sulcus effacement increased the grade one level beyond adhesion length. Intraoperative arthroscopy images were evaluated for the incidence and severity of adhesions. Adhesions were graded intraoperatively as mild (rare, small adhesions), moderate (multiple or large adhesions), or severe (many adhesions disrupting labral function). A grade of 0 was assigned if no adhesions were present. Graders were blinded to each other, and Wilcoxon signed-rank test compared diagnosis methods. Sensitivity, specificity, and predictive values (PPV, NPV) were also calculated.

Results: We identified 42 patients, 45 hips with pre-operative MRA undergoing revision hip arthroscopy. On MRA grading, there were 41 patients with adhesions (93%), of which 14 were considered severe (33%), 22 moderate (52%), and 6 mild (14%). On intraoperative grading (ICC 0.73, Kappa 0.35), there were 32 cases (71%) with 14 considered severe (31%), 10 moderate (22%), and 8 mild (18%). There was no difference in severity assessment between pre-operative MRA and intraoperative findings (P<0.001). Pre-operative MRA was moderately able to predict intra-operative adhesions (sensitivity 90.6%, PPV 69%). Specificity could not be calculated.

Conclusion: Axial T1 FS MRA is a sensitive tool to assess for capsulolabral adhesions in the revision arthroscopy setting. MRA best predicts severe adhesions and is moderately predictive of mild and moderate adhesions.

Level of Evidence: IV

Keywords: hip, femoroacetabular impingement, revision hip arthroscopy, MRA, adhesions, hip arthroscopy

INTRODUCTION

Hip arthroscopy is an effective means of addressing femoroacetabular impingement (FAI) in young adults. However, some patients have recurrent pain post-operatively and may require revision arthroscopy. Persistent pain following hip arthroscopy can be due to multiple factors making it difficult to diagnose the precise cause. Inadequately corrected structural disease (acetabular dysplasia or cam deformity) is the most common indication for revision surgery, but a thorough workup should also consider various pathologies including re-tearing of the labrum, chondral defects, previously unaddressed instability or capsular laxity, and development of adhesions, among others.[1-4]

Capsulolabral adhesions, in particular, are a known cause of postoperative pain that are seen during revision arthroscopy but can be challenging to diagnose pre-operatively.[1,3,5-7] These fibrous bands of scar tissue form during the normal healing process and connect the labrum to the joint capsule.[5] They have been shown to interfere with hip range of motion, disrupt the suction seal function of the labrum, and increase friction forces within the joint contributing to cartilage damage. Each of these can contribute to overall hip dysfunction following primary hip arthroscopy.[4,5,8] As such, patients with capsulolabral adhesions often require revision arthroscopy with lysis of adhesions to restore hip function (Figure I).[3,7,9]

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Magnetic resonance imaging (MRI) and magnetic resonance arthrography (MRA) are commonly used pre-operatively to characterize damage to the hip associated with FAI.[10-12] Both have shown strong accuracy in detecting intra-articular pathology such as acetabular labral tears and cartilage damage with some studies finding MRA to be superior to standard MRI.[11,13] Pre-operative MRA has a clear role in characterizing the more common sequelae of FAI, however, it is not yet known how well MRA can detect more subtle pathology such as capsulolabral adhesions. The purpose of this study is to determine the accuracy of pre-operative MRA in detecting capsulolabral adhesions in patients undergoing revision hip arthroscopy. We hypothesize that pre-operative MRA would accurately identify capsulolabral adhesions in this context.

METHODS

Patient Selection

We retrospectively reviewed patients undergoing revision hip arthroscopy for persistent pain by a single surgeon between 2019 and 2022. Patients who had pre-operative axial MRA of the operative hip were included in our study. Those without pre-operative MRA were excluded. Patient information including demographics and surgical procedures performed was not collected as it was beyond the scope of our study and not covered under our Institutional Review Board exemption status.

MRA Grading

After identifying our cohort, two musculoskeletal radiologists from our institution reviewed pre-operative axial T1 FS MRA to 1) identify the presence or absence of capsulolabral adhesions and 2) assess the severity of the adhesions. Each radiologist was blinded to intraoperative findings and diagnoses. If present, the radiologists graded the adhesions as mild (grade I), moderate (grade II), or severe (grade III). If no adhesions were present, the patient was assigned grade 0. Adhesion length was the primary driver of severity grading with adhesions < 5mm considered mild, 5-10mm moderate, and > 10mm severe (Figure II). Additionally, the presence of paralabral sulcus effacement increased the grade one level beyond what the adhesion length would dictate. For example, a 4 mm adhesion with sulcus effacement would be elevated to grade II. This classification system was designed by our radiologists.

Intraoperative Grading

Intraoperative arthroscopy images stored in the electronic medical record were independently reviewed by 3 members of the clinical team (SL, CS, MH). All reviewers were blinded to each other. Intraoperative grades were assigned on a similar scale with mild (grade I) denoting rare, small adhesions, moderate (grade II) multiple or large adhesions, and severe (grade III) many adhesions disrupting labral function (Figure III). Again, a grade of 0 was assigned if no adhesions were present. Similar to the MRA grading, the intraoperative classification system was designed by the primary surgeon in this study. After all grading was complete, a single consensus severity grade was agreed upon for each hip.

Statistical Analysis

We calculated the incidence of adhesions for both the MRA and intraoperative groups. For intraoperative grading, we determined the intraclass correlation coefficient (ICC) and Fleiss Kappa value to assess interrater reliability of the graders. The two diagnostic techniques were directly compared using a Wilcoxon signed-rank test. A P-value < 0.05 was considered significant. Finally, we calculated the sensitivity, specificity, and positive and

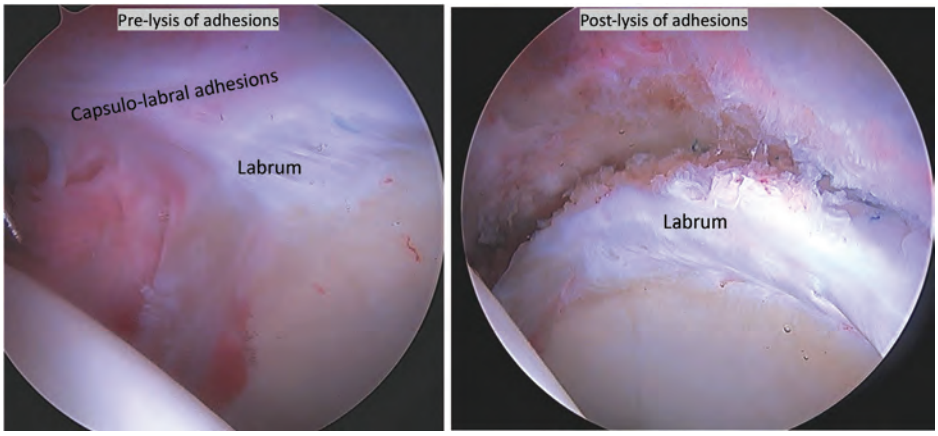

Figure I. Intraoperative photos demonstrating capsulolabral adhesions before (Left) and after (Right) lysis of adhesions during revision hip arthroscopy.

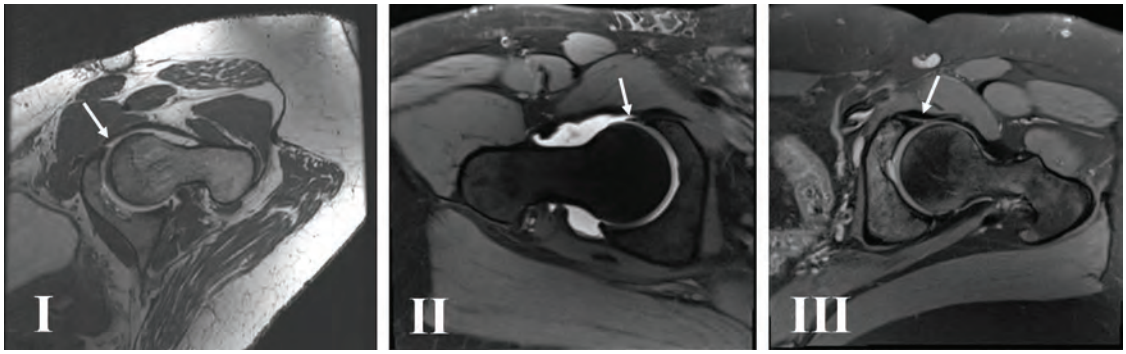

Figure II. MRA examples of capsulolabral adhesions. Left: Grade I - < 5mm. Middle: Grade II – 5-10mm. Right: Grade III - > 10mm.

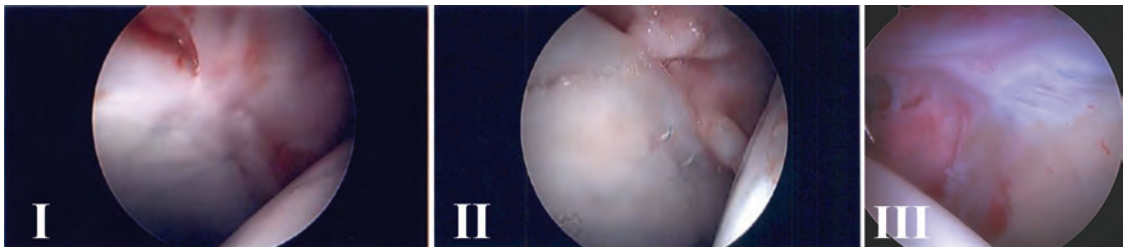

Figure III. Intraoperative examples of capsulolabral adhesions. Left: Grade I – single small adhesion. Middle: Grade II – multiple or large adhesions. Right: Grade III – large adhesion disrupting labral suction seal function.

negative predictive values (PPV, NPV) for pre-operative axial MRA grading. A false positive was assigned if adhesions were seen on MRA but not intraoperatively. Similarly, a false negative was assigned if no adhesions were seen on MRA but seen intraoperatively.

RESULTS

We identified 46 patients (50 hips) who underwent revision arthroscopy. Five hips were excluded due to lack of pre-operative MRA of the operative hip leaving us with a final cohort of 42 patients (45 hips) for analysis.

Pre-Operative MRA Grading

Out of 45 hips, 42 (93.3%) were found to have capsulolabral adhesions on MRA (Table I). Of those cases, 6 were graded as mild (14.3%), 22 as moderate (52.4%), and 14 as severe (33.3%).

Intraoperative Grading

We identified 32 adhesions cases (71.1%) intraoperatively of which 8 (25%) were considered mild, 10 (31.3%) moderate, and 14 (43.8%) severe (Table II). We calculated an ICC score of 0.71 and Kappa value of 0.35 suggesting moderate reliability and fair agreement, respectively.

Comparison of Techniques

We found no difference between the two diagnostic methods ($P<0.001$) used in this study. The 2x2 table used to calculate sensitivity, specificity, and predictive values is depicted in Table II. There were 13 false positive and 3 false negative cases. Pre-operative MRA was moderately predictive of intraoperative adhesions with a sensitivity of 90.6% and PPV of 69% (Table III).

DISCUSSION

We found that pre-operative MRA can accurately predict the severity of capsulolabral adhesions seen during revision hip arthroscopy with a sensitivity of 90.6% and PPV of 69%. MRA was most effective in diagnosing severe adhesions, but less effective for diagnosing moderate or mild adhesions.

Looking specifically at capulolabral adhesions in revision hip arthroscopy, our accuracy estimates appear to be in line with the present literature. In 2011, Dudda et al. performed a similar cohort study assessing the predictive value of pre-operative MRA in patients who underwent open FAI surgery through a surgical hip dislocation and had persistent symptoms post-operatively. They found that pre-operative MRA could reliably identify adhesions with a sensitivity, specificity, and PPV of 100% in a total of 21 patients who were confirmed to have adhesions

Table I. Diagnosis and Severity Assessment of Capsulolabral Adhesions Both on Pre-Operative MRA and During Revision Hip Arthroscopy

	MRA (%)	Intraoperative (%)
Number of Cases	42 (93.3)	32 (71.1)
Adhesion Severity		
Mild (Grade I)	6 (14.3)	8 (25)
Moderate (Grade II)	22 (52.4)	10 (31.3)
Severe (Grade III)	14 (33.3)	14 43.8)

Table II. 2x2 Table Used to Calculate Sensitivity, Specificity, and Predictive Value of Pre-Operative MRA Grading

		Intraoperative Adhesions	
		Yes	No
MRA Adhesions	Yes	29	13
	No	3	0

There were 29 true positives, 13 false positives, 3 false negatives, and 0 true negatives in our study.

Table III. Sensitivity, Specificity, Positive Predictive Value (PPV), and Negative Predictive value (NPV) of Pre-Operative MRA in Diagnosing Capsulolabral Adhesions

Pre-Operative MRA	
Sensitivity	90.60%
PPV	69%
Specificity	N/a*
NPV	N/a*

*Unable to calculate due to 0 false negative results in our study.

intraoperatively at revision hip arthroscopy.[14] Though we found comparatively lower sensitivity and PPV rates, we feel this could be related more to differences in morbidity associated with the index surgery in each study. Adhesions are known to develop as part of the natural course of healing and inflammation.[5] It stands to reason that an open surgical hip dislocation would result in more inflammation than the less invasive hip arthroscopy causing more severe adhesion development, and, therefore, generate higher detection rates on pre-operative MRA. This could explain the difference in sensitivity and PPV rates between our studies without detracting from the value of pre-operative MRA in the revision hip arthroscopy setting. It is also important to note that Dudda et al. only performed revision arthroscopy in patients with MRA evidence of adhesions. If MRA was negative or demonstrated other potential causes of persistent pain (residual deformity, etc.) patients were treated with revision open surgery or conservative treatment. It is challenging to say if patients who underwent open revision may have also had adhesions in which case the estimated sensitivity and PPV in their study would decrease.

On a broader scope, the present literature appears to be mixed on whether MRA is superior to traditional MRI in evaluating for intra-articular hip pathology. Tian et al. directly compared pre-operative MRI and MRA detection of labral tears to intra-operative findings in 90 patients undergoing primary hip arthroscopy. They found that MRA had a significantly higher sensitivity (90.5%) and NPV (84.6%) than traditional MRI (61% and 53.4%, respectively).[15] Conversely, a systematic review by Smith et al. comparing MRI and MRA in the detection of chondral lesions found that traditional MRI was the superior diagnostic test with a pooled specificity of 94% compared to 86% for MRA.[12] It is important to note that these studies were not specific to patients with persistent pain following arthroscopy.

Combining these studies with our data might suggest that the accuracy or utility of MRI versus MRA depends more on the abnormality in question than the imaging modality itself. For example, contrast extravasation can be helpful in identifying labral tears but may obscure gross pathology such as cartilaginous lesions. We feel that adhesion detection may benefit from contrast imaging as they can be a more subtle finding. This is supported by the high sensitivity seen in our study. In summation, there are no evidence-based guidelines for the use of MRI and/or MRA in the setting of previous arthroscopy, but we advocate for MRA to improve detection of capsular defects and capsulolabral adhesions.

A possible alternative to using MRA or MRI for diagnosing adhesions is ultrasound. This modality carries the added benefit of being considerably less costly and often more readily available. Ultrasound also allows for dynamic assessment and visualization of the hip through a full range of motion. Being able to see in real time what is happening in the joint when a patient reaches the end point of their motion or experiences pain could help identify subtle pathology. Adhesive capsulitis of the shoulder is an analogous condition to hip capsulolabral adhesions for which ultrasound diagnosis has been well studied. Wu et al. performed a meta-analysis assessing the utility of ultrasound in diagnosis adhesive capsulitis of the shoulder finding 88% sensitivity, 96% specificity, and a 23.89 positive likelihood ratio.[16] Other studies in the shoulder have concluded that ultrasound was as reliable as MRI in diagnosing adhesive capsulitis and

that the severity of ultrasound findings such as ligament thickness significantly correlated with the severity of a patient's clinical presentation.[17,18]

Though the current data on diagnostic shoulder ultrasound appears encouraging, ultrasound's role in assessing capsulolabral adhesions of the hip has not been as well characterized. It is important to recognize that although adhesive capsulitis and hip capsulolabral adhesions may be analogous conditions, the hip may present additional challenges for diagnostic ultrasound as it is a much more constrained joint often with a larger overlying soft tissue envelope compared to the shoulder. Both factors can impede visualization of fine details potentially limiting the ability to identify more subtle pathology such as low-grade adhesions. Despite this, the dynamic visualization, increased availability, and other benefits of ultrasound compared to MRI remain enticing. Its role in diagnosing hip adhesions is an area worthy of future investigation.

Capsulolabral adhesions clearly pose a diagnostic challenge placing a larger emphasis on identifying ways to prevent them from occurring in the first place. One technique is encouraging early hip range of motion in the immediate post-operative period. Multiple studies have described the use of hip circumduction exercises or a continuous passive motion machine beginning immediately after surgery as part of their standard post-operative protocol specifically to prevent adhesion formation with overall favorable results.[19-23] Furthermore, Willimon et al. performed a risk factor analysis in patients with adhesions and found that introducing hip circumduction into the post-operative rehabilitation protocol was associated with a significant decrease in the incidence of adhesions in their cohort of over 1200 hips. In fact, patients who did not perform hip circumduction exercises were 4.1 times more likely to develop adhesions.[24]

Another potential avenue is chemoprophylaxis against adhesion formation with a recent systematic review identifying losartan as a potentially promising agent.[23] Angiotensin II acts to upregulate transforming growth factors-beta 1 (TGF-beta 1) which is a known cytokine contributing to fibrosis in skeletal muscle. Losartan blocks the angiotensin II receptor and has been shown to decrease the degree of fibrosis seen after injury in mouse models.[25] To date, there have been few clinical studies in the orthopedic literature. Arraut et al. in 2022 found that patients prescribed losartan 3 months prior to total knee arthroplasty exhibited greater post-operative range of motion than controls, however, this did not reach statistical significance.[26] Losartan has not yet been studied in the context of hip arthroscopy which could be a focus of future investigations.

Limitations

One limitation of our study was the way in which intraoperative grades were assigned. As there is no standardized classification system for capsulolabral adhesions, there exists some inherent subjectivity when determining what could be characterized as mild, moderate, or severe. Additionally, all grading was based on still photos uploaded to the patient's EMR. It is possible that the photo could under- or overestimate the severity of the adhesions depending on clarity, angle of the scope camera, etc. In contrast, assigning grades in real time based on a video or dynamic view of the hip joint during arthroscopy could give a better intraoperative assessment of the true severity of the adhesions. Such a method, however, would not be feasible given the design of our study and the goal of minimizing bias by separating graders from the operative surgeon. Another limitation was the lack of a false positive finding preventing us from calculating specificity and NPV. While the sensitivity and PPV findings are encouraging, specificity and NPV could further support the diagnostic utility of MRA in detecting adhesions. Additionally, not all MRA studies were performed at the same institution. This introduces the possibility that variations in quality could impact radiologic assessment, however, it is unlikely that these variations were significant enough to alter our overall findings. Lastly, the radiologists at our institution are musculoskeletal-trained radiologists, which may not be present at every institution. A finding as subtle as a capsulolabral adhesion could potentially be missed by a general radiologist without musculoskeletal training, which is a potential limitation of this study.

CONCLUSIONS

Axial MRA is a sensitive tool to assess for capsulolabral adhesions in the revision hip arthroscopy setting. MRA are best at predicting severe adhesions and are moderately predictive of mild and moderate adhesions. Further assessment of less invasive detection measures may be warranted.

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COVID-19 DISRUPTION OF KNEE ARTHROSCOPIES

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ABSTRACT

Background: The purpose of this study was to examine the proportion of patients who returned for their previously scheduled knee arthroscopy procedure following state-mandated cancellation of elective procedures during COVID-19 lockdown.

Methods: We reviewed a retrospective cohort of patients who had planned knee arthroscopies, excluding ligament reconstruction and irrigation/debridement, cancelled for a date between March and June 2020. The cohort was evaluated for scheduling outcome, returned versus did not return for surgery, before March 2022. Cancellation and reschedule dates, reason for not returning for surgery, patient demographics, and planned surgical characteristics were collected. Characteristics between patients who returned versus did not return were compared using statistical tests of independence.

Results: The cohort consisted of 66 patients; 53 (80%) rescheduled and 13 (20%) did not return. For those who rescheduled, the average time between cancellation and surgery was 115 days (sd=16 days). There were various reasons for not rescheduling surgery: eight (62%) had symptom alleviation; two (15%) had logistical barriers; three (23%) were lost to follow-up. Obesity status had a trend towards significance with lower proportion of rescheduled procedures for non-obese patients (68%) compared to obese patients (89%, p=0.057).

Conclusion: Our study highlights a natural experiment in forced delay of elective knee arthroscopies, which may be a surrogate for conservative management. The proportion of patients who did not return for a scheduled knee arthroscopy surgery (20%) is higher than what has been reported previously (11%) and 62% of these patients found symptom relief. However, 80% of the cohort did return for knee arthroscopy in within two years, suggesting delaying surgery will not alleviate symptoms for the majority of patients.

Level of Evidence: IV

Keywords: knee arthroscopy, meniscus tear, COVID-19, meniscus tears, meniscectomy, meniscal repair

INTRODUCTION

Knee arthroscopy is one of the most commonly performed procedures in orthopedics. In the United States, as of 2010, the number of knee arthroscopy procedures exceeded 650,000, placing it as the third most performed orthopedic ambulatory surgery and 11th most performed ambulatory surgery overall.[1] Despite this prevalence of knee arthroscopies, its application has been largely debated, especially with respect to treatment of knee osteoarthritis and degenerative meniscus tears.

Current guidelines by the American Academy of Orthopedic Surgeons strongly recommend against performing a knee arthroscopy to treat patients with symptomatic osteoarthritis of the knee.[2] This is in large part due to findings in randomized-controlled trial studies comparing patient outcomes after arthroscopic lavage with or without debridement and sham surgery as well as physical therapy.[3,4] Contrary to widespread belief around that time, the trials provided strong evidence against the efficacy of knee arthroscopy lavage or debridement compared to that of sham surgery[3,4] and of no significant difference in symptom improvement, including mechanical symptoms of catching and locking, when comparing knee arthroscopy versus physical therapy.[4] Patients with mild or moderate arthritis with degenerative meniscus tears also realized no greater improvements with partial meniscectomy versus exercise therapy[5] or other conservative treatments.[6] Furthermore, knee arthroscopy for treatment of knee osteoarthritis was not more economically advantageous when compared to conservative treatments.[7]

Although there have been overall decreases in knee arthroscopy procedures for treatment of osteoarthritis, arthroscopy prevalence remains high[8] and there is conflicting evidence that knee arthroscopy can still im-

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prove symptoms in a subset of patients who have failed nonoperative management.[9] In addition, the efficacy of knee arthroscopy in treating osteoarthritis and meniscus tears is supported.[10-14] Given this ongoing debate, more information is needed to understand the characteristics of patients likely to benefit from knee arthroscopies.

Currently in orthopedics, surgery cancellation rates range from 10% to 40% depending on the country and patient population.[15,16] Reason for cancellation may include improper medical workup, lack of preoperative fasting, hospital-related causes, and patient-related factors, one of the patient related factors being improvement of symptoms.[15,16] Related to these reasons are some of the patient characteristics associated with cancellation of elective orthopedic surgical procedures including age, spoken language, smoking status, insurance type, and prior experience with anesthesia.[17] However, in recent times, there has not been a forced cancellation of all orthopedic elective procedures, which may have impacted patient decision-making behavior, knee symptoms, and associated characteristics of patients who return for knee arthroscopies compared to patients who do not return.

In this sense, the COVID-19 pandemic has given us a unique opportunity to better understand the necessity of knee arthroscopy procedures. During the COVID-19 pandemic, all elective surgeries including knee arthroscopies were cancelled, by statewide mandate, from March to June of 2020. This involuntary disruption in knee arthroscopy surgeries forced a delay in surgery, which may have resulted in a change in level of physical activity (e.g., rest or increased movement) and knee symptoms.

The purpose of this study was then to examine the proportion of patients who returned versus did not return for a knee arthroscopy procedure after the COVID-19 shutdown. We hypothesized the proportion of patients who do not return for surgery would exceed the proportion of knee arthroscopies cancelled in the absence of forced shutdown, evaluated from the literature.

METHODS

This is a retrospective cohort study of patients who had surgery orders placed for a knee arthroscopy procedure prior to or in March of 2020 and had their surgery scheduled after March 2020 cancelled as a result of the COVID-19 pandemic shutdown. There were 11 different orthopedic surgeons at a single orthopedic center who performed knee arthroscopy procedures during the study period. All data were abstracted from a single electronic health record. Knee arthroscopies were identified by Current Procedural Terminology (CPT) code on the surgical order and included: diagnostic arthroscopy, arthroscopy with loose body removal, synovectomy, chondroplasty, lysis of adhesions, retinacular release, microfracture, meniscectomy, and meniscal repair. Patients who were scheduled for irrigation and debridement for an infection or ligamentous repairs were excluded. Other exclusions included pregnant individuals, children under the age of 18, and prisoners. This study was approved by the PeaceHealth System Institutional Review Board (IRB, Protocol #1952805).

The primary outcome was dichotomized into whether the patient returned or did not return for surgery and was determined through patient chart review of surgery scheduling records. For patients who did not return for surgery, cancellation reason was also abstracted. Among patients who did return for surgery, the duration between surgery cancellation and performed procedure date was calculated. Additionally, patients who had not returned for surgery were called to confirm that they had not proceeded with a knee arthroscopy surgery elsewhere. If they did not have a knee scope arthroscopy procedure elsewhere, their reason for not returning for surgery was collected as some patients did not have a reason recorded in the electronic health record. If they did have their procedure elsewhere, the date of their knee scope was gathered. For all patients, various patient and planned surgical characteristics were abstracted from the electronic health record system. The abstracted characteristics included: age, sex at birth, race, ethnicity, body mass index (BMI), smoking status, indicating diagnosis for surgery, severity of arthritis, presence of mechanical symptoms, types of attempted conservative measurements (physical therapy, brace, and steroid injection), planned procedure at the time of ordering surgery, insurance type, and location of residence, determined by zip code and categorized into local (approximately 15 miles or less) versus out-of-area (greater than 15 miles).

Patient characteristics were stratified by returned versus did not return for surgery and compared using Pearson's chi-square (χ^2) test of independence, Student's t-test, or Fisher's exact test as indicated. The level of statistical significance was set at $\alpha = 0.05$. Patient age was categorized to older than versus younger than or at age 50. BMI was also categorized to obese versus non-obese (greater than or equal to versus less than 30). All data were analyzed in Stata version 16.0 (StataCorp, College Station, TX).

RESULTS

There were 66 patients who had a future knee arthroscopy procedure cancelled during the initial COVID-19 shutdown; among them, 53 patients (80%) returned for the knee arthroscopy procedure and 13 patients (20%) did not return (Table 1). Reasons for not returning after forced cancellation are also listed in Table 1 and

Table 1. Proportion of Patients Who Returned Versus Did Not Return for a Knee Arthroscopy Procedure After Covid-19 Mandated Cancellation in March 2020 and Reason for Not Returning or Mean Day Count Among Patients Who Did Return

	Did not return within 2 years (%)	Returned within 2 years (%)
Total number of patients	13 (20%)	53 (80%)
Reason for not returning		
Symptom alleviation	8 (62%)	-
Logistical barriers	2 (15%)	
Lost to follow up	3 (23%)	
Mean days between forced cancellation and surgery, mean ± sd	-	115 (± 16)

(N=66).

include: eight patients (62%) had symptom alleviation; two (15%) had logistical barriers; three (23%) were lost to follow-up. For patients who rescheduled a cancelled knee arthroscopy, the average time between cancellation and rescheduled surgery was 115 days with a standard deviation of 16 days (Table 1).

Table 2 compares patient characteristics stratified by patients who returned for surgery compared to patients who did not return. There were no statistically significant differences in patient characteristics between scheduling outcome. Obesity, however, did have a trend towards significance. Patients with obesity had a higher proportion of rescheduled procedures performed (89%) compared to patients with obesity (68%, p=0.057). Table 2 also contains the type of knee arthroscopies that were in the surgery orders for our cohort of 66 patients (stratified by whether patient returned or did not return). The majority of these procedures were meniscectomies (79%).

DISCUSSION

This study took advantage of the mandatory statewide cancellation of elective procedures as a natural experiment for examining the result of a forced delay in knee scope procedures on future surgery rates. The results of our study support our hypothesis that the proportion of patients who did not reschedule their knee arthroscopy procedures after a forced delay in surgery due to the COVID-19 would be higher than previously established. In our study, approximately one-fifth of patients (20%) whose knee scopes were cancelled during the COVID-19 shutdown did not return for surgery. This proportion of cancelled surgeries is higher than a prior report for knee arthroscopies which cited 11%.[17]

For patients who did not reschedule their knee arthroscopy procedure, eight patients (62%) had documented improvement in symptoms during the COVID-19 lockdown. This result supports prior trials citing improvement in knee symptoms following arthroscopy is no better than conservative management for specific knee etiologies.[2-6] Three patients who did not proceed with surgery were lost to follow up, with no documented reason for not proceeding with knee arthroscopy in the electronic health record system and from difficulty reaching the patient by phone. We cannot be certain if these patients did not return for surgery because of symptom alleviation compared to any other reason or barrier for not returning for planned care. However, majority of the patients who did not return had an improvement in symptoms that led them to not return for their knee arthroscopy surgery after it was cancelled during COVID-19 shutdown. Additionally, among patients who did not return for surgery, ten were scheduled for a meniscectomy surgery which suggests that symptom improvement with rest may be true particularly for patients who have meniscus tears.

There is a body of research that supports the efficacy of knee arthroscopy procedures,[10-14] and our study does not refute or substantiate the necessity of knee arthroscopy surgery. After a period of forced delay, it is important to note the majority of patients (79%) rescheduled and completed the knee arthroscopy procedure. At a mean delay of 106 days (sd = 13 days), it is likely symptoms were not sufficiently alleviated.

Our study found reasons for cancellation of elective orthopedic surgeries prior to the pandemic, such as patient age and smoking status,[17] were not different between patients who returned versus did not return for knee arthroscopy. Our study, however, did find a trend towards significance in obesity status when looking at whether patients returned for knee arthroscopy after a forced delay. We identified more than four-fifths of our patients (89%) who were obese at the time of cancellation returned for surgery compared to 68% in non-obese patients (p = 0.057). Although not statistically significant, this patient characteristic may have been so with a greater population size. Given that there is a four-fold increase in knee joint compressive force for every pound increase in body weight, patients with obesity would be

Table 2. Pre-Operative Patient Characteristics for Knee Arthroscopy Procedures That Were Cancelled by State Mandate During the Covid-19 Shutdown (March 2020), Stratified by Patients Who Returned Versus Did Not Return in the Subsequent Two Years

	Patients who proceeded with surgery	Patients who canceled surgery	p-value
Total number of patients	53 (80%)	13 (20%)	-
Mean Age (years old)	50 (± 14)	52 (± 17)	0.614
Age Category	53	13	0.235
≥ 50 years old	27 (75%)	9 (25%)	
< 50 years old	26 (86%)	4 (14%)	
Sex Assigned at Birth	53	13	0.858
Male	30 (81%)	7 (19%)	
Female	23 (79%)	6 (21%)	
Race and Ethnicity	53	13	0.404
White and Non-Hispanic	38 (79%)	10 (21%)	
Other	8 (73%)	3 (27%)	
Declined	7 (100%)	0 (0%)	
Mean BMI	31.5 (± 6.6)	29.0 (± 4.4)	0.196
Obesity Status	53	13	0.057
BMI ≥ 30	34 (89%)	4 (11%)	
BMI < 30	19 (68%)	9 (32%)	
Smoking Status	48	13	1.000
Former/Never	45 (79%)	12 (21%)	
Current	3 (75%)	1 (25%)	
Mechanical Symptoms	53	13	0.267
No	9 (69%)	4 (31%)	
Yes	44 (83%)	9 (20%)	
Pre-Operative Physical Therapy	53	13	0.948
No	28 (80%)	7 (20%)	
Yes	25 (81%)	6 (19%)	
Brace Use	53	13	0.578
No	33 (83%)	7 (17%)	
Yes	20 (77%)	6 (23%)	
Steroid Injection	53	13	0.555
No	32 (78%)	9 (22%)	
Yes	21 (84%)	4 (16%)	
Knee Arthroscopy Procedure	53	13	0.653
Diagnostic	1 (50%)	1 (50%)	
Debridement	6 (75%)	2 (25%)	
Microfracture	3 (100%)	0 (0%)	
Meniscal Repair	1 (100%)	0 (100%)	
Meniscectomy	42 (81%)	10 (19%)	

Statistical tests of significance; Students t-test (Age, BMI); χ^2 (Sex, Pre-Operative Physical Therapy, Location of Residence); Fisher's exact (all else). (N=66).

Table 2. Pre-Operative Patient Characteristics for Knee Arthroscopy Procedures That Were Cancelled by State Mandate During the Covid-19 Shutdown (March 2020), Stratified by Patients Who Returned Versus Did Not Return in the Subsequent Two Years (continued)

Insurance Type	53	13	0.224
Commercial	18 (72%)	7 (28%)	
Medicaid	17 (94%)	1 (6%)	
Medicare	7 (70%)	3 (30%)	
Other	11 (85%)	2 (15%)	
Change in Insurance	53	13	0.589
No	47 (78%)	13 (22%)	
Yes	6 (100%)	0 (0%)	
Location of Residence	53	13	0.422
In area	31 (84%)	6 (16%)	
Out of area	22 (76%)	7 (24%)	

Statistical tests of significance; Students t-test (Age, BMI); χ^2 (Sex, Pre-Operative Physical Therapy, Location of Residence); Fisher's exact (all else). (N=66).

feeling more force compared to patients without obesity. Consequentially, an increase in compressive force is likely translated to increased symptoms, which has been supported in literature.[18] As such, our results lead us to consider whether obesity may have exacerbated knee symptoms, leading to a higher rate of rescheduled knee arthroscopies.

Previous literature has focused on how obesity is related to complications following a knee arthroscopy surgery. However, there is a dearth of knowledge in how obesity influences surgical decision-making for knee arthroscopy procedure. One study has found weight loss through laparoscopic sleeve gastrectomy surgery in some morbidly obese patients to delay orthopedic interventions including knee arthroscopy procedures and total knee replacements.[19] However, there is overall a limited knowledge in the topic of indication for a knee arthroscopy procedure in patients with obesity. Additional research is needed to better explain our finding, and determine the best approach for management of symptomatic knees in patients who are obese.

Limitations

Our study had some limitations. This study was retrospective and was limited by the scope of documentation available in the electronic health record. Specifically, we were not able ascertain the reason for surgery cancellation for two patients who were lost to follow up (23%) even after attempting to call the patients who had not returned for their knee scope procedures. Additionally, our sample size was a relatively small cohort of 66 patients. Most importantly, we did not collect a baseline cancellation rate of knee arthroscopy procedures in the absence of COVID-19 in our orthopedic institution. Although, we were able to compare our results to an already established value in literature, we were not able to accurately evaluate elective knee arthroscopy cancellation rate pre-COVID-19 shutdown. However, given there has not been an event in our history in which 100% of elective arthroscopies were cancelled without surgeon, patient, or payer decision-making, our natural experiment may better isolate the impact of surgical delay on future surgical rates.

CONCLUSION

The proportion of patients who did not return for surgery (20%) is higher than what has been reported previously for knee arthroscopies (11%)[17] and 62% of these patients found alleviation of symptoms with time. However, 80% of the cohort did return for knee arthroscopy in within two years, suggesting delaying surgery will not alleviate symptoms for the majority of patients.

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ACUTE HAMSTRING INJURY IN A MIDDLE-AGED RECREATIONAL ATHLETE DURING INDEPENDENCEBALL: A CASE REPORT

Benjamin J. Miller, MD, MS[1]

ABSTRACT

Background: Injuries during sports and other athletic activities will vary depending on the physical action and physiology of the individual. Specifically, middle-aged individuals, commonly defined as 40-65-years-old, are at a transition period physically. Activities that were previously low risk can be a new source of unanticipated vulnerability and subsequent disability. This is a case of an acute hamstring strain sustained by a 52-year-old physically active female while running the bases during an informal recreational game of Independenceball. The injury was witnessed by three orthopaedic surgeons. The diagnosis was made by mechanism and physical examination and resolved with non-operative treatment with gradual improvement and eventual return to full activity. Injuries such as these are common in middle-aged recreational athletes; individuals should be aware of the risks and attempt to mitigate injury appropriately while retaining a healthy and active lifestyle.

Level of Evidence: IV

Keywords: hamstring injury, independenceball, aging

INTRODUCTION

The human body experiences clear changes with aging. This coincides with a modern emphasis on continued physical health and nutrition, with many individuals continuing to participate in recreational activities such as sports of various levels of competitiveness, endurance athletics, weightlifting, and cross fit. Aging results in bodies that are harder to recover after activity and more prone to injury, even with activities that are not viewed as high risk.

The first known playing of Independenceball was on July 3, 2022 in Iowa City, IA and is loosely based on the American recreational sport of kickball, typically played informally in primary schools and on playgrounds. The suggested regulation Independenceball is a standard kickball, with coloring consistent with the American flag (Fig. 1). Independenceball was inspired by the Independence Day holiday, celebrating victory in the American War of Independence and enshrined on July 4 in recognition of the Declaration of Independence on the same day in 1776. The game consists of two teams. One team is on defense and begins play by rolling the Independenceball to the offensive player, who kicks the ball into play and runs to base (Fig. 2). There are four bases, similar to baseball, and a run is scored when an offensive player crosses "home plate." An "inning" consists of alternating opportunities for each side to be on offense. Each side has two outs per inning, and games are played for three innings (longer if the game is tied at the end of three innings). An out can only occur with contact between the ball and a runner, by tagging or throwing, when they are not on a base.

Independenceball has two named unique rules. The first occurs when a defensive player catches a kick directly from the offensive player. Instead of the kicker being out, as is the case in kickball, this action by the defense reverses the direction that the base runners circle the bases. For example, if there is a runner on the base to the right of home plate (the standard "first" base) and the ball is caught, that runner proceeds back to home plate and scores a run, while the kicker runs to the standard "third" base to the left of the kicker. "Third" base then remains the first base the kicker will run to until the ball is again caught by a defender, or the inning ends. This rule is known as a "Valley Forge" and turns the direction of the runners, just as the American army emerging from the encampment at Valley Forge was a turning point in the American Revolutionary War.

The second unique rule occurs when a defensive player throws the ball at an offensive runner. If the ball bounces off the runner, the runner is simply out. However, if the runner is able to catch the ball in the air, then the runner remains out, but all of the runner's teammates on or between the bases automatically score. In essence, the runner becomes a martyr and sacrifices themselves to help their team. This action is called a "Crispus" in reference to Crispus Attucks, who became

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Figure 1. Two adolescent players holding a regulation Independenceball.

Figure 2. A photograph of an Independenceball match played in July, 2024.

the first casualty and martyr of the Revolutionary War when he was killed on March 5, 1770 during the Boston massacre.

Independenceball is a young sport, and many rules continue to be debated as controversies present during gameplay. For instance, it was determined to be legal to have more than one runner on a single base at the same time, as this is not explicitly forbidden by the rules. Ideally the two teams consist of adults on one side, and children on the other. In the first three successive matches of Independenceball, in 2022, 2023, and 2024, participation was compulsory and all those present were expected to take part. There was no formal period for warming up or discussion of potential risks.

CASE REPORT

At the time of injury, the patient was a 52-year-old healthy female with a past medical history significant only for mild hypothyroidism managed effectively with 50 mcg daily of Synthroid (most recent Thyroid Stimulating Hormone level of 2.05 µIU/mL [range 0.27-4.20 µIU/mL] prior to injury). She did not have a history of treatment with steroids (systemic or injected), prior tendon injury, or prior hip or gluteal pain. She currently works as a fitness instructor and was a competitive cheerleader in high school.

Her turn kicking for Independenceball was initially uneventful. She made solid contact with the ball and kicked it into the outfield, sending the defensive players scrambling to collect the ball and limit the offense's advancement around the bases. As she rounded first base and continued toward second, she had visible pain in the posterior aspect of her right proximal thigh, causing her to slow abruptly and limp to second base in clear discomfort. This was witnessed by three orthopaedic surgeons, one a team physician for a major university, all who had immediate suspicion for an acute hamstring injury. She was able to walk with assistance and a limp but did not require presentation in the Emergency Department and was neurovascularly intact. Pain was controlled at rest but was significant with any attempt at ambulation with tenderness in the proximal posterior thigh.

Five days after the injury she continued to have substantial pain with activity, was not able to return to work, and presented to the Sports Medicine Clinic. She was evaluated with plain x-rays (Fig. 3) and a physical examination. Her physical examination demonstrated bruising along the right posterior medial thigh, distally nearly to the knee. She did not have any obvious deformity or asymmetry of her thighs, but did have tenderness over the ischial tuberosity and biceps femoris origin. She had pain with resisted knee flexion but retained 5/5 strength. The x-rays demonstrated calcification near the ischium and origin of the hamstrings, suggestive of chronic tendinosis or a prior subclinical insult as a potential contributor to the current injury. She was diagnosed with a proximal to mid-substance hamstring strain and referred to physical therapy.

Over the course of the next six weeks, she had three formal physical therapy visits and continued to improve. She returned to work as a fitness instruction one month from the injury and felt fully recovered at 5 months.

DISCUSSION

Muscle injuries are common among athletes of all ages. Hamstring tears specifically account for 30% of lower extremity injuries with a substantial rate of re-injury (12-31%).[1] Sports that require intense moments of lower

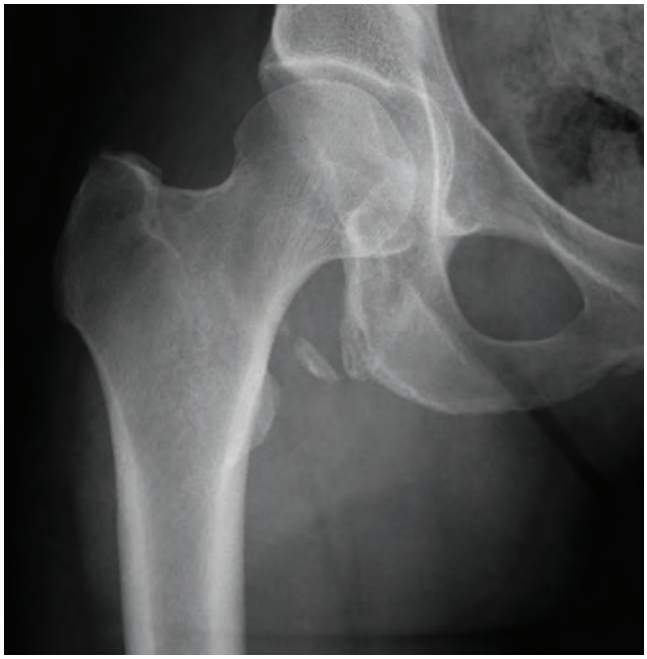

Figure 3. Right hip x-ray demonstrating calcifications adjacent to the ischial tuberosity and hamstring origin.

extremity acceleration (soccer, football, running, jumping) are of highest risk and the severity of injury can vary from minor disruption of muscle fibers to complete tears. The injury is thought to occur during eccentric contraction just after the swing phase of gait during heel strike with the hamstring on maximal tension. The anatomy of the hamstrings (biceps femoris, semimembranosis, and semitendinosis) is such that they cross both the hip and knee joints which likely contributes to the high rate of injury relative to other muscles and tendons. The biceps femoris is most commonly injured. Risk factors include inadequate preparation (e.g. deconditioning, no warming up, dehydration), muscular imbalance, anatomic anomalies, and prior injury.[1] Uncontrolled hypothyroidism has been postulated as a causal factor for a tendon rupture but is unlikely to be a contributing factor in this patient.[2]

This patient was in very good physical health, supported by her vocation as a fitness instructor. In this case the explanation for the injury is potentially threefold. First, she was a competitive cheerleader earlier in life, and her x-ray demonstrated calcifications that could represent chronic tendinosis or pre-existing pathology, predisposing her to an acute-on-chronic injury.[3] Second, she did not have any formal warm-up prior to participation. Finally, her middle-aged status likely contributed to her propensity for injury.

Age has been demonstrated clinically as an independent risk factor for hamstring injuries.[4] The reasons for this are not settled, but postulations include decreased muscle mass, strength, changes to muscle structure, increased body weight, and decreased flexibility. There are known biologic changes to muscle that have an impact on physiology, notability reduced efficacy of muscle stem cells,[5] aberrant signaling between stem cells and the extracellular matrix,[6] and increased fibrosis of skeletal muscle,[7] all leading to impairments of muscle regeneration. Although primarily applied to the elderly (sarcopenic) population, age-related changes are a continuum that show gradual attenuation and increased susceptibility to injury as one ages.

Hamstring injury management is guided by the severity of injury. Operative repair is recommended for complete tears of more than one proximal tendon and avulsion fractures of the ischium with >2 cm of displacement.[1] The majority of injuries are myofascial and can be treated nonoperatively.[3] An initial period of rest, ice, compression, and elevation can be followed by progression of strengthening and stretching as tolerated. Running should be limited for at least 6 weeks in higher grade tears and only when pain has resolved. The risk of retear remains significant and increases with the grade of the injury.

The role of prevention of hamstring injuries has been extensively studied and was summarized in a meta-analysis of 108 randomized controlled trials.[8] Eccentric strengthening can reduce injury and improve strength while stretching is more successful at increasing flexibility. Implementation of a warm-up that includes stretching, strengthening, balance, and agility has also been shown to reduce lower extremity injuries in certain populations.[9]

To conclude, hamstring injuries are common in athletes of all ages; the risk of injury increases with age and in sports that require explosive eccentric hamstring contraction. Most injuries may be treated nonoperatively but may take several months to recover with a substantial rate of retear. In future Independenceball games, participants will be informed about the possible risk of injury (especially in the more seasoned recreational athletes), participation will be voluntary, and participants will be led in a warm-up of dynamic stretching and light jogging prior to the first pitch. As Independenceball gains in popularity nationally, this will remain a consistent recommendation to participants, hosts, and sanctioned governing bodies.

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LONG HEAD OF BICEPS TENDINOPATHY: A SCOPING REVIEW OF CLASSIFICATIONS AND PROPOSED NOVEL CLASSIFICATION SYSTEM

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ABSTRACT

Background: While authors have subclassified long head of biceps tendon (LHBT) lesions in numerous ways, there is no classification system based solely on the arthroscopic appearance of the LHBT. We present a scoping review of the existing classification systems for LHBT tendinopathy and propose a novel classification based on its intraoperative, arthroscopic appearance.

Methods: We conducted a comprehensive search of classification systems for LHBT pathology using EMBASE and Ovid-Medline platforms. Our proposed classification system consists of four types based on intraoperative arthroscopic appearance of the LHBT: normal (A), erythema without fraying (B), fraying (C), and labral anchor instability (D). Fourteen arthroscopic videos and thirteen photos were reviewed by three orthopaedic sports medicine surgeons and two orthopaedic sports medicine fellows. Intra-and inter-observer reliability were assessed using Krippendorff's Alpha (α).

Results: Seventeen full length articles were included in our review, including classification systems based on visual characteristics, advanced imaging, and histology. For our proposed classification, there was excellent inter- and intra-observer reliability between all reviewers (α=0.92). Inter-observer reliability when reviewing arthroscopic photos was also excellent (α=0.81). There was excellent agreement for all reviewers between video and photo cases (α=0.81).

Conclusion: The current literature lacks a concise classification system for LHBT tendinopathy based on its intraoperative, arthroscopic appearance. Our proposed classification system is intended to offer a simple and reproducible way to describe LHBT tendinopathy based on intraoperative arthroscopic appearance of the tendon. This classification has excellent inter- and intra-observer reliability when reviewing arthroscopic video cases as well as excellent inter-observer reliability when reviewing arthroscopic photos. This serves as a validation of classification for a future planned randomized control trial comparing LHBT tenodesis to benign neglect in the setting of rotator cuff repair.

Level of Evidence: III

Keywords: long head of biceps tendon, biceps tendinopathy, classification, shoulder arthroscopy

INTRODUCTION

The long head of biceps brachii tendon (LHBT) is a known generator of shoulder pain. Its importance as an active shoulder stabilizer is debated but it is, at a minimum, a passive stabilizer of the glenohumeral joint.[1] LHBT pathology comprises a spectrum of disease and includes tenosynovitis, tendonitis, tendinosis, partial tears, instability, and tendon rupture.[2,3] Pathology of the tendon may present as a primary process, originating in the tendon itself, or secondary to concomitant injuries to other shoulder structures such as a rotator cuff tears (RCT).[1] LHBT pathology is most commonly described in the setting of concomitant shoulder pathology including supraspinatus and subscapularis tears, superior glenohumeral and coracohumeral ligament tears, and labral lesions.[4-10]

LHBT disorders have long been described in medical journals and the language of these descriptions has evolved in stride with advancements in medical diagnostics. The earliest recognition of these include anatomic descriptions from open surgery and cadaveric dissections.[11] The paradigm shift from open to arthroscopic shoulder surgery has made intraarticular visualization the gold standard for assessing intraarticular tendon pathology as it facilitates dynamic evaluation and real-time treatment decision making.[12-14] With the development of radiographs, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography, nuances in LHBT pathology have been further appreciated.[15]

Management of LHBT pathology is influenced by the preoperative examination, age, activity level, cosmetic concerns, concomitant pathology, goals of the surgery, surgeon experience, and intraarticular appearance of the tendon. Treatment can be conservative or surgical,

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consisting of tenotomy with or without tenodesis. Debate continues regarding the proper surgical treatment when conservative measures fail, but prospective cohort studies to guide treatment protocols are lacking.[2,15,16] Undertaking such studies is complicated by an absence of a commonly used and validated classification system to accurately characterize the arthroscopic appearance of LHBT pathology intraoperatively.

Classification systems are widely used in orthopaedic surgery, and when successful, improve communication, inform treatment decisions, and advance long term outcomes.[17-20] Previous authors have subclassified LHBT lesions in numerous ways, including bicipital groove instability, degree of tendinopathy, region of disease, amount of tendon tearing, anchor instability at the labrum, or as a modifier for a classification of neighboring structures.[3,5,10,21-25] This has resulted in a heterogenous body of literature making comparison of outcomes challenging and treatment guidance vague. The primary purpose of this scoping review is to summarize the existing classification systems for long head of biceps tendinopathy. Due to the limitations with previous systems, we propose a new system based on arthroscopic appearance of the LHBT and demonstrate how this new system adds diagnostic value by establishing a common reproducible classification for future prospective clinical studies. We hypothesized that our classification would have excellent intra- and interobserver reliability when reviewing arthroscopic videos and photos.

SCOPING REVIEW

Search Strategy

We conducted a comprehensive search of existing classification systems for LHBT pathology using EMBASE and Ovid-Medline platforms, adherent to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. We included all studies that referenced or described a classification system for LHBT pathology. Non-English studies and those not referencing or describing a classification system for LHBT tendinopathy were excluded. Each title was reviewed by two of the authors. Titles were excluded if the LHBT was not referenced. Abstracts were reviewed and full manuscripts were included if the abstract referenced a classification system that included LHBT pathology.

Study Selection

A flowchart of included studies can be found in Figure 1. Our initial literature search yielded 362 papers. A review of relevance reference was performed which identified an additional 3 articles. Sixty-eight duplicates were removed. 229 papers were excluded due to clear lack of relevance based on title. A total of 68 abstracts were reviewed and 46 were excluded as they did not reference the LHBT, LHBT tendinopathy, or classification for LHBT tendinopathy. 22 full articles were reviewed in their entirety, with 5 not proposing a specific classification system for LHBT tendinopathy. Seventeen articles were therefore included in final analysis.

Review of Existing Classification Characteristics

Previous studies have attempted to subclassify LHBT lesions based on characteristics including bicipital groove instability, degree of tendinopathy, region of disease, amount of tendon tearing, and degree of anchor instability at the labrum.[3,5,10,21-25] These studies can be broadly divided into those based on arthroscopic visualization, advanced imaging, and histopathology. The most relevant studies are summarized in Table 1.

Classifications Based on Arthroscopic Visualization

Snyder and colleagues originally described superior labrum anterior and posterior (SLAP) lesions in 1990.[3] This study was based on retrospective review of arthroscopic images of superior labral pathology in 27 shoulders and was the first of its kind. LHBT pathology was included in category II, which indicates degenerative fraying of the superior labrum and detachment of the superior labrum and biceps tendon from the glenoid, and IV, bucket handle superior labral tear extending into the LHBT root. In their study, LHBT pathology was involved in 56% of SLAP lesions. This study has been expanded and reassessed by numerous authors, but the original system remains widely used.[26,27]

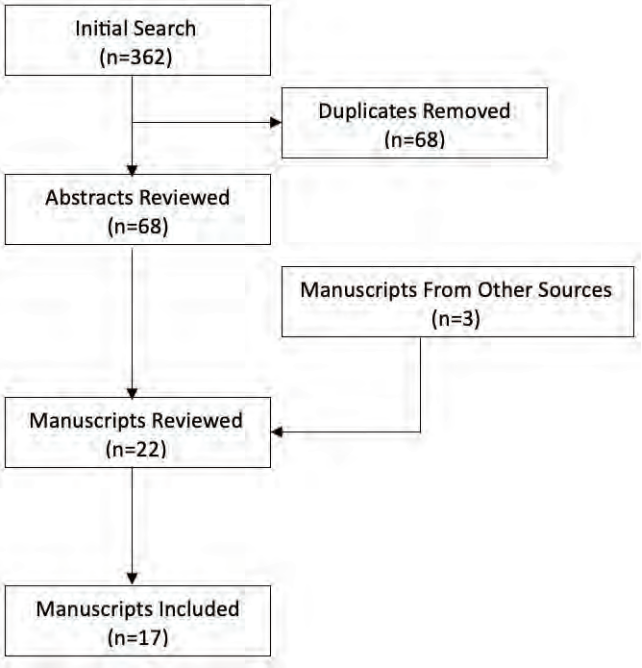

Figure 1. Literature search PRISMA diagram.

The 2007 classification by Lafosse et al. categorized LHBT injury based on the direction of instability of the tendon within the bicipital groove in the setting of rotator cuff tear (RCT).[5] Lafosse and colleagues further categorized LHBT lesions based on arthroscopic appearance. The authors reviewed 200 shoulders with known rotator cuff pathology and found a 55% prevalence of LHBT lesions. Their categorization system included 4 components: direction of instability, extent of instability, macroscopic tendon lesion, and the size of the rotator cuff lesion. LHBT lesions specifically were divided into grade 0 (normal tendon), grade I (minor lesion, defined as less than 50% erosion or loss of tendon), and grade II (major lesion, defined as greater than 50% erosion or loss of tendon).

Recently, Cardoso et al. evaluated 58 patients diagnosed with RCTs, subacromial impingement, or anterior instability and measured the width, depth and cross-sectional area of the bicipital groove using ultrasonography.[28] These patients then underwent arthroscopic surgery and health of the biceps was classified. They found no significant correlation between LHBT pathology and morphology of the bicipital groove. In a slight variation of LaFosse's description of macroscopic lesions,

Table 1. Summaries of Notable LHBT Classification Systems

Author (Year)	Purpose	Relevance to LHBT pathology	Relevant portions of classification system	Validation	Notable Characterists
Snyder[1] (1990)	Provided description and characterization of injury to the superior labrum, coined "SLAP" tear	Included description of LHBT anchor instability as a modifier of labral pathology.	Type II: Detached superior labrum and biceps anchor Type IV: Bucket-handle tear with extension into the bicep tendon root	Low to moderate interobserver agreement	Highlighted role of LHBT pathology, but only as it related to anchor instability.
LaFosse[2] (2007)	Described LHBT instability and tendinopathic appearance in setting of RCR	Demonstrated lesions of LHBT strongly to be associated with instability and size of RCT. Established widely used arthroscopic descriptor of LHBT appearance.	Descriptions of LHBT based on arthroscopic appearance: - Grade 0: Normal - Grade I: Minor lesion; localized partial loss or erosions of less than 50% of the diameter of the tendon - Grade II: Major lesion; extensive loss or erosions of more than 50% of the tendon's diameter with fraying equalizing a partial LHB rupture	Substantial intra-observer agreement for all grades Substantial, fair, and moderate Inter-observer agreement for Grades 0, 1, and 2 respectively[3]	Established now widely used description system but with demonstrated fair and moderate interobserver agreement.
Candela[5] (2021)	Evaluated the association between RCT size and LHBT pathology	LHBT pathology classification system based on 3 locations, 3 degrees of tendon inflammation, 2 degrees of section alteration, and 3 degrees of tendon integrity.	Location: - A: insertional - B: free intra-articular portion - C: the portion that enters the intertubercular groove Inflammation - 0: no inflammation - 1: low to medium-grade severity (characterized by a light red color) - 2: high-grade severity (characterized by a heavy red color) Section - 0: normal section - 1: flattened tendon Integrity - 0: normal tendon - 1: low-grade delamination (> 50% of residual tendon thickness) - 2: high-grade delamination (<50% of residual tendon thickness)	Demonstrated good to excellent intraclass correlation coefficients for all their parameters including degree of inflammation, section alteration, and tendon integrity	More detailed system, excellent interobserver correlation between 3 physicians. Notable lack of description of anchor instability.
Lu et al[6] (2022)	Described anatomic variants of LHBT with pathologic lesions in setting of RCT	RCT size but not anatomic variations were significant risk factors of LHBT lesions	LHBT descriptions - Normal - Tendinitis - Subluxation or dislocation - Partial tear - SLAP tear	Demonstrated excellent intra- and inter-observer reliability	Similar descriptive terms to LaFosse and Snyder. Type assigned to most severe pathology when multiple present.

LHBT: Long head of biceps tendon; RCT: Rotator cuff tear; RTCR: Rotator cuff repair; US: ultrasound; CSA: cross-sectional area.

Table 2. Reliability Scores of Novel Classification System

Medium	Reliability	Subjects	α	Lower CI	Upper CI
Video	Inter	All	0.92	0.90	0.94
Video	Inter	Attendings	0.88	0.81	0.94
Video	Inter	Fellows	0.96	0.92	0.98
Photo	Inter	All	0.81	0.76	0.85
Photo	Inter	Attendings	0.68	0.56	0.80
Photo	Inter	Fellows	0.75	0.60	0.87
Video	Intra	All	0.92	0.81	0.99
Video	Intra	Attendings	0.88	0.71	0.99
Video	Intra	Fellows	0.97	0.91	1.00
Photo	Intra	All	0.71	0.50	0.88
Photo	Intra	Attendings	0.68	0.38	0.92
Photo	Intra	Fellows	0.74	0.46	0.93
Video-Photo	Agreement	All	0.81	0.70	0.90
Video-Photo	Agreement	Attendings	0.77	0.61	0.91
Video-Photo	Agreement	Fellows	0.85	0.70	0.95

CI: confidence interval.

the study described LHBT as normal, tendinopathic (inflamed or frayed appearance), tendinopathic involving <50% of tendon thickness, tendinopatic involving >50% of tendon thickness, or complete rupture.

Lu et al. evaluated the correlation of anatomic variants of the LHBT anchor with pathologic lesions in the setting of RCT.[29] These authors categorized the LHBT as entirely posterior, posterior-dominant, or equal in its attachment to the glenoid labrum. The intraoperative appearance of the tendon was then classified as an adaptation of a previously described Habermayer-Walch classification, and included normal, tendinitis, subluxation or dislocation, partial tear, or SLAP tear. When multiple lesions were described, the LHBT pathologic type was classified according to the major lesion. Intra-observer reliability and inter-observer reliability were assessed by two examiners and found excellent agreement. The authors did not discover a correlation between LHBT orientation and lesions in the setting of RCT.[29]

Using a similar classification, Chen et al. has published multiple studies aimed at classifying LHBT pathology in the setting of RCT. Their classification system includes 6 types: tendinitis, subluxation, dislocation, partial tear, complete rupture, or SLAP tear.[30,31] These authors demonstrated that 82% of RCR cases demonstrated some LHBT pathology, with the largest percentage of cases (33%) being categorized type 1. The authors also reported that LHBT lesions were associated with RCTs of longer duration, larger size, and involvement of the subscapularis.

Two studies have categorized LHBT based on location: intra-articular, within the bicipital groove, or junctional.[25,32] The most robust of these classification systems was recently proposed by Candela et al., which aimed to assess LHBT pathology in the setting of RCTs.[25] In their system, the authors divided the intraarticular LHBT into 3 portions: the insertional element, the free intra-articular portion, and the section entering the intertubercular groove. Their study assessed inflammation, section alteration (i.e., tendon flattening), and tendon integrity. These authors demonstrated good to excellent intra-class correlation coefficients for all their parameters including degree of inflammation, section alteration, and tendon integrity after review by 3 physicians. They used this system during the assessment of 202 patients who underwent arthroscopic RCR and found that the degree of LHBT pathology was associated with the size of the RCT in the number of sections involved (insertional being the most common) as well as with morphological section alteration and degree of loss of integrity. However, the presence of anchor instability is lacking from this system, and its focus on different anatomic regions within the tendon make it overly complex for a prospective trial.

Another study by Benhenneda et al. used an array of individual pathologic lesions seen arthroscopically to diagnose LHBT injuries.[33] These authors simply classified the LHBT as "normal" or "pathological" based on the presence of tearing, hourglass deformity, instability, fissure, SLAP tear, chondral print, or pathologic pulley.[33] This study found varying levels of inter-observer agreement.

Classifications Based on Advanced Imaging

Kim et al. sought to classify LHBT injuries based on MRI findings and then determine the accuracy of abnormal MRI features in identifying arthroscopic features including tendon shape, fraying, and extent of the tear.[34] The authors presented a classification based on LHBT shape, fraying and extent of tearing.[34] This study had five individual grades: normal appearing tendon without fraying (1), fraying extending into the bicipital groove (2), partial tearing involving less than 50% of the tendon (3), partial tearing involving greater than 50% of the tendon width (4), and complete tendon tearing (5).

A study by Teixeira et al. evaluated the ability of CT arthrography to diagnosis LHBT lesions. The authors compared imaging findings to arthroscopic inspection and generalized LHBT lesions only as normal, tendinopathic, or ruptured.[35] Two manuscripts have also graded LHBT injuries based on the amount of inflammatory change seen under ultrasonography.[36,37]

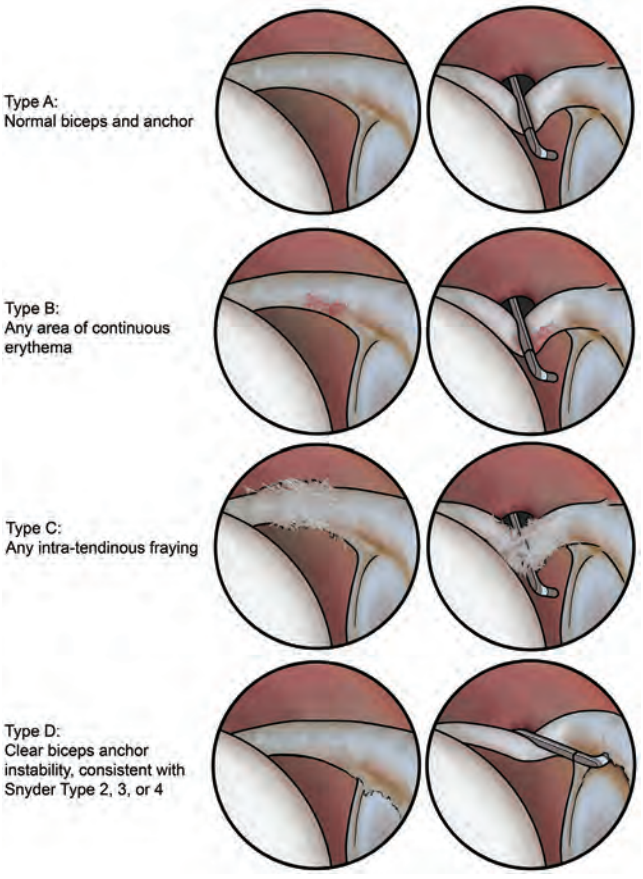

Figure 2. Illustration depicting novel classification system for long head of biceps tendinopathy.

Classifications Based on Histology

Macro- and microscopic histopathology have been used to grade severity of LHBT tendinitis by one study.[38] Wu et al. compared LHBT histology from 34 patients with chronic RCT to 8 patients undergoing hemiarthroplasty. Histology was graded on a scale of 1 to 4 based on severity of features. The authors did not demonstrate a correlation between histology and macroscopic features or duration of symptoms.

PROPOSAL OF A NOVEL CLASSIFICATION SYSTEM

Proposed Classification System and Validation Strategy

This study was approved by the institutional review board of our institution. Using the information gained from our scoping review, we propose a new classification system for LHBT tendinopathy. This system is based on the intraoperative, arthroscopic appearance of the LHBT and its superior labral anchor, consisting of four types: normal appearance (A), erythema without tendinous fraying (B), tendinous fraying (C), and labral anchor instability (D). An illustration demonstrating this classification is given in Figure 2, while example arthroscopic images are shown in Figure 3. When multiple pathologic elements are visualized, the classification defaults to the higher letter indicating greater severity. For example, if a biceps tendon appears both erythematous (B) and with an unstable labral anchor (D), then it would be classified as a type D.

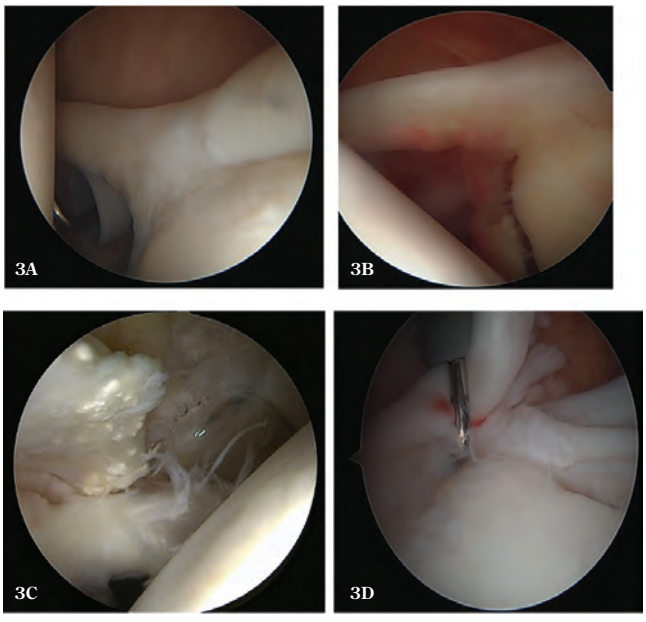

Figure 3A to 3D. Arthroscopic photograms depicting novel classification system. Type (3A) top left, (3B) top right, (3C) bottom left, and (3D) bottom right.

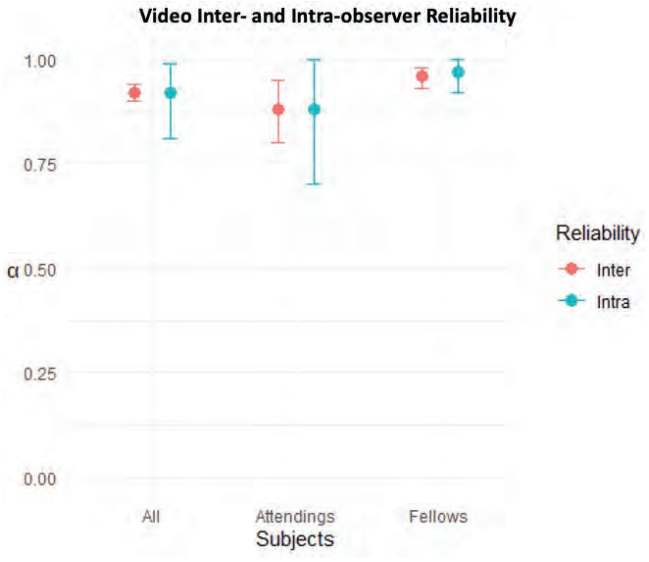

Figure 4. Inter- and intra-observer reliability of novel classification system based on arthroscopic video.

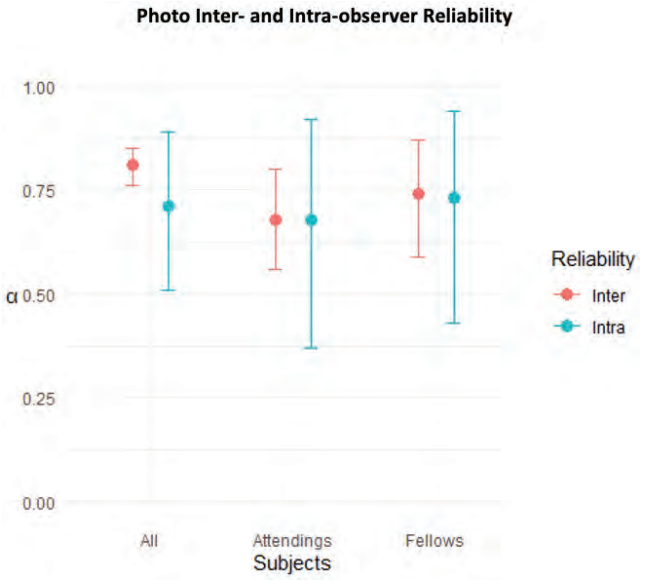

Figure 5. Inter- and intra-observer reliability of novel classification system based on arthroscopic photographs.

Fourteen arthroscopic videos and thirteen arthroscopic photos were reviewed by five surgeons including three fellowship-trained orthopaedic sports medicine surgeons and two orthopaedic sports medicine fellows. Cases were reviewed by each reviewer twice, three weeks apart. The classification system in this study was an ordinal system and therefore Krippendorff's alpha coefficient[39] (α) was used to measure both intra- an inter-rater reliability. This reliability coefficient is calculated as the ratio of observed disagreement/expected disagreement, where $\alpha \geq 0.80$ is considered excellent agreement and $\alpha = 0.667$ is considered the lowest level of acceptable agreement.[40] Bootstrapped 95% confidence intervals were calculated and all analysis were completed in R version 4.2.1.

Reliability of Novel Classification

Reliability analyses, as well as plots demonstrating these results, can be found in Table 2 and Figures 4-6, respectively. Inter-observer reliability when reviewing video cases was excellent between all reviewers (α=0.92), as well as when stratified into attending surgeons (α= 0.88) and fellows (α=0.96) alone (Figure 4). Intra-observer reliability for video cases was also excellent across all reviewers (α=0.92), attendings (α=0.88), and fellows (α=0.97). Inter-observer reliability when reviewing arthroscopic photos was excellent across all reviewers collectively (α=0.81) but less satisfactory for attending surgeons and fellows individually (α=0.68 and α=0.75, respectively; Figure 5). No group met excellent intra-observer reliability when reviewing arthroscopic photos alone (all: α=0.71; attendings: α=0.68; fellows: α=0.74). There was excellent agreement for all reviewers between video and photo cases (α=0.81; Figure 6).

DISCUSSION

The present study has two aims: first it provides a scoping review of current classification systems for LHBT pathology. Despite the number and variety of LHBT classification systems, a simple and reliable classification system focusing purely on the intraoperative appearance of the LHBT is lacking. Second, we present a novel classification system based on arthroscopic appearance of the LHBT which has excellent intra- and interobserver reliability on review of arthroscopic videos. A comparison of our classification to the most similar existing systems is offered here as is our justification for its use.

Like our proposed classification system, multiple previous studies have also sought to classify the LHBT based on arthroscopic appearance, the earliest example offered by Snyder et al.[3] While it is a useful classification system, several subsequent studies investigating intra- and interobserver reliability have called into question the reproducibility and prognostic value of the system's categorizations.[27] Importantly, the Snyder classification system was designed for labral pathology, focusing on detachment and instability of the LHBT at its labral anchor, and does not account for other commonly observed LHBT pathologies, such as erythema and fraying.[16]

Lafosse et al. proposed what is likely the most widely used classification system for arthroscopic appearance of the LHBT.[5] This study highlighted the importance

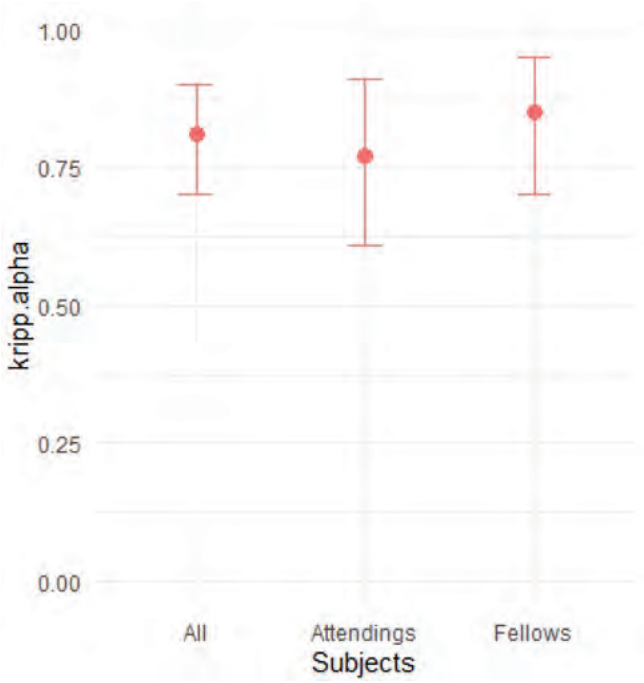

Figure 6. Agreement in classification between arthroscopic video and photographs.

of characterizing the extent of the tendon lesion based on arthroscopic appearance. The authors recommend LHBT tenodesis in all grade II lesions regardless of the status of LHBT instability or rotator cuff. This study was conducted by a single surgeon and therefore could not report intra- or interobserver reliability and did not include lesions at the biceps anchor in their system. Furthermore, their cut-off of 50% between "minor" and "major" lesions is relatively arbitrary. A 2011 study from the Multicenter Orthopedic Outcomes Network (MOON) Shoulder Group assessed the system to determine a consensus on arthroscopic grading. They found substantial intraobserver reliability in all LaFosse grades, but only fair and moderate agreement in grades 1 and 2 respectively and concluded that there is a need for a more reliable grading system.[41] Despite the Lafosse system's flaws, more recent studies on LHBT pathology have continued to utilize this classification system.[42] Cardoso et al., for example, proposed an adapted form of the Lafosse classification, but maintained the previously-discussed disadvantages of a cut-off of 50% tendon erosion between "minor" and "major" tears.[28]

In the classification presented by Kim et al., the arthroscopic appearance of the LHBT was described and correlated to MRI findings. While comprehensive, this classification was built for the purpose of correlating MRI findings to arthroscopic appearance, was not individually validated, did not aim to guide treatment outside of MRI findings, and again sets the relatively arbitrary cut-off of 50% tendon tearing between grades 2 and 3. Furthermore, this classification system did not include instability of the bicipital anchor at the labrum, which is a common indication for surgery.

Upon the foundations laid by these previous authors, we offer our system for use during an arthroscopic evaluation of the LHBT. The grading begins with a normal tendon, without visible pathology, erythema, fraying or anchor instability. We appreciate two more advanced forms of tendonitis, our first grade representing erythema without tendinous fraying, and the second grade representing any degree of tendinous fraying. A separate grade is reserved for labral anchor instability.

This is notably more simplistic system than that proposed by Candela et al., who grade both the severity of inflammation and the integrity of the tendon as a percentage of delamination and fraying.[25] The additional description of the anatomic area of the disease and degree of delamination results in a very descriptive but perhaps overly complex system. Our simplified description of tendon pathology is most like the descriptions by Habermayer-Walch and then Lu et al. who demonstrated excellent intra- and inter-observer reliability with their descriptions of the LHBT as normal, tendinitis, subluxation/dislocation, partial tear, SLAP tear.[29]

Our proposed classification has excellent inter- and intra-observer reliability when reviewing arthroscopic video cases as well as excellent inter-observer reliability when reviewing arthroscopic photos alone. The superior reliability associated with classifying video cases reflects the benefit of assessing a three-dimensional structure dynamically and highlights the importance of dynamic evaluation is classifying LHBT pathology. The advantages of our proposed classification system lie in its simplicity, reproducibility, and specificity to the LHBT. Through this study, we have aimed to describe a straightforward, reliable system for grading arthroscopic appearance of the LHBT that can be easily applied by orthopaedic surgeons.

Limitations

Our present study is not without limitations. Our number of reviewers is small but similar to previous examples in the literature. The results were derived from recorded videos or still images and thus classification of each case may be less accurate as compared to a live, in vivo assessment. Additionally, the reviewers were of different skill level and experience, and all associated with a single institution putting the results at risk of confounding by sampling bias. The current study does not suggest treatment decisions based on our classification nor does it report patient outcomes.

CONCLUSION

In this article we provide a scoping review of current classification systems for LHBT injuries. We review the most prominent classification systems and highlight their range, utility and drawbacks. Notably, there are few systems which focus specifically on the intraoperative, arthroscopic appearance of the LHBT and of those that do exist, inter- and intra-observer reliability is lacking. This reality complicates efforts for the development of randomized controlled studies. With this background, we propose a simple method for classifying the intraoperative arthroscopic appearance of the LHBT. This classification has excellent inter- and intra-observer reliability between orthopaedic sports medicine surgeons and fellows when reviewing arthroscopic video cases, excellent inter-observer reliability when reviewing arthroscopic photos alone, and excellent agreement between video and photo cases. This study serves as a validation of a novel classification for a future planned randomized control trial comparing LHBT tenodesis to benign neglect in the setting of rotator cuff repair.

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THE IMPACT OF METABOLIC SYNDROME ON 30-DAY OUTCOMES IN GERIATRIC DISTAL FEMUR FRACTURE SURGERIES

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ABSTRACT

Background: Distal femur fractures are a rising cause of morbidity among the US aging population. Due to the urgent nature of orthopaedic trauma management, preoperative optimization is often limited. Metabolic syndrome (MetS), defined by abdominal obesity, hypertriglyceridemia, dyslipidemia, hyperglycemia, and hypertension, has been associated with increased risk of postoperative complications among many surgical subspecialties. The purpose of the study was to investigate the impact of MetS on postoperative outcomes of patients with distal femur fractures.

Methods: The ACS-NSQIP database was queried for patients with distal femur fracture between 2015-2021. Patients were matched for demographics, comorbidities, and pre- and intraoperative variables using Pearson-Chi square tests. Postoperative complications were compared between groups using univariate and multivariable logistic regression analyses..

Results: 516 (14.2%) of distal femur fracture patients had a diagnosis of MetS. MetS was significantly associated with higher odds of acute renal failure (OR 2.72 [95% CI 1.02-6.90]; p = 0.038), cardiac arrest (OR 3.13 [95% CI 1.28 - 7.27]; p = 0.009), and non-home discharge (OR 1.36 [95% CI 1.06 -1.76]; p=0.018) (Table 1). There was no statistically significant difference in length of stay, surgical site infection, myocardial infarction, stroke, deep venous thrombosis, pulmonary embolism, 30-day mortality, or reoperation rate between MetS and non-MetS group.

Conclusion: When compared to distal femur fracture patients without MetS, MetS patients were likely to be age > 70, on dialysis, with a history of congestive heart failure, and have bleeding disorders. Further, MetS patients had higher odds of adverse 30-day outcomes and non-home discharge.

Level of Evidence: III

Keywords: distal femur, fracture, trauma, geriatric

INTRODUCTION

Lower extremity fragility fractures are a rising cause of disability and death for the United States' aging population.1 Distal femur fractures make up approximately 5% of all femur fractures, with an incidence of 4.5 cases per 100,000 individuals annually. Notably, over half of these fractures are observed in individuals aged 70 years and older.[1] Surgical fixation of these fractures is one of the most demanding orthopaedic surgical procedures, complicated by the involvement of osteoporotic bone or by the fracture being comminuted, intra-articular, or periprosthetic, yet distal femur fracture incidence continues to rise.[2-5] The increased rate of total knee arthroplasty, which is estimated to increase to 3.5 million procedures annually by 2030, has led to a concurrent increase in periprosthetic femur fractures.[5] Common management of distal femur fractures include operative fixation with single or dual-plate fixation, intramedullary nail, combination of nail and plate, and even distal femur replacement.[6-8] Although outcomes are favorable with adequate reduction and fixation, some patients will suffer long-term sequelae of fracture nonunion, post-traumatic arthritis, and post-operative infection.[8-10]

Due to the urgent nature of orthopaedic trauma management, preoperative optimization is often limited. However, a growing body of literature in elective orthopaedic surgery procedures has shed light on the

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Table 1. Baseline Clinical Characteristics Between MetS and Control (No MetS) Groups

Characteristic	MetS	No MetS	p value
Age(years)			**<0.001**
65-69	139 (26.9%)	449 (14.4%)	
70-79	238 (46.1%)	1071 (34.4%)	
80-89	115 (22.3%)	1090 (35.0%)	
90+	24 (4.7%)	501 (16.1%)	
Race			**<0.001**
White	394 (76.4%)	2418 (77.7%)	
Black or African American	50 (9.7%)	177 (5.7%)	
Asian	7 (1.4%)	52 (1.7%)	
American Indian or Alaska Native	5 (1.0%)	23 (0.7%)	
Native Hawaiian/Pacific Islander	0 (0.0%)	2 (0.1%)	
Unknown/Not reported	3 (0.6%)	434 (14.0%)	
Other	1 (0.2%)	5 (0.1%)	
Gender			0.651
Female	426 (82.6%)	2539 (81.6%)	
Male	90 (17.4%)	572 (18.4%)	
Body Mass Index (BMI; kg/m^2)			**<0.001**
< 25	0 (0.0%)	1130 (36.3%)	
25-29.9	0 (0.0%)	998 (32.1%)	
30-34.9	196 (38%)	506 (16.3%)	
> 35	320 (62%)	477 (15.3%)	
Diabetes			**<0.001**
Insulin-Dependent Diabetes Mellitus	275 (53.3%)	213 (6.8%)	
Non-Insulin Dependent Diabetes Mellitus	241 (46.7%)	220 (7.1%)	
Smoker within the past year	34 (6.6%)	286 (9.2%)	0.065
Functional status prior to surgery			0.963
Independent	406 (78.7%)	2429 (78.1%)	
Partially Dependent	83 (16.1%)	519 (16.7%)	
Dependent	18 (3.5%)	115 (3.7%)	
Unknown	9 (1.7%)	48 (1.5%)	
Pre-operative Ventilator Use	3 (0.6%)	8 (0.3%)	0.419
History of Severe COPD	58 (11.2%)	300 (9.6%)	0.295
History of Congestive Heart Failure (CHF)	42 (8.1%)	161 (5.2%)	**0.009**
Hypertension Requiring Medication	516 (100%)	2126 (68.3%)	**<0.001**
Chronic Steroid Use	37 (7.2%)	173 (5.6%)	0.178
Bleeding Disorders	119 (23.1%)	482 (15.5%)	**<0.001**
> 1 Unit Transfused of RBCs 72h Before Surgery	47 (9.1%)	286 (9.2%)	0.999
Disseminated Cancer	7 (1.4%)	39 (1.3%)	0.999
Ascites	0 (0.0%)	7 (0.2%)	0.591
Dialysis	26 (5%)	74 (2.4%)	**0.001**

Table 1. Baseline Clinical Characteristics Between MetS and Control (No MetS) Groups (continued)

History of Systemic Sepsis			0.607
Prior Sepsis	5 (1.0%)	19 (0.6%)	
Prior Septic Shock	1 (0.2%)	3 (0.1%)	
Prior SIRS	59 (11.4%)	395 (12.7%)	
Preoperative Data			
Transferred from			**0.027**
Home	354 (68.6%)	2254 (72.5%)	
Nursing home/chronic care	28 (5.4%)	205 (6.6%)	
Acute care hospital inpatient	56 (10.9%)	236 (7.6%)	
Outside ED	69 (13.4%)	335 (10.8%)	
Other/unknown	9 (1.7%)	81 (2.6%)	
ASA Class			**<0.001**
I	1 (0.2%)	14 (0.5%)	
II	27 (5.2%)	543 (17.5%)	
III	373 (72.3%)	2000 (64.3%)	
IV	113 (21.9%)	544 (17.5%)	
V	0 (0.0%)	4 (0.1%)	
Time to operation			0.823
0-1 day	340 (65.9%)	2061 (66.2%)	
>1 day	176 (34.1%)	1050 (33.8%)	
Anesthesia Type			0.350
General	458 (88.8%)	2641 (84.9%)	
Other/Unknown	58 (11.2%)	470 (15.1%)	

effect of metabolic diseases and syndromes on patient outcomes. Metabolic syndrome (MetS) is considered present when a patient has a minimum of three criteria from the following list: (1) waist circumference >102 centimeters for males or >89 centimeters for females, (2) fasting triglycerides over 150 mg/dL, (3) fasting HDL less than 40 mg/dL for males or less than 50 mg/dL for females, (4) fasting glucose ≥100 mg/dL, (5) blood pressure ≥130/85 mmHg.[11,12] Over a third of adults and half of adults aged ≥60 years are diagnosed with MetS.[13] Patients with MetS have an increased risk for cardiovascular sequalae and all-cause mortality after operative intervention.[14,15]

The biochemical changes associated with MetS heighten the risk of surgical complications after fractures. While a causal relationship has not been established, patients diagnosed with fracture nonunion frequently have a diagnosis of MetS.[16,17] Further, MetS conditions, such as diabetes, are associated with a high risk of delayed wound healing and wound complications.[18]

The purpose of this project was to investigate the impact of MetS on post-operative outcomes among patients with distal femur fractures. Characterizing and understanding this association could lead to improved strategic care and surgical optimization for patients with MetS who sustain distal femur fracture.

METHODS

Database

The American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) was the source of data for this retrospective cohort study. ACS-NSQIP encompasses data from a network of more than 600 hospitals and captures 30-day perioperative data from different surgical specialties. The available data include demographics, comorbidities, intraoperative variables, and postoperative outcomes and are extracted from patients' medical records or through direct contact with patients after discharge. Variables are collected by a group of surgical and clinical reviewers that receive extensive training that results in a low inter-reviewer disagreement rate under 2%.[19] Institutional Review Board approval was not required.

ACS-NSQIP data were merged into a dataset. Primary Current Procedural Terminology (CPT) codes for distal femur fracture fixation (27509, 27511, 27513, 27514) were

used to identify patients that met inclusion criteria (aged ≥65, fixation between 01 January 2015 and 31 December 2021).[20]

Preoperative and surgical variables were requested and obtained from ACS-NSQIP. The body mass index (BMI) of patients was calculated using extracted height and weight variables for analysis (Figure 1). Metabolic syndrome (MetS) was defined according to established criteria, as previously employed in other ACS-NSQIP studies, which include the concurrent presence of (1) a BMI of ≥30 kg/m^2, (2) diabetes mellitus, and (3) hypertension requiring medication.[21] The study population was categorized into two distinct groups: (1) patients with metabolic syndrome (MetS) and (2) those without metabolic syndrome (non-MetS).

Variables

Data variables were categorized demographics, comorbidities, preoperative information, intraoperative details, and postoperative data. Table 1 provides a comprehensive breakdown of variables within each category. The postoperative variables under investigation included length of stay (LOS), defined as the number of days from surgery to discharge, discharge location, and outcomes within 30 days. LOS was categorized into two groups: 0 to 5 days and greater than 5 days, using the median LOS as the threshold. Table 2 presents the 30-day outcomes considered in the study.

Statistical Analysis

An initial comparison for differences in demographics, comorbidities, preoperative, and intraoperative data was completed using a Pearson-Chi square test without adjustments. Variables with a p-value <0.1 became adjusted covariates in logistic regression models, and Pearson–Chi-square tests were used to examine unadjusted significant associations between MetS and postoperative outcomes. Postoperative outcomes that had associations with a p-value <0.05 were subjected to individual multivariate logistic regression analysis. This analysis adjusted for significant covariates including age, race, American Society of Anesthesiologists (ASA) grade, bleeding disorders, dialysis, history of congestive heart failure (CHF) within 30 days prior to surgery, operative time, and transfer status. The aim was to assess the impact of MetS on 30-day outcomes exclusively. Multivariate logistic regression results were reported as adjusted odds ratios (OR) with 95% confidence intervals

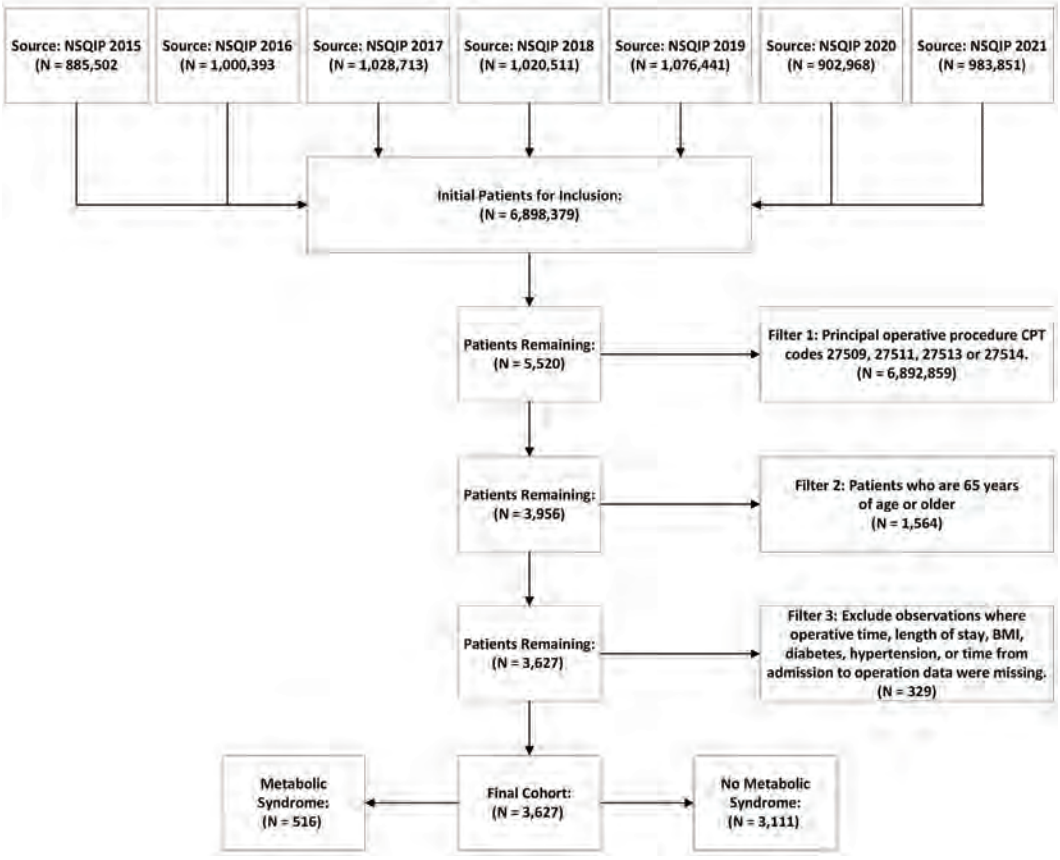

Figure 1. Source and Filter Flowchart. Study flowchart.

(CI). To retain the granularity of data and examine the potential linear relationship between MetS and LOS, a continuous analysis using multiple linear regression was performed. These complementary analytical frameworks were used to provide a thorough understanding of the impact of MetS on LOS. Any p value <0.05 was considered significant. Analyses for this study were completed using R-4.3.0 (R Core Team, Vienna, Austria).[22]

RESULTS

Baseline Characteristics

The study encompassed a total of 3,627 patients, among whom 516 individuals (14.2%) fulfilled the criteria for MetS. Table 1 provides an overview of the characteristics of the study cohort. Patients identified with MetS were more commonly found to be aged between 70 and 79 years, undergoing dialysis, with a history of CHF, bleeding disorders, and a higher American Society of Anesthesiologists (ASA) classification. MetS patients were also more likely to have been transferred from an outside emergency room or acute care hospital.

Outcomes

Table 2 displays the MetS and 30-day outcome unadjusted comparison. Utilizing a multivariate logistic regression model (adjusted for covariates and/or baseline differences outlined in Table 1), the MetS group exhibited significantly elevated odds of cardiac arrest (OR 3.13 [95% CI 1.28 - 7.27]; p=0.009), acute renal failure (OR 2.72 [95% CI 1.02-6.90]; p=0.038), and non-home discharge (OR 1.36 [95% CI 1.06 -1.76]; p=0.018) (Table 3). There were no significant differences in 30-day mortality, deep venous thrombosis (DVT), myocardial infarction, pulmonary embolism, re-operation rate, stroke, surgical site infection (SSI) or time to surgery between the MetS and non-MetS groups.

Factors associated with LOS are shown in table 4. A history of CHF and prolonged operative time were both significantly associated with LOS. CHF alone is associated with an increase LOS of 1.7 days. Likewise, for every extra minute of operative time, there was an associated increase of 0.005 days of stay, roughly equivalent to 7 minutes. In practical terms, every 15 minutes of surgery correlated with an additional 1.8 hours of stay. The small standard error for CHF and operative time suggests a precise estimate of the variability. MetS was associated with an increase LOS of 0.42, but this association was not significant (p=0.07).

DISCUSSION

Several population studies have demonstrated that MetS is associated with an increased risk for reduced bone mineral density (BMD) and fragility fractures.[23-26] As distal femur fracture incidence and MetS are projected to increase in the next decade, investigating the influence of metabolic disorders on outcomes of individuals with distal femur fractures is of importance. This study is the first to demonstrate correlation between MetS and distal femur fracture postoperative outcomes in geriatric patients. Importantly, we demonstrate that MetS is associated with increased risk of cardiac arrest, acute renal failure, and non-home discharge for geriatric patients with distal femur fracture that receive surgical management.

Complications and Non-Home Discharge

The presence of a MetS diagnosis in postoperative distal femur fracture patients was associated with a higher risk of cardiac arrest (p=0.003), acute renal failure (p=0.005), and non-home discharge (p=0.029) compared to non-MetS patients. These results are concordant with previous studies. Even among elective surgery populations with detailed preoperative risk mitigation, such as total joint arthroplasty, patients with MetS were more likely to be discharged to skilled nursing facilities.[27] Likewise in acute trauma settings, database studies of postoperative outcomes in hip and ankle fractures also found an increased non-home discharge among patients with MetS.[21,28]

Time to Surgery

In this study 65.9% of patients with MetS and 66.2% of patients with non-MetS had time to surgery <1 day. We found no difference in time to surgery between the two cohorts (p=0.823) (Table 1). This contrasts a previous study in hip fractures that reported that patients with MetS had a longer time to surgery, likely due to the longer time needed for medical optimization.[21] Though our patients with MetS had a high comorbidity burden, it does not seem to have played a role in time to surgery. As it stands, there is no consensus regarding the relationship between the outcomes of distal femur fractures and time to surgery, and this serves as a topic of future research.

Surgical Site Infections (SSI)

The study incidence of SSI was 1.5% overall, lower than the established literature value of 3.6%.[29] We did not observe a significant difference between MetS and non-MetS patients in the occurrence of deep SSI (0.6% v 0.3%, p=0.605). The likely reasons for this are attributed to the limitations of the database, which only captures SSIs diagnosed within the first 30-days following surgery. Known risk factors for SSI include diabetes mellitus, obesity, open fractures, preoperative reduced albumin level, smoking, and temporary use of external fixation.[29] Many manifestations of MetS have

Table 2. Unadjusted Analysis for Significant Complications Developing Between the Two Groups

Characteristic	MetS	No MetS	p value
Length of Stay (LOS/days)			**0.033**
0-5	249 (48.3%)	1662 (53.4%)	
> 5	267 (51.7%)	1449 (46.6%)	
Superficial SSI	5 (1.0%)	31 (1.0%)	0.999
Deep SSI	3 (0.6%)	10 (0.3%)	0.605
Organ/space SSI	2 (0.4%)	3 (0.1%)	0.312
Pneumonia	18 (3.5%)	101 (3.2%)	0.879
Pulmonary embolism (PE)	6 (1.2%)	40 (1.3%)	0.985
Acute Renal Failure	8 (1.6%)	13 (0.4%)	**0.005**
Urinary tract infection	31 (6.0%)	146 (4.7%)	0.241
CVA/Stroke	4 (0.8%)	18 (0.6%)	0.821
Myocardial infarction	9 (1.7%)	49 (1.6%)	0.925
Cardiac Arrest	10 (1.9%)	18 (0.6%)	**0.003**
Deep vein thrombosis (DVT)	5 (1.0%)	34 (1.1%)	0.982
Sepsis	5 (1.0%)	38 (1.2%)	0.786
Mortality	21 (4.1%)	125 (4.0%)	0.999
30-Day readmission	50 (9.7%)	246 (7.9%)	0.200
30-Day unplanned reoperation	13 (2.5%)	74 (2.4%)	0.970
Discharge destination			**0.029**
Home	94 (18.2%)	704 (22.6%)	
Non-home	422 (81.8%)	2407 (77.4%)	

been correlated with increased risk of SSIs, such as hypertension, hyperglycemia, and obesity. In particular, hypertension paradoxically increases the rate of SSIs. Whereas persistent hypertension increases the risk of SSI through greater intra-operative bleeding and poor perfusion of soft tissues, aggressive treatment of hypertension may also lead to a reduction of perfusion in the soft tissues and postpone wound healing.[30] Similarly, stress hyperglycemia among patients with no known history of diabetes, induces microvascular dysfunction which results in reduced tissue perfusion, predisposing tissues to infections.[31-33] Finally, patients with BMI>30 were five times more likely to have SSI after surgery than non-obese patients.[34] Technical difficulties secondary to the excess soft tissue lead to longer operative times and tissue trauma that influence wound healing.[35]

Length of Stay (LOS)

It has been previously reported that the presence of MetS is associated with longer LOS in the orthopaedic trauma patient.[21,28] Although this association was not statistically significant (p=0.07) in our data, among our cohort, MetS was associated with an additional 0.4 days of LOS. Other associations in our data that contributed to longer LOS included longer operative time and a diagnosis of CHF. Others have observed the relationships between increased operative time and LOS/non-home discharge dispositions.[36] While the factors involved in LOS are multifaceted, extended operative time tends to be linked with greater case complexity. Consequently, this often results in prolonged LOS and non-home discharge to acute rehabilitation or skilled nursing facilities.[37]

Limitations

ACS-NSQIP data are limited to 30 postoperative days. This limits some clinically relevant long-term postoperative outcomes, such as post-operative infections, fracture nonunion, and mortality. As detailed above, SSIs our database only allowed for queries of SSIs diagnosed within the first 30 days following the surgery, accounting for just the initial third of the 90-day SSI diagnosis window.[38] This could result in an underestimation of the impact of MetS on SSI risk. Further, we were unable to evaluate the impact of MetS on fracture nonunion, a diagnosis typically made at 9 months of index surgery. Insulin insufficiency, hyperglycemia, and oxidative stress are believed to hinder the differentiation of osteoblasts, enhance the activity

Table 3. Multivariate Logistic Regression Assessing the Independent Impact of Mets on Postoperative Outcomes

Dependent variables	Odds ratio [95% CI]	p value
Length of Stay (LOS/days) > 5	1.11 [0.91–1.36]	0.296
Acute Renal Failure	2.72 [1.02–6.90]	**0.038**
Cardiac Arrest	3.13 [1.28–7.27]	**0.009**
Non-home discharge	1.36 [1.06–1.76]	**0.018**

Table 4. Multiple Linear Regression Analysis of Factors Associated With Total Length of Stay

Dependent variables	Estimate Coefficient	Std. Error	p value
Metabolic Syndrome	0.415	.231	0.072
History of Congestive Heart Failure	1.65	0.348	< 0.001
Operative Time	0.005	0.001	0.002

of osteoclasts, and disrupt the natural apoptosis process of chondrocytes and osteoblasts, thereby interfering with the normal process of fracture healing.[39-41] Future studies investigating multi-year outcomes of MetS and geriatric distal femur fracture fractures would help capture further relationships on fracture union.

An additional limitation of the ACS-NSQIP database is a lack of specific variables pertaining to factors such as the type of fracture, surgical technique, choices of implants, and it does not make distinctions between native femur and periprosthetic fractures. These are critical factors to understanding surgical outcomes and the lack of availability limit the generalizability of our conclusions. Additionally, studies conducted using ACS-NSQIP may be subject to selection bias, since the data therein is collected only from participating hospitals. Differences in defining metabolic syndrome are acknowledged to exist. While we applied a predetermined definition drawn from prior orthopedic, spine, and general surgery research, it is possible that employing alternative definitions could lead to significant variations in the patient population.[42-44]

FUTURE DIRECTIONS

Given the results of the present study and the limitations of the database, future studies investigating multi-year outcomes of MetS and geriatric distal femur fracture fractures would help capture further relationships on fracture union. Since a causal relationship cannot be established using ACS-NSQIP data, additional research would be helpful to further investigate the findings here with a more targeted ability to tease out direct relationships between MetS and functional outcomes.

CONCLUSIONS

Patients who have operative treatment for distal femur fractures and have concurrent metabolic syndrome are at a greater risk of adverse 30-day outcomes and non-home discharge. This high-risk cohort may benefit from a more tailored postoperative care plan. This may involve strategically scheduled clinic visits to oversee clinical recovery, reduce readmissions, and alleviate the economic strain on the healthcare system.

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PREDICTING COMPLICATIONS FOLLOWING PATELLA FRACTURE REPAIR USING THE 5-ITEM MODIFIED FRAILTY INDEX

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ABSTRACT

Background: Several studies have found the 5-item modified frailty index (mFI-5) to be a reliable indicator of poor postoperative outcomes following various surgical procedures. This study aims to evaluate whether the mFI-5 continues to serve as a reliable predictor for patients undergoing patella fracture repair.

Methods: The NSQIP database was queried to identify patients ages 50 or older who underwent surgery for patella fractures between 2006-2019. The mFI-5 was calculated based on the presence of the following 5 comorbidities: diabetes, CHF, hypertension, COPD, and dependent functional status. Frailty scores were stratified based on number of comorbidities: mFI-5 = 0, 1, and ≥ 2. Bivariate and multivariate analyses were used to compare the complication rates among the mFI-5 scores.

Results: A total of 2,917 patients with an average age of 67 years were included. As the mFI-5 score increased from 0 to 1, patients had an increased risk of readmission (OR 2.94), reoperation (OR 2.15), urinary tract infection (OR 3.49), and discharge to a non-home location (OR 1.41). In addition to these risks, patients with a score of 2 or greater also had an increased risk of mortality (OR 4.40), wound (OR 3.37), pulmonary (OR 8.69), and sepsis complication (OR 5.58), bleeding requiring transfusion (OR 4.56), and length of stay > 7 days (OR 2.48) when compared with patients with a score of 0.

Conclusion: Increasing mFI-5 scores were significantly associated with increased morbidity and mortality following patella fracture repair.

Level of Evidence: III

Keywords: patella fracture, open reduction internal fixation, extensor mechanism repair, frailty, complications, modified frailty index

INTRODUCTION

Patella fractures as a result of low-energy traumatic incidents are becoming increasingly prevalent, particularly among the geriatric and female populations.[1-2] Given the geriatric demographic's heightened susceptibility to postoperative complications,[3-5] orthopedic surgeons are beginning to consider patellar fractures as fragility fractures.[6] As a result, the need for a tool capable of predicting these complications in patella fracture repair surgery has become paramount.

In response to this imperative, the 5-item modified frailty index (mFI-5) emerges as a potential solution. This index, a streamlined version of the 11-item modified frailty index (mFI-11), has demonstrated comparable predictive capabilities in various orthopedic procedures.[7-11] Comprising only five variables - diabetes mellitus, congestive heart failure (CHF), hypertension requiring medication, chronic obstructive pulmonary disease (COPD), and dependent functional status - the mFI-5 retains its predictive efficacy while offering enhanced ease of use in clinical settings.

The mFI-5's increasing adoption by orthopedic surgeons reflects its potential to optimize patient assessment and inform clinical decision-making. However, its applicability in the context of patella fracture repair surgery remains unexplored. Given the rise in patella fractures and their associated complications, there exists a critical research gap that the mFI-5 could address. By evaluating a patient's comorbidities and frailty status, the mFI-5 could theoretically offer insights into the impact of these factors on patella fracture repair outcomes.

This study aims to fill this gap by investigating the suitability of the mFI-5 for predicting postoperative complications in patella fracture repair surgery. Drawing from the index's established efficacy in other orthopedic procedures and recognizing the unique challenges posed by patella fractures, this research seeks to shed light on

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the index's potential utility within this specific context. Through determining whether the mFI-5 can serve as a reliable tool to guide preoperative risk assessment, surgeons can then better refine their patient selection and ultimately enhance the overall outcomes of patella fracture repair surgeries. Our hypothesis is that due to the nature of patellar fracture, individuals with higher mFI-5 scores will demonstrate higher postoperative complication rates than those with lower scores.

METHODS

This retrospective study was conducted by utilizing the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) database. With over 700 participating hospitals, this nationwide database includes numerous patients undergoing major surgical procedures.[12] Trained clinical reviewers at each participating site collect various patient data with strong inter-rater reliability.[13] All patient information is de-identified in the database.[14]

Patient Selection

From the years 2006 to 2019, all patients who underwent surgery for patella fracture were identified. Specifically, International Classification of Diseases, 9th (ICD-9) and 10th (ICD-10) diagnostic codes 822.0, 822.1, and S82.0-S82.099 were used to identify patients who had patella fractures. Current Procedural Terminology (CPT) codes indicating open reduction internal fixation (ORIF) or extensor mechanism repair were further used to identify those who had surgery for their patella fractures.[15] Patients were excluded from the study if they had missing baseline values, such as their biological sex or race. Patients with missing data for any of the comorbidities included in the mFI-5 were also excluded. Since frailty is associated with aging and is of less clinical relevance in younger patients, those under the age of 50 years were excluded in concordance with prior reports.[16]

Patient Characteristics

Patient demographic data were collected and included the following: biological sex, age, body mass index (BMI), race, and American Society of Anesthesiologists (ASA) classification. BMI was further categorized into the following groups: underweight (<18.5 kg/m^2), normal weight (18.5-24.9), overweight (25.0-29.9), obese (30.0-34.9), severely obese (35.0-39.9), and morbidly obese (>40.0). The mFI-5 used in this study consisted of the following patient items: history of diabetes mellitus, CHF within 30 days of surgery, hypertension requiring medication, history of COPD or pneumonia, and non-independent functional status, defined as being partially or totally dependent on another person for daily living activities such as feeding, bathing, or dressing. The mFI-5 has been validated against the original mFI-11 and has been used previously to predict outcomes in various surgical subspecialties.[17-18] The mFI-5 score was calculated for all patients in this study by adding the number of variables present in each patient, with a possible score between 0 and 5 (Table 1). Patients were stratified into the following groups based on the number of comorbidities met within the mFI-5 score: mFI-5 = 0, 1, and ≥ 2.

Outcomes and Complications

Thirty-day outcomes were assessed and were grouped into broad categories including wound (superficial or deep surgical site infections, organ/space infections, or wound dehiscence), pulmonary (pneumonia, reintubation, or failure to wean off ventilator for more than 2 days), renal (renal failure/insufficiency), cardiac (cardiac arrest or myocardial infarction), thromboembolic (deep vein thrombosis, pulmonary embolism, or stroke), and sepsis (sepsis or septic shock). Other outcomes analyzed included mortality, readmission, reoperation, urinary tract infection, bleeding requiring transfusion, length of stay greater than 7 days, and discharge to a location other than home.

Statistical Analysis

To compare each complication between patients with different mFI-5 scores, Pearson's chi-square analyses were used. Complications were further analyzed on multivariate analysis to control for age, gender, race, BMI, and total operative time, and the results were reported as odds ratios with 95% confidence intervals. Statistical Package for the Social Sciences version 28 was used for the analyses in this study, and a p-value of less than 0.05 was considered statistically significant.

Table 1. Comorbidities Included in the mFI-5

Comorbidities
1. Non-insulin or insulin dependent diabetes mellitus
2. CHF within the 30 days before surgery
3. Hypertension requiring use of medication
4. History of COPD or pneumonia
5. Partially or totally dependent functional health status

mFI, modified frailty index; CHF, congestive heart failure; COPD; chronic obstructive pulmonary disease.

RESULTS

Demographics

In total, 2,917 patients who were 50 years or older underwent surgery for patella fractures (Table 2). The majority of the identified patients were female (78.1%) and the average patient age was 67 years (+ 10.0 years). Included patients were predominately White (72.2%), and nearly all patients had an ASA classification of II (50.7%) or III (41.2%). Most of the patients in the study were overweight (33.2%), followed by normal weight (32.2%) and obese (18.2%).

mFI-5 Scores

The mFI-5 score for all patients in the study ranged from 0 to 5. However, for statistical comparisons, the following groups were categorized: mFI-5 score of 0, mFI-5 score of 1, and mFI-5 score of 2 or greater. Patients mostly had a mFI-5 score of 0 (40.3%) or 1 (36.9%), followed by a score of 2 (19.6%), then a score of 3 (2.9%), 4 (0.2%) and 5 (0.1%) (Table 2).

Complications

On bivariate analysis, compared to patients with mFI-5=0, those with mFI-5=1 were more likely to require readmission ($p<0.001$), reoperation ($p=0.001$), develop cardiac complications ($p=0.044$), urinary tract infections ($p=0.003$), have a length of hospital stay greater than 7 days ($p=0.039$), and be discharged to a non-home location ($p<0.001$). Compared to patients with mFI-5=0, those with mFI-5=2 or greater were more likely to experience mortality ($p=0.002$), readmission ($p<0.001$), reoperation ($p<0.001$), wound complications ($p<0.001$), pulmonary problems ($p=0.002$), cardiac complications ($p=0.002$), sepsis complications ($p=0.022$), urinary tract infections ($p=0.013$), bleeding requiring transfusion ($p=0.013$), length of stay greater than 7 days ($p<0.001$), and be discharged to a non-home location ($p<0.001$). Relative to patients with mFI-5=1, those with mFI-5=2 or greater were more likely to experience mortality ($p=0.010$), wound complications ($p=0.032$), pulmonary problems ($p=0.043$), length of stay more than 7 days ($p=0.022$), and discharge to a destination other than home ($p<0.001$) (Table 3).

After controlling for potential confounding variables on multivariate analysis, compared to patients with mFI-5=0, those with mFI-5=1 had an increased risk of readmission (OR 2.94; 95% CI 1.75 to 4.94; $p<0.001$), reoperation (OR 2.15; 95% CI 1.27 to 3.64; $p=0.005$), urinary tract infection (OR 3.49; 95% CI 1.25 to 9.72; $p=0.017$), and discharge to a non-home location (OR 1.41; 95% CI 1.10 to 1.80; $p=0.007$). Similar risks were seen when comparing patients with mFI-5=2 or greater to patients with mFI-5=0, except that in addition, those with mFI-5=2

Table 2. Baseline Characteristics of Patella Fracture Patients

Variable	Overall
Total patients, n	2,917
Gender, %	
Female	78.1
Male	21.9
Age, mean (SD), years	67.23 (10.00)
BMI, mean (SD), kg/m2	27.68 (6.40)
BMI Category, %	
Underweight (<18.5)	3.5
Normal Weight (18.5-24.9)	32.2
Overweight (25.0-29.9)	33.2
Obese (30.0-34.9)	18.2
Severely Obese (35.0-39.9)	7.3
Morbidly Obese (>40.0)	4.1
Race, %	
White	72.2
Black or African American	6.3
Hispanic	13.4
American Indian	0.7
Asian	6.9
Native Hawaiian	0.4
ASA Class, %	
I (normal healthy)	5.2
II (mild systemic disease)	50.7
III (severe systemic disease)	41.2
IV (severe systemic disease with threat to life)	2.9
mFI Score, %	
0	40.3
1	36.9
2	19.6
3	2.9
4	0.2
5	0.1

SD, standard deviation; BMI, body mass index; ASA, American Society of Anesthesiologists; mFI, modified frailty index.

Table 3. Bivariate Analysis of Postoperative Complications for Patella Fracture Patients

Complications	mFI score = 0	mFI score = 1	p-value: mFI score = 1 vs mFI score = 0¶	mFI score > 2	p-value: mFI score > 2 vs mFI score = 0¶	p-value: mFI score > 2 vs mFI score = 1¶
Total patients, n	1,175	1,077		665		
Mortality, n (%)	3 (0.3)	4 (0.4)	0.621	10 (1.5)	**0.002**	**0.010**
Readmission, n (%)	22 (2.4)	57 (6.8)	**< 0.001**	45 (9.2)	**< 0.001**	0.122
Reoperation, n (%)	23 (2.0)	46 (4.3)	**0.001**	32 (4.8)	**< 0.001**	0.594
Wound complication, n (%)	8 (0.7)	15 (1.4)	0.093	19 (2.9)	**< 0.001**	**0.032**
Pulmonary complication, n (%)	2 (0.2)	5 (0.5)	0.211	9 (1.4)	**0.002**	**0.043**
Renal complication, n (%)	0 (0.0)	3 (0.3)	0.070	2 (0.3)	0.060	0.933
Cardiac complication, n (%)	1 (0.1)	6 (0.6)	**0.044**	7 (1.1)	**0.002**	0.243
Thromboembolic complication, n (%)	12 (1.0)	8 (0.7)	0.482	4 (0.6)	0.351	0.729
Sepsis complication, n (%)	2 (0.2)	3 (0.3)	0.585	6 (0.9)	**0.022**	0.078
Urinary tract infection, n (%)	5 (0.4)	18 (1.7)	**0.003**	10 (1.5)	**0.013**	0.787
Postoperative transfusion, n (%)	5 (0.4)	12 (1.1)	0.059	10 (1.5)	**0.013**	0.479
Length of stay > 7 days, n (%)	28 (2.4)	42 (3.9)	**0.039**	42 (6.3)	**< 0.001**	**0.022**
Non-home discharge, n (%)	151 (13.5)	255 (25.1)	**< 0.001**	228 (37.0)	**< 0.001**	**< 0.001**

¶Pearson's chi-squared test.
Bolding equals significance p<0.05.
mFI, modified frailty index.

Table 4. Multivariate Analysis of Postoperative Complications for Patella Fracture Patients

Complications	mFI score = 1 (reference group is mFI score = 0)		mFI score > 2 (reference group is mFI score = 0)		mFI score > 2 (reference group is mFI score = 1)	
	p-value	Odds ratio (95% CI)	p-value	Odds ratio (95% CI)	p-value	Odds ratio (95% CI)
Mortality	0.926	1.077 (0.225 to 5.153)	**0.034**	4.399 (1.117 to 17.328)	**0.013**	4.550 (1.369 to 15.126)
Readmission	**< 0.001**	2.942 (1.752 to 4.942)	**< 0.001**	3.696 (2.096 to 6.517)	0.144	1.371 (0.898 to 2.093)
Reoperation	**0.005**	2.147 (1.267 to 3.639)	**0.010**	2.193 (1.203 to 3.996)	0.818	1.057 (0.657 to 1.703)
Wound complication	0.148	1.931 (0.792 to 4.707)	**0.009**	3.367 (1.355 to 8.366)	0.063	1.948 (0.963 to 3.939)
Pulmonary complication	0.372	2.178 (0.394 to 12.043)	**0.010**	8.691 (1.671 to 45.205)	0.088	2.677 (0.864 to 8.302)
Cardiac complication	0.167	4.605 (0.528 to 40.130)	**0.430**	0.970 (0.898 to 1.047)	0.330	1.750 (0.568 to 5.390)
Sepsis complication	0.443	2.088 (0.318 to 13.726)	**0.049**	5.582 (1.009 to 30.881)	0.146	2.862 (0.694 to 11.813)
Urinary tract infection	**0.017**	3.486 (1.250 to 9.724)	**0.013**	4.452 (1.362 to 14.547)	0.972	0.986 (0.445 to 2.183)
Postoperative transfusion	0.190	2.089 (0.694 to 6.295)	**0.013**	4.559 (1.377 to 15.087)	0.615	1.253 (0.519 to 3.024)
Length of stay > 7 days	0.102	1.525 (0.920 to 2.527)	**< 0.001**	2.475 (1.444 to 4.242)	0.062	1.537 (0.979 to 2.414)
Non-home discharge	**0.007**	1.407 (1.099 to 1.800)	**< 0.001**	2.610 (1.983 to 3.435)	**< 0.001**	1.852 (1.453 to 2.362)

Bolding equals significance p<0.05.
mFI, modified frailty index; CI, confidence interval.

or greater also had an increased risk of mortality (OR 4.40; 95% CI 1.12 to 17.33; p=0.034), wound complication (OR 3.37; 95% CI 1.36 to 8.37; p=0.009), pulmonary complication (OR 8.69; 95% CI 1.67 to 45.21; p=0.010), sepsis complication (OR 5.58; 95% CI 1.01 to 30.88; p=0.049), bleeding requiring transfusion (OR 4.56; 95% CI 1.38 to 15.09; p=0.013), and length of stay greater than 7 days (OR 2.48; 95% CI 1.44 to 4.24; p<0.001). Compared to patients with mFI-5=1, those with mFI-5=2 or greater had an increased risk of mortality (OR 4.55; 95% CI 1.37 to 15.13; p=0.013) and discharge to a non-home destination (OR 1.85; 95% CI 1.45 to 2.36; p<0.001) (Table 4).

DISCUSSION

As the number of patella fractures increases in the United States due to our aging population, effective methods of predicting post-surgical outcomes is needed.[19] The mFI-5 index has been shown to be a viable alternative to the longer mFI-11 index in predicting the risk of various postoperative complications following patellar fracture repair and other orthopedic surgeries.[7-11] For patellar fracture repair in particular, our study found that patients with mFI-5 scores of 1 or above demonstrated increased likelihood of readmission, reoperation, urinary tract infection, and discharge to a non-home location. While it seems intuitive that frail patients should have an increased risk of various postoperative complications, the purpose of this paper is to elucidate specifically which comorbidities pose the greatest threat to this population so that surgeons can better optimize their patients' outcomes.

Our findings parallel previous literature that examined the mFI-5 and its ability to determine an individual's postoperative risk. For example, Weaver et al. also found that following elective posterior lumbar fusion, increased mFI-5 scores were predictive of increased odds of readmission, non-home discharge, urinary tract infection, and unplanned reoperation in addition to other significant variables unique to their study.[20] In another study performed by Shah et al., it was found that patients with higher mFI-5 scores who underwent correction for an adult spinal deformity had an increased risk of urinary tract infection, reoperation within 30 days, and readmission within 30 days.[21] Similar to our study, they determined that a mFI-5 score of 1 was an independent predictor of reoperation. They also found that a score of 2 was an independent predictor of readmission. Interestingly, this varied from our study which found that as a patient's score increased from 0 to 1, they had a significantly increased risk of readmission. This discrepancy was likely due to the different risks inherent in each of the surgeries being performed.[20-21]

Our findings are also supported by other studies that have determined which risk factors most likely lead to complications following patella fracture repair. In a retrospective study of geriatric patella fractures performed by Kapilow et al., it was determined that geriatric and therefore more frail patients have a high risk of mortality, discharge to a non-home location, unplanned readmission, and unplanned reoperation. While the comorbidities studied by Kapilow et al. varied slightly from those listed on the mFI-5, there were some similarities. Namely, the presence of hypertension and diabetes which were found to be independent risk factors for discharge to a non-home location. This study, however, did not find dependent preoperative functional status to be an independent predictor of any of the postoperative complications studied whereas ours did as it is included as part of the mFI-5.[22] This suggests that some of the variables listed in the mFI-5 may not be as predictive as others when specifically dealing with patella fracture repair surgery. More research may be beneficial to determine which, if any, of the comorbidities listed on the mFI-5 have a greater impact on postoperative outcomes than the others.

Most studies agree that the mFI-5 is a useful tool that surgeons should use to stratify patients according to individual levels of risk. Our findings support its reliability in comparison to the larger mFI-11 and, due to its ease of use, we recommend that the mFI-5 be used to assess an individual's risk of postoperative complications following patella fracture repair. Specifically, we suggest that patients with a mFI-5 score above 0 be made aware of the various complications they are most at risk for based on the procedure being performed and their mFI-5 score. For example, if a patient was planning to undergo patella fracture repair and had a mFI-5 score of 1, they should be informed as to how they are more likely to have a greater medical burden in the form of reoperation, non-home discharge, and readmission. Additionally, if the patient were to progress to a score of 2 before the surgery, they should be informed that they are now significantly more likely to have a serious postoperative complication such as death, bleeding, and increased length of stay.

Ideally, the information generated by this research would be used to develop targeted interventions for those patients with the highest levels of risk, ultimately leading to improved quality of life and reduced healthcare costs. By more accurately informing patients of the risks inherent in each operation, healthcare providers can empower individuals to make informed decisions regarding their healthcare and, in the case of individuals with higher mFI-5 scores, generate discussions about alternative treatment options if necessary.

The main strength of this study is the utilization of a large nationwide database rather than that from a single institution, increasing the external validity of our study. Nonetheless, there are limitations that should be addressed when interpreting the results of this study. First, we were unable to cluster patients based on the severity of their comorbidity or the subsequent need for treatment due to the lack of granular information available within the database. Another limitation with using the NSQIP database is that we were unable to identify the initial indication for patella fracture repair. This potentially introduced confounding variables such as how the severity of trauma incurred by the patient may have impacted their operative outcomes and complications. Additionally, we were limited to the demographic variables collected by the database as well as the assumption that they were all accurately coded. Finally, CPT codes used to identify patients in this study were initially designed for insurance purposes and not research purposes - this represents a potential for bias based on financial incentive.

CONCLUSION

The mFI-5 is an effective tool in determining a patient's frailty as well as postoperative complications following patellar fracture repair surgery. Specifically, our research determined that higher mFI-5 scores lead to increased odds of readmission, reoperation, wound complication, pulmonary complication, sepsis complication, urinary tract infection, unplanned postoperative transfusion, increased length of stay, and non-home discharge.

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3D-PRINTED ONE-THIRD TUBULAR PLATES IN AN ANKLE FRACTURE MODEL: A BIOMECHANICAL STUDY

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ABSTRACT

Background: 3D printing is a fast-growing technology in orthopaedic surgery. The utility of 3D-printed orthopaedic implants has yet to be fully defined. This biomechanical study examines the capabilities of one such implant in an ankle fracture model.

Methods: One-third tubular plates were 3D-printed using CFR-PLA (carbon fiber-reinforced polylactic acid) and PC (polycarbonate). Samples and stainless-steel controls were used to fix Weber B Sawbones fibula fracture models and analyzed with lateral bending, torsional, and torsional failure mechanical testing.

Results: Stainless-steel one-third tubular plates were shown to have superior mechanical properties than the 3D-printed plates overall in valgus bending and with torsional failure. However, CFR-PLA 3D-printed plates demonstrated greater strength in torsion testing..

Conclusion: The differences in mechanical properties between stainless-steel one-third tubular plates and 3D-printed plates, while statistically significant, are likely not clinically significant. 3D-printed implants could be used as a viable alternative in ankle fracture fixation in the future.

Clinical Relevance: To the authors' knowledge, this is the first biomechanical study performed on 3D-printed plates in an ankle fracture model. Given the increasing use of 3D printing, the findings described here could establish a basis for future areas of research.

Keywords: 3D printing, biomechanics, trauma, ankle fracture, implant

INTRODUCTION

Ankle fractures are common debilitating fractures that considerably impact patients' quality of life.[1,2] Available studies suggest an incidence rate of 4.22 per 10,000 person-years with a mean age of 37 ± 22.86 years.[3-5] Ankle fractures occur in all ages and sexes but with a bimodal distribution curve of higher incidence in younger men and older women.[6] Ankle fracture as a category can encompass several different fracture patterns. 60-70% of ankle fractures are unimalleolar, 15-20% are bimalleolar, and 7-12% are trimalleolar fractures.[4,5,7] Treatment guidelines for ankle fractures generally recommend some form of immobilization or fixation, which are readily available in developed nations. Currently, supplies needed for these treatments and procedures are not as easily obtained or available in developing nations and forward-operating military units.[8-10] Orthopaedic care in these environments often depends on the creativity of local surgeons, volunteerism, and donations of supplies.[11-13] Alternative solutions to these challenging environments, with their scarcity and minimal supply chains, have implications for the future and can provide insight into fracture care on theoretical long-duration space flight missions.[14-16]

Three-dimensional (3D) printing is a rapidly improving technology that has emerged as a potential solution to medical challenges. The increasing affordability and accessibility of 3D printers and 3D-printable materials, as well as access to open-source software and design libraries, have brought 3D printing to a larger audience that includes medical personnel.[17-22] There are several different types of 3D printers. In this study, we used fused deposition modeling (FDM) printers, which extrude melted polymer material onto a build surface in a layered fashion to create a model. As the printers and supplies are affordable and have a wide variety of polymer filaments and printing options, this style of printer is the most accessible.

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3D printing has proven applicable to several scenarios in orthopaedics. The most prevalent use of orthopaedic 3D printing is preoperative planning, simulation, and educational modeling for patients and students.[23-38] 3D-printed preoperative planning models have been shown to shorten operating time, improve surgical quality, reduce waste by allowing the surgeon to choose appropriate implants and supplies before the surgery, and increase the surgeon's comfort level during complex surgical cases.[23-26] However, the realm of 3D-printed surgical implants has been confined primarily to metal 3D printing processes. For example, 3D-printed custom knee and hip implants are available, but their use is limited due to regulatory hurdles and expenses.[39] Further research is needed to establish the efficacy of 3D-printed polymers for use in surgical implants.

Polymer 3D-printed surgical implants have the potential to be a low-cost alternative to stainless-steel implants.[40,41] However, 3D-printed constructs made from polymer-based filaments are unlikely to match the mechanical strength of their surgical steel counterparts. There are several common, low-cost materials used with desktop 3D printers, such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), carbon fiber-reinforced polylactic acid (CFR-PLA), polycarbonate (PC), and polyether ether ketone (PEEK).[42-45] Carbon fiber, carbon fiber composite materials, and PEEK have previously been identified as candidates for fracture fixation due to strength and biocompatibility.[42,46-56]

While the material properties of FDM 3D printing constructs are unlikely to rival surgical steel plate mechanics, bones like the fibula do not experience heavy loading. When broken, the fibula could undergo fixation with materials weaker than surgical steel. The fibula is dynamic, experiencing distal migration, anterior-posterior and medial-lateral translation, and rotation. These motions are constrained by several ligamentous attachments and articulations with the tibia and talus. Biomechanical studies suggest that the fibula experiences bending and torsional moments in vivo, with more significant loading in ankle valgus/eversion and dorsiflexion. The maximum axial force on the fibular is approximately 6-7% of the total body weight during a gait cycle.[1-7] In the context of the previously mentioned ankle fractures, fibula fractures would be classified as lateral malleolus fractures. The Danis-Weber classification system describes distal fibular fracture location in relation to the ankle joint.[57] The most common of these are Danis-Weber B fractures (~90%), followed by Danis-Weber A (8%) and Danis-Weber C (2%) (Figure 1).[58]

While 3D printers can create and design constructs with specific dimensions, the mechanical properties of 3D-printed polymer surgical implants are less predictable or well-understood. The purpose of this study was to test the biomechanics of an ankle fracture model fixed with 3D-printed one-third tubular plates, which are commonly used to repair fractures of the fibula that are assumed to be "non-weight bearing" (e.g., those seen in Danis-Weber B) as the forces on the fibula are thought to be negligible compared to those on the tibia.[59,60]

The study objectives were to assess the utility of 3D-printed CFR-PLA and PC one-third tubular plates for fixation of Danis-Weber B distal fibula fractures, as compared to the industry standard stainless-steel plates. We hypothesized that 3D-printed plates would have sufficient strength to hold fixation of a Danis-Weber B distal fibula fracture.

METHODS

Sample Preparation

The 3D-printed eight-hole one-third tubular plate design was created in Fusion360 (Version 2.0.15995, Autodesk Inc., San Francisco, CA) for 3D printing. This study used two FDM printers: the Prusa i3 MK3S+ (Prusa Research, Prague, Czech Republic) and the Ender 3 v2 (Creality 3D Technology Co., Shenzhen, China). Both printers were equipped with a 0.4 mm hardened steel nozzle. PrusaSlicer (Version 2.5.0, Prusa Research, Prague, Czech Republic) was used to slice the models in preparation for printing. Two types of filament were used: carbon fiber-reinforced polylactic acid (CFR-PLA) (CarbonX, 3DXTECH, Grand Rapids, MI) and polycarbonate (PC) (Polymaker, Changshu, China). These materials were chosen based on the results of a previous study that examined the mechanical properties of 3D-printed plates made from CFR-PLA, PC, ABS, and plain polylactic acid

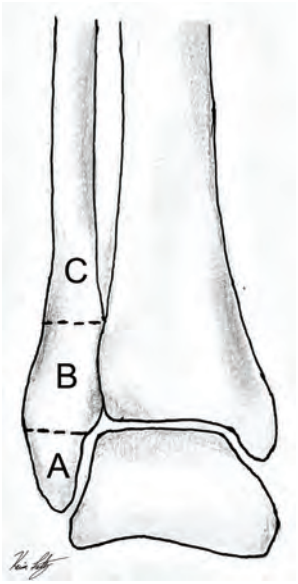

Figure 1. The Danis-Weber Classification.

(PLA).[61] The best-performing materials were chosen and tested in a Sawbones model to better evaluate plate performance in a biomechanically accurate scenario. Plates were printed with 100% infill. A 3D printing filament dry cabinet (StatPro, Production Automation Corporation, Minnetonka, MN) maintained consistent temperature and humidity during and between prints. A priori sample size estimate for power = 0.8 determined that an n = 6 was required for each group. CFR-PLA and PC plates were printed for each test. Stainless-steel one-third tubular plates were used as the control group for each test, and all fracture models were secured with stainless-steel 3.5 mm screws (DePuy-Synthes, Paoli, PA).

Composite fibula models (model #3427-1, Sawbones, Vashon Island, WA) were utilized for mechanical testing. These Sawbones models were prepared by placing each fibula in a customized cutting jig and making a cut with a micro-sagittal saw simulating a Danis-Weber Type B fracture with a standardized length of 23 cm from the cut to the distal end of the fibula. These fracture models had 1 mm of bone loss based on the kerf of the saw blade. Each specimen was fixed with a 3.5 mm lag screw and an assigned one-third tubular plate based on the group. Each plate was fixed to the fracture model laterally with three proximal bicortical 3.5 mm stainless-steel screws (18 mm in length) and three distal unicortical 3.5mm stainless-steel screws (12 mm in length) (Figure 2).

Each specimen was tested in three parts sequentially after fixation: lateral bending strength, torsional strength, and torsional failure strength. Intact sawbone fibulas were also tested to establish a biomechanical reference. Mechanical testing protocols for distal fibular plate fixation were designed based on testing in prior literature.[61-72]

Lateral Bending Test

A custom jig was used to hold samples fixed on the proximal end of the fibula while a valgus bending force was applied distally, 135 mm from the fixed segment (Figure 3a). The bending stiffness and bending strength were measured at 3 mm axial displacement of each construct. This test was performed in a servo-hydraulic materials testing system (Model 8874, Instron, Norwood, MA). Each fibula sample was aligned at the center of the bending fixture. The loading was applied at a rate of 0.5 mm/sec, starting at 1N and increasing incrementally until attaining 3 mm of vertical displacement. The displacement was held for 5 seconds, the load was gradually reduced at a rate of 0.5 mm/sec back to 1N preloading, and then this load was held for 5 seconds. Each construct was cycled six times. The load and displacement data were collected over the last five cycles at 200 Hz. The valgus bending aspect of the testing was non-destructive in nature. From the force and displacement data, the bending stiffness (slope of the load-deflection curve) was calculated by linear regression, the apparent flexural rigidity (EI) was calculated as load multiplied by the specimen exposed length (135 mm) divided by one unit of curvature (1/displacement), and the mean bending strength at 3 mm displacement was calculated as the average loading during the 5-second hold while displaced.

Torsional Test

The same samples were then secured to a different custom jig to test for torsional strength. Samples were fixed proximally and distally with an exposed length of 135mm. These were then attached to the servo-hydraulic materials testing system, ensuring that the axis of alignment corresponded with the longitudinal axis of the fibula diaphysis (Figure 3b, 3c).

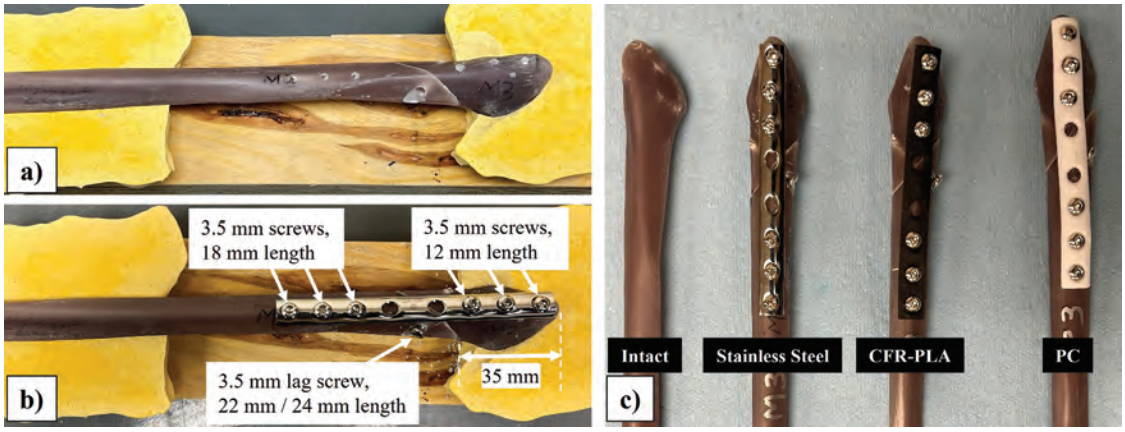

Figure 2A to 2C. (2A) Fracture models were created by cutting composite Sawbones samples with a custom jig to simulate a Danis-Weber Type B fracture pattern. (2B) Fracture models were fixed with a 3.5 mm fully threaded cancellous stainless-steel lag screw (lagged by technique) and with 1/3 tubular plates, secured with three bicortical 3.5 mm screws proximally and three unicortical 3.5 mm screws distally. (2C) Intact fibula, control (stainless-steel plate), CFR-PLA plate sample, and PC plate sample.

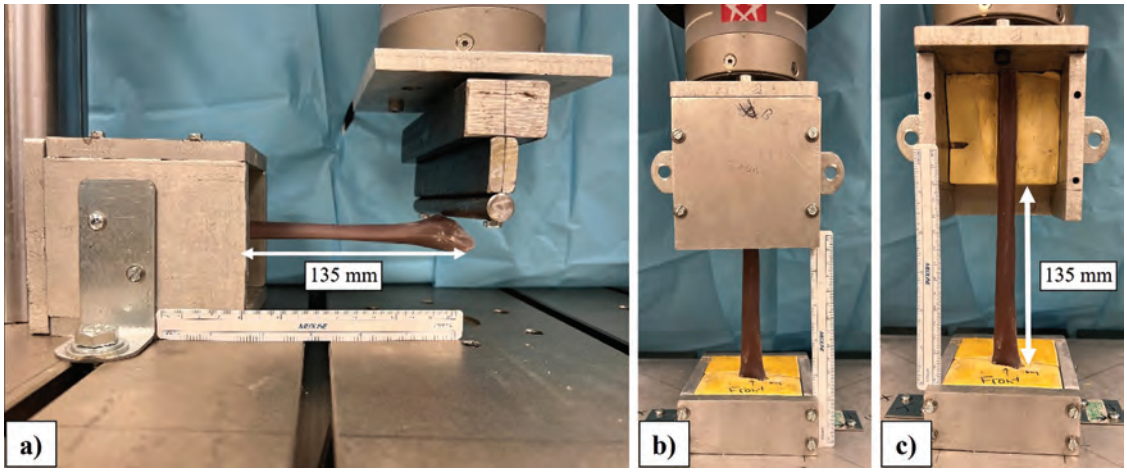

Figure 3A to 3C. (3A) Valgus bending testing setup. (3B) and (3C) torsional strength and torsional failure testing setup.

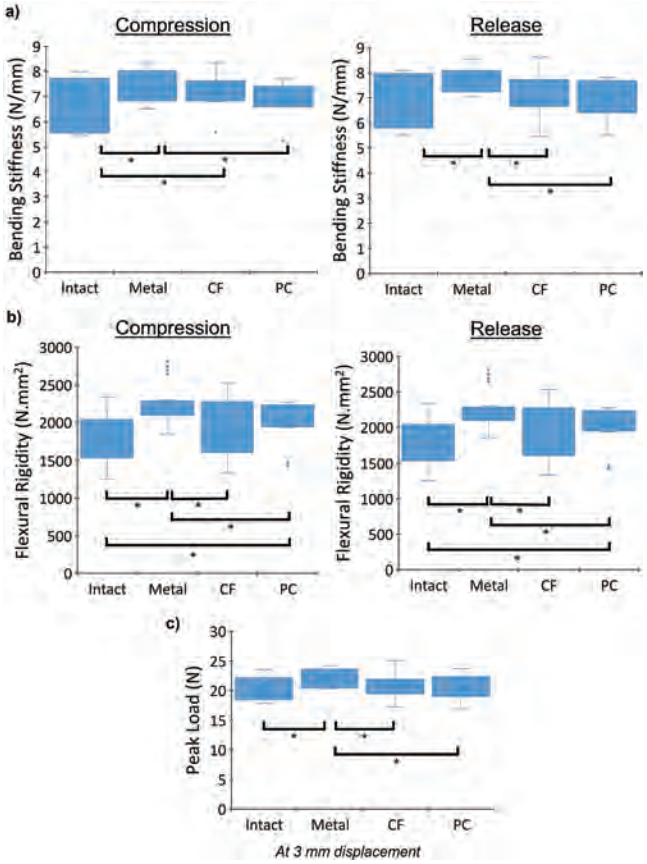

Figure 4A to 4C. Lateral bending test. Valgus bending force was applied to the distal fibula at a rate of 0.5 mm/s, increasing to a maximum of 3 mm displacement. Bending stiffness (4A) and rigidity (4B) were recorded in both the compression and release phases of testing. Peak load (4C) was recorded at 3 mm displacement.

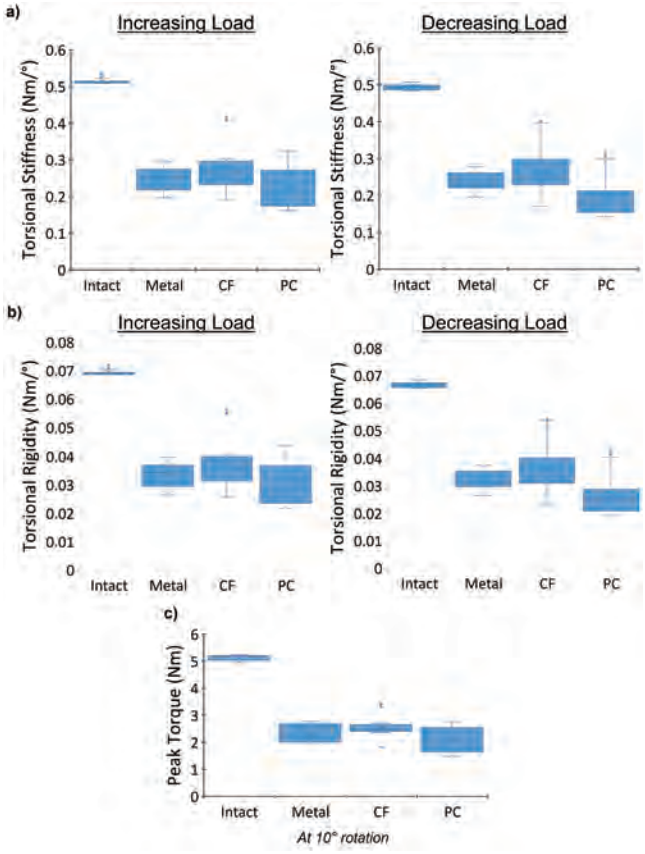

Figure 5A to 5C. Torsional test. Samples were axially loaded to 10N, then external rotation was applied at a rate of 2 degrees/s, increasing until failure or to a maximum of 10 degrees rotation. Torsional stiffness (5A) and rigidity (5B) were recorded in both the increasing load and decreasing load phases of testing. Peak torque (5C) was recorded at 10 degrees of displacement.

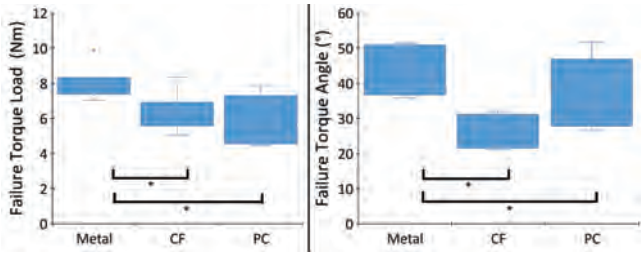

Figure 6. Torsional failure test. Samples were axially loaded to 10N, then external rotation was applied at a rate of 2 degrees/s, increasing until failure. Failure was defined as either a fibula fracture or a decrease in maximum torque, whichever occurred first. Torque and rotation angle at failure were recorded.

Each specimen was axially loaded to 10N (under load control). External rotation was applied from 0 to 10 degrees at a rate of 2 degrees/second. The sample was held at 10 degrees rotation for 5 seconds; then, the load was gradually reduced at a rate of 2 degrees/second back to neutral and held for 5 seconds. Each construct was cycled six times. The torque and rotation angle data were collected over the last five cycles at 200 Hz. This torsional testing was non-destructive in nature. Torsional stiffness was calculated by linear regression of the torque-rotation slope (Nm/deg), mean torsional rigidity was calculated as torque-rotation slope (Nm/deg) multiplied by specimen exposed length (0.135 m), and the mean torsional strength at 10 degrees external rotation was calculated as the average loading during the 5-second hold while rotated.

Torsional Failure Test

After bending and torsional testing were completed, each construct was tested and analyzed for ultimate strength in torsion. The setup for this testing is similar to the previous torsional test (Figure 3b, 3c). Each specimen was axially loaded to 10N (under load control). External rotation was then applied from 0 degrees to complete structural failure at a rate of 2 degrees/second. Failure was defined as either a fibula fracture or a decrease in maximum torque, whichever occurred first. Torque and rotation angle were recorded at a frequency of 200Hz.

Statistical Analysis

Means and standard deviations of the data retrieved from bending, torsional, and torsional failure testing were calculated for each construct. One-way analysis of variance (ANOVA) was performed with IBM SPSS statistics software (Version 24.0; IBM Corporation, Armonk, NY). Least significant difference (LSD) multiple comparisons post hoc analysis was used to identify any observed differences between groups ($p < 0.05$).

RESULTS

Lateral bending testing demonstrated that stainless-steel plates (control) had a mean bending stiffness of 7.38 ± 0.64 N/mm during the compression phase and 7.71 ± 0.52 N/mm during the release phase, CFR-PLA plates had a mean bending stiffness of 7.11 ± 0.85 N/mm during compression and 7.02 ± 0.96 N/mm during release, PC plates had a mean bending stiffness of 6.76 ± 0.79 N/mm during compression and 6.97 ± 0.81 N/mm during release (Figure 4a). There were statistically significant differences in bending stiffness between the control and the PC plates during the compression and release phases of testing and between the control and the CFR-PLA plates during the release phase. Testing also demonstrated that the control plates had a mean flexural rigidity of 634 ± 68 N·mm^2 during the compression phase and 2232 ± 264 N·mm^2 during the release phase, CFR-PLA plates had a mean flexural rigidity of 632 ± 94 N·mm^2 during compression and 1914 ± 388 N·mm^2 during release, PC plates had a mean flexural rigidity of 613 ± 89 N·mm^2 during compression and 2007 ± 274 N·mm^2 during release (Figure 4b). Statistical significance was also found between the flexural rigidity of the control plate and both 3D-printed plates during the release phase. Mean peak load at 3 mm displacement was 22.06 ± 1.55 N for the stainless-steel plates, 20.81 ± 2.40 N for CFR-PLA, and 20.52 ± 2.21 N for PC (Figure 4c). The load for the control plates was statistically higher than that recorded in the CFR-PLA and PC constructs.

Torsional testing demonstrated that the mean torsional stiffness for the control plates was 0.25 ± 0.03 Nm/deg with increasing load and 0.24 ± 0.02 Nm/deg with decreasing load, mean torsional stiffness for CFR-PLA plates was 0.28 ± 0.07 Nm/deg with increasing load and 0.27 ± 0.07 Nm/deg, and mean torsional stiffness for PC plates was 0.22 ± 0.05 Nm/deg with increasing load and 0.19 ± 0.05 Nm/deg with decreasing load (Figure 5a). The mean torsional rigidity for the control plates with increasing load was 0.033 ± 0.004 Nm^2/deg and 0.032 ± 0.003 Nm^2/deg with decreasing load, mean torsional rigidity for CFR-PLA plates was 0.038 ± 0.009 Nm^2/deg with increasing load and 0.036 ± 0.010 Nm^2/deg with decreasing load, and mean torsional rigidity for PC plates was 0.030 ± 0.007 Nm^2/deg with increasing load and 0.026 ± 0.0106 Nm^2/deg with decreasing load (Figure 5b). The mean peak torque at 10 degrees of external rotation was 2.35 ± 0.30 Nm for the control plates, 2.54 ± 0.45 Nm for CFR-PLA plates, and 2.07 ± 0.43 Nm for PC plates (Figure 5c). All findings from the torsional testing proved to be statistically significant from each other.

The mean peak torque at failure was 7.9 ± 1.0 Nm for the stainless-steel controls, 6.3 ± 1.1 Nm for CF plates, and 5.9 ± 1.4 Nm for PC plates. The mean torque angle

at failure for the control plates was 43.4 ± 6.6 deg, 25.4 ± 4.9 deg for CFR-PLA, and 35.9 ± 10.3 deg for PC (Figure 6). Mean peak torque and angle at failure were significantly higher in the stainless-steel controls than in either experimental group.

DISCUSSION

To our knowledge, this study is the first to test 3D-printed one-third tubular plates in an ankle fracture model. The materials utilized in this study, CFR-PLA and PC, are biocompatible and were chosen from a previous study as the strongest of several materials to test biomechanically.[26,46-49,51-54,61,73-77]

During the valgus bending tests, the stainless-steel plates demonstrated a significantly higher stiffness and rigidity than both 3D-printed plates during the release phase but a similar rigidity to both plates and a similar stiffness to the CFR-PLA plates during compression. The difference between the stainless-steel and PC plates was statistically significant during compression but likely not clinically significant, as the confidence interval of the control included the mean PC value. It took significantly more force to displace the stainless-steel plates to 3 mm than either 3D-printed plate. However, the clinical significance is likely negligible as the confidence interval of the control included the means of both sample groups.

For the torsional tests, the CFR-PLA samples had the greatest stiffness, rigidity, and peak torque at 10 degrees, statistically significant from the results from both the control and the PC plate groups. Stainless-steel controls surprisingly had the second-highest values. The means and confidence intervals for the controls and both experimental groups again suggest that the statistical significance would not translate to clinical significance.

During the torsional failure tests, all comparisons were statistically significant. Stainless-steel controls failed at the greatest torque and the largest torsional angle, CFR-PLA failed at the second-highest torque but at the smallest angle, and PC failed at the lowest torque but the second-highest angle.

We can conclude from the results that stainless-steel plates perform well and tend to outperform the 3D-printed plates, as expected. However, CFR-PLA 3D-printed plates out-performed the stainless-steel controls in torsional testing and there was considerable overlap in the means and confidence intervals of the stainless-steel plates when compared to the 3D-printed plates for lateral bending. This indicates that while there was a statistical significance between the mechanical properties of the 3D-printed plates and that of the stainless-steel controls, there may not be a clinical significance. These plates could be viable backup options in environments of scarcity or with poor supply chains, such as in developing countries, forward operating units in the military, or during long-term space flight in the future. This line of thought warrants further study in an in vivo model, which is outside the scope of this study.

This study has its limitations. As a biomechanical study utilizing sawbones, this study has limited ability to comment on in vivo applicability and clinical relevance other than to suggest that 3D-printed plates could be a viable alternative to the gold standard when necessary. Two CFR-PLA plates broke during screw application, which could indicate that the material, while rigid, is too brittle for practical use. This brittleness could prove catastrophic to the plate if screws are overtightened onto the construct during surgery and should be noted.

Future studies are necessary to determine the clinical applicability of stabilizing a healing ankle fracture with 3D-printed one-third plates and to determine the biological response to polymer implants.

The role of 3D printing in orthopaedic implants is not well-established. With further study, innovation, and broader adaptation, creating, generating, and utilizing 3D-printed implants has the potential to become a feasible and cost-effective option. With that in mind, the biomechanical properties of these implants must be studied.

This study suggests that while there are differences in mechanical properties between stainless-steel one-third tubular plates and 3D-printed plates, fracture fixation can be achieved with 3D-printed plate constructs.

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DOES FIXATION METHOD AFFECT THE CORRELATION OF MRUST AND HEALING STRENGTH?

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ABSTRACT

Background: Previous biomechanical studies correlating strength of healing with mRUST are limited to a single mode of intramedullary fixation. This study evaluated the correlation between mRUST and biomechanical strength in a fracture healing model using fixation methods that generated different modes of healing.

Methods: Biomechanical data were sourced from previous ovine osteotomy studies and included 24 sheep, 12 fixed with rigid constructs and 12 fixed with a single relatively stable construct. The sheep were sacrificed at 9 weeks and the tibiae were loaded to failure in torsion. Load to failure was recorded as a percentage of the contralateral intact tibia. Standardized 9 week radiographs were reviewed and the mRUST score was recorded.

Results: A fracture was considered biomechanically healed if it retained 72% of the strength of the contralateral side. In the rigid group, the mRUST score correctly determined the biomechanical healing state in 6/12 fractures. Specifically, it correctly labeled 6 fractures ununited and incorrectly labeled 6 ununited fractures as healed. In the relative stability group, the mRUST correctly determined the biomechanical healing state in 9/12 fractures. Specifically, it correctly labeled 1 fracture ununited and 8 fractures united. The mRUST correctly predicted healing in 9/12 fractures stabilized with a residual fracture gap, but only 4/12 stabilized without a residual fracture gap.

Conclusion: This is the first study to evaluate the biomechanical accuracy of the mRUST score in fracture models using both rigid and relatively stable fractures. The results suggest a disparity in the accuracy of the mRUST to predict biomechanical healing in rigid fixation versus relative fixation constructs and in fractures stabilized with and without residual fracture gaps.

Clinical Relevance: Caution should be used when applying the score to fractures stabilized with rigid fixation methods without residual fracture gaps.

Keywords: callus, mRUST, biomechanical strength, fracture healing

INTRODUCTION

The use of the modified Radiographic Union Scale for Tibia Score (mRUST) for evaluating radiographic fracture healing in the clinical setting has gained popularity due to its excellent interobserver reliability for clinical and experimental healing assessment across several different fracture types.[1-3] However, the correlation between radiographic mRUST scores and the mechanical strength of healing is less clear.[2,4,5] It is essential to investigate this correlation as it can inform clinical decision-making about appropriate weight-bearing and rehabilitation protocols. Previous biomechanical studies investigating the correlation between the strength of healing and mRUST have been limited to a single method of relatively stable intramedullary fixation in primarily small animal studies, thereby restricting its generalizability to other modes of fracture healing.[2,6,7] Specifically, there are no large animal models investigating the correlation between mRUST scores and mechanical strength of healing in fractures treated with rigid fixation such as compression plating or locked plating. This study aims to expand on these findings by assessing the relationship between mRUST and biomechanical strength in an ovine fracture healing model using both rigid and relatively stable fixation methods that generate distinct modes of healing. We hypothesized that the mRUST would accurately predict the biomechanical healing status in rigid and relatively stable fixation cases.

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METHODS

Biomechanical data were sourced from two previous ovine osteotomy studies originally performed to evaluate flexible plate constructs using an established large animal fracture healing model.[8,9]

Animal model

A total of 24 adult Swiss Alpine sheep were randomized to receive a transverse osteotomy of either the right or left hind tibia, followed by fixation with either rigid or relatively stable fixation methods (Table 1). Surgical details were described previously.[8,9] A total of 12 sheep were stabilized with rigid constructs. Six sheep (RIGID COMP) were stabilized with an absolutely stable construct achieved using standard compression plating with six 4.5 mm screws placed in compression. The initial stiffness of this absolutely stable compression plating construct is mathematically undefined, as no gap is present at the compressed fracture site. An additional six sheep (RIGID GAP) were fixed with a locked plate over a 3 mm gap with six 4.5 mm locking screws. The initial axial stiffness of the locked construct was 6239 ± 740 N/mm. The final twelve sheep were stabilized with relatively stable active plate designed to allow axial motion while maintaining mechanical strength. The active plates were engineered with a biphasic stiffness profile, exhibiting an initial axial stiffness of 677 ±161 N/mm that increased to 1805 ± 116 N/mm as the applied load increased past 700 N due to the design of the motion elements. Six sheep (ACTIVE GAP) were stabilized with an active plate and a 3 mm gap, and another six sheep (ACTIVE NO GAP) were stabilized with an active plate that had direct opposition of the fracture ends but was not specifically compressed. Operative and postoperative protocols were similar in all groups.[8,9] Weekly radiographs were obtained immediately postoperatively and at weekly intervals beginning at postoperative week 3. At each time point, an AP and two oblique lateral views (+10° and -10° from a true lateral) were obtained to visualize the anterior, posterior, medial and lateral cortices without obstruction from the medially applied plate.

All sheep were sacrificed at postoperative week 9. The operative tibia and contralateral nonoperative tibia were harvested. Mechanical testing was performed by cementing the proximal and distal ends of the tibia in mounting fixtures separated by 170 mm and aligned with the tibial shaft axis. The specimens were attached to a materials testing machine (Instron 870) using an x-y table to allow translation but prevent rotation of the apparatus around the diaphyseal axis. The specimens were loaded in torsion at a rate of 10°/min until failure by fracture. The strength of the operative and nonoperative tibia were calculated as the load at which failure occurred. The percentage of strength recovery of the operative tibia relative to the contralateral tibia was calculated.

RUST and mRUST score calculation

Radiographs obtained immediately before sacrifice at 9 weeks after surgery were collected and deidentified, so the type of fixation was not apparent (Figure 1). Three fellowship-trained orthopedic trauma surgeons evaluated the radiographs in random order to score each cortex with a value of 1-4 using the previously described mRUST scoring technique.[1] The cortex values were collected, and the mRUST scores (ranging from 4-16) were calculated. The Interclass Correlation Coefficient (ICC) for the three evaluators was calculated.

A fracture was considered biomechanically healed if it achieved at least 72% of the strength of the contralateral tibia. The empty screw holes in the operative tibia were 16% of the diameter of the tibia. Empty screw holes of this size will weaken the bone by 20% in torsional testing.[10] Therefore, a strength of 72% represents a relative strength recovery of 90% relative to the contralateral side, assuming a perfectly healed bone will fail at 80% load due to the empty screw holes. A fracture was considered radiographically healed if the mRUST score was greater than or equal to 13.[1,2]

Table 1.

Group	RIGID COMP	RIGID GAP	ACTIVE GAP	ACTIVE NO GAP
Stability	Rigid/ Absolute	Rigid	Relative	Relative
Stiffness (N/mm)	Undefined	6239 ± 740	1805 ± 116	1805 ± 116
Gap (mm)	Compressed	3	3	No gap

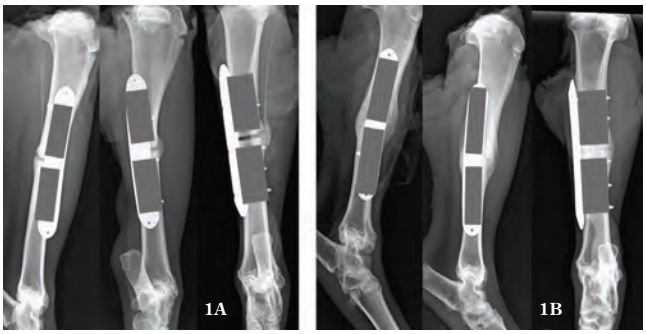

Figure 1A to 1B. Examples of radiographs used to determine mRUST scores. (1A) Locked Plate, mRUST 12, strength 7.9% of contralateral side, (1B) Active plate, mRUST 15, Strength 80.3% of contralateral side.

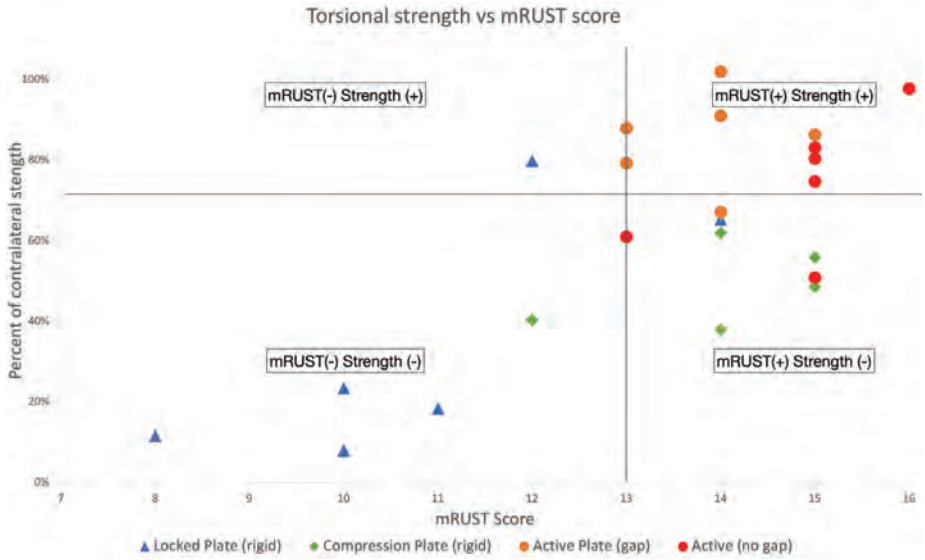

Figure 2. mRUST score versus percentage of strength recovery relative to the contralateral tibia. The fractures were considered biomechanically healed if they achieved 72% strength recovery and radiographically healed if they had a mRUST score of 13 or greater.

RESULTS

Mechanical testing

Mechanical testing found the average strength recovered for the cohort was 61% ± 27% of the contralateral tibia. All 12 fractures stabilized with rigid techniques fractured at least partially through the original osteotomy site whereas all 12 fractures stabilized with relatively stable constructs failed though a residual screw hole.[8,9] For the entire group, 10 of the 24 fractures achieved 72% strength relative to the contralateral tibia and were considered biomechanically healed. Fractures stabilized with rigid techniques (RIGID COMP and RIGID GAP) achieved biomechanical healing in only one (RIGID GAP) of 12 fractures. The average strength recovery for tibiae stabilized with rigid techniques was 43% ± 23% of the contralateral tibia. Fractures stabilized with relatively stable (ACTIVE GAP and ACTIVE NO GAP) fixation achieved biomechanical healing in 9 of the 12 fractures. The average strength recovery for the relatively stable group was 80% ± 15% of the contralateral tibia. The biomechanically healed tibiae had an average mRUST score of 14.3 ± 1.2. The biomechanically unhealed group had an average mRUST of 12.7 ± 2.2.

Radiographic analysis

The ICC for the three reviewers was 0.93 (95% CI 0.86-0.97). Radiographic evaluation using the mRUST score showed that 18 out of the 24 fractures achieved a score greater than or equal to 13, indicating radiographic healing.[1,2] In the rigid fixation group, one of the six fractures stabilized with a locked plate, and five of the six compression plate constructs achieved an mRUST score greater than 13, indicating radiographic healing. In the relatively stable fixation group, all 12 fractures achieved an mRUST score greater than or equal to 13, indicating radiographic healing.

Correlation of mRUST and Mechanical Strength

The mRUST score was positively correlated with biomechanical strength relative to the contralateral tibia (Figure 2). The mRUST score correctly determined the biomechanical state of healing in 14 of 24 fractures. Specifically, the mRUST score correctly classified 9 of the 10 biomechanically consolidated fractures as healed and 5 of the 14 biomechanically ununited fractures as not healed. Of the 10 fractures incorrectly classified by the mRUST, 9 were classified as healed radiographically but had not achieved sufficient strength to be considered biomechanically healed, and one was classified as not healed when biomechanically consolidated. The fractures incorrectly classified as healed included three fractures stabilized with relatively stable fixation, four fractures stabilized with compression plating, and one with locked plating. The healed fracture incorrectly classified as not healed was stabilized with a locked plate.

Comparing the performance of the mRUST between the relatively stable and rigid fixation groups showed varying results. In fractures fixed with relatively stable fixation (ACTIVE GAP and ACTIVE NO GAP), it correctly classified 9 out of 12 cases. However, in fractures

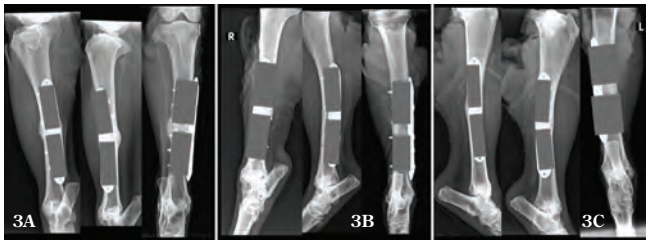

Figure 3A to 3C. Three cases with a mRUST of 15 but biomechanically unhealed. (1A) Active plate, strength 50.8% of contralateral side, (1B) Compression plate, strength 48.6% of contralateral side, (1C) Compression plate, strength 55.1% of contralateral side.

fixed with rigid fixation (RIGID COMP and RIGID GAP), it only accurately identified 5 out of 12 fractures. The mRUST misclassified 6 rigidly fixed fractures (5 compression plates and l locked plate) as healed radiographically when not fully consolidated biomechanically and one (locked plate) as not healed when biomechanically healed.

Three fractures with an mRUST of 15 that were not biomechanically healed were further investigated as their score was near the maximum of 16. These fractures only regained 51.7% (sd 3.7%) of the strength of the contralateral tibia. They included one relatively stable fixation (ACTIVE NO GAP) and two compression plate cases (RIGID COMP) (Figure 3).

The effect of a residual fracture gap after fixation was also investigated. Six of the relatively stable group (ACTIVE GAP) and the locked plate group (RIGID GAP) both had a 3 mm fracture gap present for a total of 12 tibia with a residual fracture gap. Of these 12, the mRUST correctly identified the healing state in nine cases, five as healed and four as unhealed. It incorrectly classified two fractures as healed when not consolidated biomechanically and one fracture as not healed when biomechanically consolidated. In the 12 fractures stabilized without a gap, the mRUST correctly predicted the biomechanical state of healing of 4 fractures, all in the active plating group.

DISCUSSION

The mRUST score is an important tool for assessing fracture healing in both clinical and research settings. In the clinical setting, it provides surgeons with a non-invasive, standardized metric to gauge fracture healing, informing decisions about rehabilitation, weight-bearing, and patient care. In research, it offers a consistent measure to evaluate and compare the efficacy of various treatments and interventions with regard to fracture healing. Understanding the accuracy of the mRUST score as a predictor of healing is paramount as it ensures that decisions, whether in patient care or in research outcomes, are based on reliable and valid determinations of fracture healing. Previous investigations support the accuracy of the mRUST but are limited to primarily small animal studies using mostly relatively stable homogenous methods of intramedullary fixation. This study represents the first attempt to evaluate the mRUST score in a cohort of fractures stabilized with heterogenous fixation methods that have different mechanical environments and result in healing with different amounts of callus. Both rigid and flexible fixation techniques with and without residual fracture gaps were included.

Our results agree with previous studies showing a positive correlation between the mRUST score and biomechanical fracture healing.[2] Using a large animal fracture model and employing multiple fixation methods that generate differing amounts of callus, we were able to further define the utility of the mRUST score. Specifically, we found the mRUST was most accurate for fractures treated with relatively stable fixation that produced callus, correctly predicting biomechanical healing in 75% of the fractures. Previous studies showing the mRUST to be an accurate predictor of biomechanical healing predominantly use intramedullary fixation, a fixation technique that produces a relatively stable mechanical environment and healing with callus. The secondary stiffness of the active plate is consistent with that of an intramedullary nail,[11,12] resulting in healing with callus formation.

We found the mRUST less accurate in fractures treated with rigid fixation. Both compression plating and locked plating constructs are extremely rigid relative to intramedullary fixation or active plating. The mRUST correctly predicted the biomechanical healing status in less than half of the fractures treated with rigid fixation. The mRUST performed better in the locked plating group, correctly predicting a lack of healing in 67% of cases. The rigid locked plate constructs were mostly not healed at nine weeks. It is unclear from this study how the locked plate group would perform had the fractures been allowed to heal completely before mechanical testing. The mRUST performed poorly in the compression plate group, incorrectly predicting healing in 5/6 fractures that were not biomechanically healed. The anatomical reduction of the fracture combined with the low amount of callus formed by the rigid compression plating constructs likely resulted in high mRUST scores despite poor healing, as the presence or absence of bridging callus could not be determined.

One confounding factor in comparing the mRUST between the rigid and relatively stable constructs is the presence of a residual fracture gap in the locked plate and active plate groups. Both the locked plate group and the relatively stable active plate group with a residual

fracture gap performed better than the compression plate group. It is likely that the presence of a fracture gap aided in determining the presence or absence of bridging callus, a critical factor in assigning the mRUST score. Three fractures without a residual gap (two compression plating and one active plate without a gap) had an mRUST score of 15 but only recovered 50% of the strength of the contralateral tibia. A score of 15 out of a maximum of 16 is considered radiographically healed. This risk of a significant error in predicting healing warrants caution when using the mRUST score for fractures stabilized without a residual fracture gap.

The ability of the mRUST to predict the eventual healing of fractures was not evaluated in this study. Rather, this study assessed the mRUST score at one time point in the healing process. As such, this study does not determine the ability of the mRUST to predict if the fracture will eventually heal. For example, it is possible that the score would have performed much better if the evaluation had been performed at 24 weeks of healing rather than nine weeks. Previous clinical studies have shown that bridging at a single cortex is predictive of eventual fracture union.[13,14]

This study has several limitations. First, the definition of a biomechanically healed fracture can be criticized. Many previous studies define 90% stiffness recovery relative to the contralateral bone as healed.[1,2] We chose a lower level of strength recovery, understanding that the presence of empty screw holes in the operative bone will decrease its strength. All of the relatively stable constructs failed through a residual screw hole rather than the osteotomy site. If the data were evaluated at a 90% recovery threshold, the mRUST would perform much worse. Specifically, it would incorrectly predict healing in 7 additional fractures that were not biomechanically healed. A known limitation of the mRUST in plate constructs is the plate obscuring the medial cortex.[1] This makes evaluating cortical bridging near the plate difficult, possibly affecting the mRUST score. We obtained 10-degree rotational lateral views to prevent inaccurate readings, but it remains possible that the scores were affected. Previous work evaluating mRUST accuracy used nondestructive stiffness testing as a surrogate for biomechanical strength rather than destructive strength testing. Biomechanical healing is defined by load to failure, and we chose this as the ultimate definition of strength rather than employing a surrogate measure. This makes comparison with previous studies using a surrogate definition of healing difficult. The retrospective nature of using data from previous studies limited our ability to control specific fixation types and times of strength testing. This may limit the generalizability of the data to other fixation methods and follow-up lengths.

In conclusion, although supportive of the mRUST score, these results highlight the need for caution in using mRUST to determine biomechanical healing. One must be especially diligent when using mRUST to judge healing using compression plating techniques and constructs with anatomic alignment that do not form abundant callus. The mRUST performs best when residual fracture gaps are present and when fractures heal with callus. These findings emphasize the importance of ongoing research aimed at refining the use of the mRUST score and adjunctive clinical methods to determine fracture healing.[3]

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SUBSTANTIAL LOSS OF SKELETAL MUSCLE MASS OCCURS AFTER HIGH ENERGY TRAUMA

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ABSTRACT

Background: The aim of this study was too quantify loss of skeletal muscle mass that occurs early after high energy trauma and determine the association with poor nutrition intake.

Methods: This prospective cohort study was completed at a midwest academic level 1 trauma center. Patients aged 18 – 55 years old with acute open fracture of the extremity/pelvis and/or two or more injured extremities treated with operative fixation were enrolled. Body composition was measured with bioelectrical impedance analysis at time of injury, 6 weeks, and 12 weeks after injury (Lean Body Mass (LBM), Skeletal Muscle Mass (SMM), Percent Body Fat (%BF)).

Dietary intake was measured with the Vioscreen® survey at time of injury and at 3 months. Baseline to post-operative changes in body composition were evaluated using repeated measures generalized linear models (GLM). To determine whether body composition changes differed according to baseline protein insufficiency, subjects were grouped according to baseline protein insufficiency status (<0.8 g protein/Kg Bodyweight, y/n) and analyses were repeated with addition of a group*time interaction term to GLM models.

Results: Twenty patients (male, n=16 (80%)), mean age 37.7 SD 12.4 years) from June 2021 – June 2022 were enrolled. Subjects lost significant LBM at 6 weeks (mean = -5.2kg SD5.6kg, p=0.0007), 12 weeks (mean = -5.3kg SD5.5 kg, p=0.0017), and 24 weeks (mean = -8.3kg SD 7.3kg, p=0.0037). and significant SMM at 6 weeks (mean= -3.0kg SD 3.3kg, p=0.0009), 12 weeks (mean = -3.1 kg SD 3.2 kg, p=0.0013) and 24 weeks (mean = -4.8kg SD 4.4kg, p= 0.0049). There was also a significant increase in %BF seen at follow-up (0.45% SD 0.16%, p<0.05). Five out of 20 subjects were protein deficient at the time of injury. Protein deficiency was not associated with loss of LBM or SMM.

Conclusion: This study documented significant loss of LBM and SMM and increases in %BF after high energy musculoskeletal trauma. Insufficient protein intake was not associated with greater loss of muscle mass in this small series.

Level of Evidence: II

Keywords: trauma, nutrition, muscle loss, lean body mass, functional

INTRODUCTION

Orthopedic surgeons that care for victims of high-energy trauma are well aware of the muscle atrophy and weakness that can persist for years after these devastating injuries.

Decreased physical function and failure to return to pre-injury occupation are common long term outcomes after high energy trauma.[1-3] Muscle atrophy and loss of skeletal muscle mass have been shown to contribute to functional losses after injury. Studies have shown up to a 10% decrease in baseline muscle mass persisting 6 months after geriatric femoral neck and intertrochanteric fractures.[4-6] Much of the current literature related to muscle loss after orthopedic trauma focuses on the geriatric population with fragility fractures rather than the younger, high-energy trauma population.[4]

After injury and surgical treatment, the body enters a catabolic state to meet metabolic demands needed for healing.[7,8] Limited oral intake is incapable of meeting increased metabolic demand, forcing the body to breakdown functional muscle mass to compensate for nutrition deficiencies.[9-12] Among hip fracture patients, poor nutrition is associated with impaired physical function and loss of independence after fixation.[13,14] Additionally, muscle loss after trauma contributes to impaired physical function.[4,5,15,16] Poor nutrition and loss of muscle mass likely also contributes to functional limitations in younger patients after high-energy trauma.

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To our knowledge there are no previous investigations quantifying the loss of skeletal muscle mass that occurs after high-energy orthopaedic trauma. We hypothesized that loss of muscle mass will be greater in patients with poor nutrition after trauma. The aims of this study were to 1) Quantity loss of skeletal muscle mass that occurs after high energy musculoskeletal trauma, 2) Determine if inadequate protein intake contributes to loss of muscle mass, and 3) Explore the relationship between loss of skeletal muscle mass and a) physical function and b) surgical complications.

METHODS

Eligible subjects were adult trauma patients (age 18-55 years) with either an open fracture of the extremity/pelvis or two or more injured extremities with fractures indicated for operative fixation. These inclusion criteria were selected to focus on a younger population with high energy trauma and to decrease the influence of comorbid conditions on recovery, more frequent among older populations. Exclusion criteria included those lacking decision-making capacity (head injury, dementia, delirium, or intellectual disability), vulnerable populations (prisoners, non-English speaking, and pregnant women), or those with medical contraindications incompatible to the study (unable to consume an oral diet, unable to ambulate prior to injury, patients with a pacemaker or implantable cardioverter defibrillator device that prevents measurement of body composition, patients with an active malignancy or who are undergoing chemotherapy/radiation).

Screening

Patients admitted to a Level I trauma center (University of Iowa Hospitals and Clinics) as trauma activation, with qualifying operative musculoskeletal injuries were screened and approached for consent and prospectively enrolled within 72 hours of hospital admission. All patients were treated according to standard of care for their injuries.

Outcomes

Changes in body composition (Lean Body Mass (LBM), Skeletal Muscle Mass (SMM), and Body Fat % (%BF),) were assessed using Bioelectrical Impedance Analysis (BIA) at baseline, 6 weeks, and 3 months and 6 months after surgery.[17] Caloric and macro- and micronutrient intake and activity levels were measured using validated food frequency questionnaire and activity surveys (Vioscreen®, VioCare®), during the hospital admission for trauma and 3 months after trauma to assess protein intake prior to injury and during the healing phase after trauma. The Vioscreen® survey is a web-based program based on validated Food Frequency Questionnaires, designed to record dietary intake for the prior 3 months.[18] Nutrition intake was compared to the Dietary Reference Intakes put forth by the NIH Institute of Medicine and reviewed by a registered dietician.[19] Insufficient protein intake was defined as the recommended dietary allowance (RDA) of 0.8 g protein/kg Bodyweight.[20] Health Eating Index (HEI) scores, a measure of dietary quality, were used to evaluate subject's overall nutrition intake.[21] Patientreported physical function (PROMIS-PF) was collected at baseline, and 3 months after trauma.

Post-operative complications were recorded prospectively up to 6 months after trauma. (Figure 1.)

Statistical Analysis

Baseline characteristics were described using mean±SD for continuous variables and frequency (percentage) for categorical variables. Pearson correlation coefficients were used to explore potential associations between baseline macro/micro-nutritional intakes and body composition.

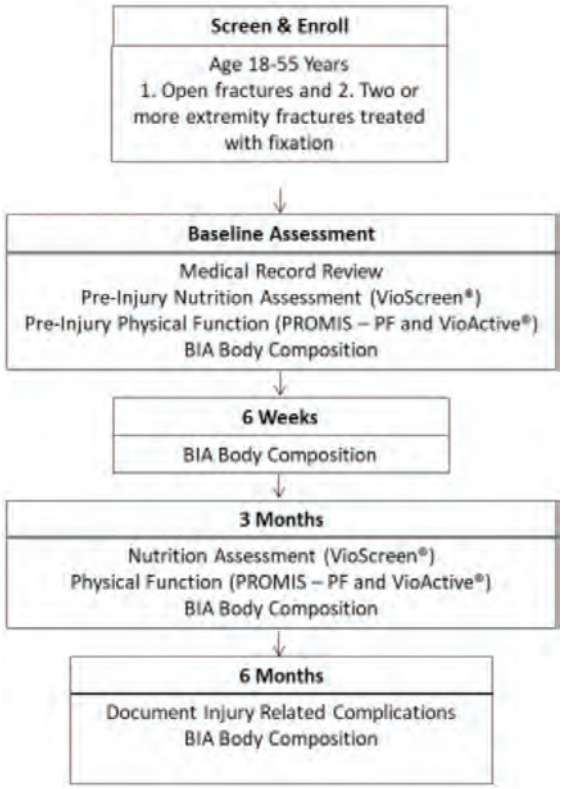

Figure 1. Enrollment and outcomes collected at each study time point for high energy orthopaedic trauma patients undergoing operative fixation.

Table 1. Baseline Demographics

(n= 20)	Mean (SD)
Age (yrs)	37.7 ± 12.4
BMI (Kg/m^2)	29.3 ± 7.4
Length of Stay (days)	5.5 ± 3.8
Sex (n, % female)	4 (20%)
Race	n (%)
African American/Black	3 (15%)
White	17 (85%)
Hispanic	1 (5%)
Tobacco Use (n, % current)	10 (50%)
Education	n (%)
High School/GED	2 (10%)
Some college	2 (10%)
Unknown	16 (80%)
Alcohol Abuse	3 (15%)
Injury Mechanism:	n (%)
Motor Vehicle Crash	7 (35%)
Fall from Height	4 (20%)
Ground Level Fall	1 (5%)
Firearm/Blast Injury	4 (20%)
Sports Related Injury	1 (5%)
Pedestrian victim vs. MVC	1 (5%)
Other	2 (10%)
Protein Insufficiency (RDA definition: Protein/kg body weight <0.80)	5 (25%)

BMI- Body Mass Index. RDA – Recommended Dietary Allowance. MVC – Motor Vehicle Crash.

Post-operative changes in measures of body composition, including LBM, SMM and %BF, as well as self-reported physical functional level (PROMIS-PF) were evaluated using repeated measures generalized linear models (GLM). These analyses were repeated, following inclusion of a group*time interaction to GLM models, to determine whether subjects grouped according to a) baseline protein insufficiency, defined as <0.8 g protein/Kg Bodyweight (y/n), and b) post-operative complication (y/n), differed in post-operative changes in body composition. Logistic regression was used to evaluate whether subjects with versus without (referent) baseline protein insufficiency had significantly greater odds of post-operative complications. Analyses were completed using SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC).

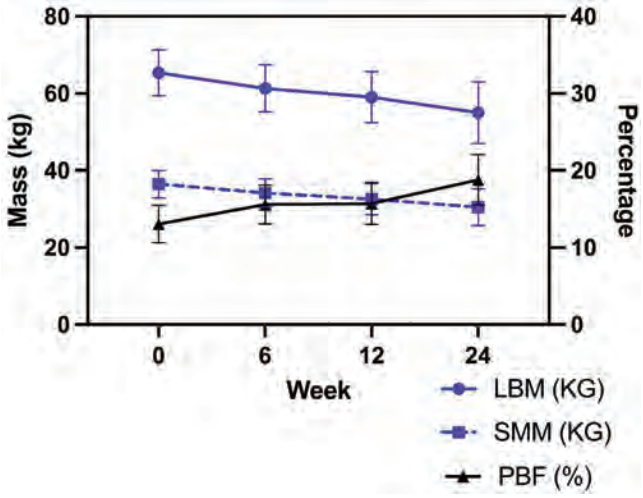

Figure 2. Body composition changes in Lean Body Mass (LBM), Skeletal Muscle Mass (SMM) and Percent Body Fat PBF (%) after operative fixation in patients sustaining high energy musculoskeletal trauma.

RESULTS

From June 2021 – March 2022, 101 subjects met the screening inclusion criteria. Seventy-seven patients were either excluded based on criteria, were unapproachable within the enrollment time frame, or declined participation. Ultimately 25 patients were consented and enrolled. Two patients were excluded for lack of follow-up, 2 were excluded for lack of baseline body composition measurements, and one patient was excluded due technical complications with recording their body composition measurements. Twenty subjects were included in final analysis. The cohort was primarily male (n=16, 80%) with a mean age of 37.7 and SD of 12.4 years, motor vehicle accidents were the most common injury mechanism (Table 1).

Change in body composition (lean body mass, skeletal muscle mass, %Body Fat)

Results of repeated measures GLM analyses revealed significant loss of LBM at 6 weeks (mean = -5.2kg SD 5.6kg, p=0.0007), 12 weeks (mean = -5.3kg SD 5.5 kg, p=0.0017), and 24 weeks (mean = -8.3kg SD 7.3kg, p=0.0037). Subjects also lost significant SMM at 6 weeks (mean= -3.0kg SD 3.3kg, p=0.0009), 12 weeks (mean = -3.1 kg SD 3.2 kg, p=0.0013) and 24 weeks (mean = -4.8kg SD 4.4kg, p= 0.0049). (Figure 2.) Subjects had significant increases in %BF at 6 weeks (mean = 5.6 SD 8.1 %BF, p=0.007), 12 weeks (mean = 6.3 SD6.8 BF, p=0.002) and 24 weeks (mean = 13.1 SD 12.0 %BF, p= 0.0047). (Figure 2.) On average subjects incurred an increase of 0.45 SD

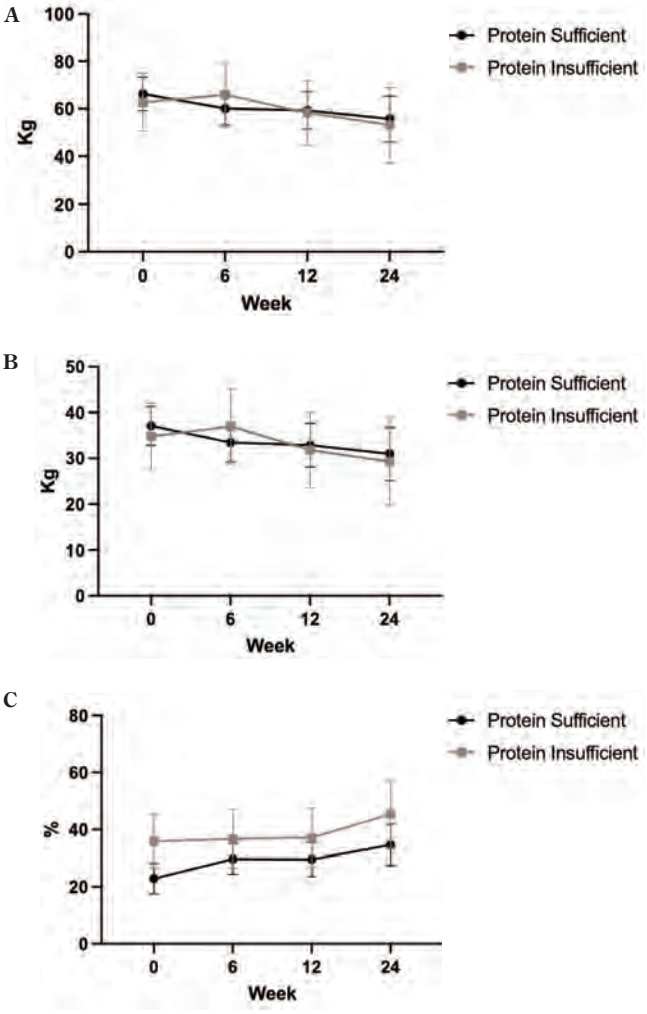

Figure 3A to 3C. (3A) Lean Body Mass. Changes in Lean Body Mass among those with Sufficient vs. Insufficient Protein Intake at baseline. (p=0.82). (3B) Skeletal Muscle Mass. Changes in Skeletal Muscle Mass among those with Sufficient vs. Insufficient Protein Intake at baseline. (p=0.80). (3C) Percentage Body Fat. Changes in %BF in those with Sufficient vs. Insufficient Protein Intake at baseline (p=0.86).

0.16 %BF per week (p=0.0079). The change in %BF at 12 weeks demonstrated moderately strong inverse correlations with changes in LBM (ρ = -0.79, p<0.001) and SMM (ρ= -0.82, p<0.001).

Changes in Physical Function

Overall PROMIS-PF scores at baseline were low (mean = 41.4 ± 17.9) and demonstrated non-significant changes at 12 weeks (mean difference = -11.4 ± 24.0, p=0.147) and 6 months (mean difference = 10.0 ± 20.4, p = 0.135) from baseline. There was no association between either baseline PROMIS-PF and body composition changes (LBM, SMM, %BF) or change in PROMIS-PF and body composition changes at any timepoint during follow-up (all p>0.05).

Table 2. Complication Rates Occurring Within 6 Months of Surgery After High Energy Trauma

Complications (n= 20)	N (%)
Medical	1 (5%)
DVT	1 (100%)
Surgical	7 (32%)
Nonunion	0
Surgical Site Infections	6 (86%)
Other	1 (14%)
SSI Treatment Outcomes	(n=6)
Topical antibiotics	1 (17%)
Oral Antibiotics	2 (33%)
Surgical Debridement	3 (50%)
Readmission	2 (11%)
Reoperation	3 (16%)
Any complication	7 (35%)

No non-unions were recorded.

Dietary Protein Intake

Overall, dietary adequacy in this study cohort was poor yet comparable to that of the general U.S. population based on Healthy Eating Index (HEI) 2010 scores (Cohort average 60.7 SD 10.1, Population average 56.6 SD 0.53, p=0.089). Insufficient protein intake (RDA definition of <0.80 ratio of protein intake g/body weight kg) was common prior to injury (n=5/20) (Table 1). Protein insufficiency was associated with higher percent body fat at baseline, (Protein Insufficient n=5, mean = 35.8% SD 8.6% BF vs. Protein Sufficient n=15, mean = 22.9% SD 11.9% BF, p=0.0362). However, there were no differences in baseline LBM or SMM among those with adequate vs. insufficient protein intake (both p>0.05). At baseline, PROMIS-PF scores did not differ between those with adequate vs. insufficient protein intake (p= 0.694). Subjects with compared to without baseline protein insufficiency did not differ in post-operative changes in body composition (SMM, LBM, %BF) at any point throughout follow-up. (all pvalues for interaction >0.05), Figure 3a-c.) However, the higher rates of %BF seen among those with insufficient protein intake were maintained throughout follow-up. (Figure 3c.)

Complications Related to Trauma

Overall, 7 of 20 participants experienced at least 1 post-op complication (surgical complications 7/20 and medical complications 1/20). The incidence of post-operative surgical site infections was high (6 of 7 surgical

complications). SSI treatment outcomes included use of topical antibiotics (n=1), oral antibiotics only (n=2), and surgical debridement (n=3). Rates of re-admission (n=2, 10%) and unplanned re-operation (n=3, 16%) were common as well. (Table 2) There were no differences in body composition changes (LBM and SMM) among those who experienced complications compared to those who did not (both $p>0.05$). There was no association between insufficient protein intake at baseline and post-operative complication rates (OR=1.33 (95%CI:0.17-10.74), p=0.787).

DISCUSSION

This prospective observational cohort study characterized changes in body composition during recovery from high energy musculoskeletal trauma in a young adult population (age 18-55 years). This study found substantial loss of lean body mass, and skeletal muscle mass with gain in percent body fat throughout follow-up. At six months after surgery, subjects lost an average of 13.1% of their baseline LBM and 13.6% of their baseline SMM. Insufficient protein intake prior to injury was common and was associated with a higher baseline percent body fat. However, it was not associated with changes in lean body mass or skeletal muscle mass during follow-up. Over one-third of subjects in study cohort experienced a complication the majority of which were surgical site infections (n=6, 30%). Body composition changes (LBM or SMM) were similar among those who experienced a complication compared with those who didn't. ($p>0.05$). Improvements in patient reported physical function were not seen at either 3 months or 6 months postoperatively.

The results of the current study coincide with much of the current literature demonstrating loss of muscle mass occurs postoperatively following fixation after orthopedic trauma. In a previous investigation of a large heterogenous trauma population, Hendrickson et al. identified that significant loss of FFM occurred within 6 weeks after injury, whereas those receiving conditionally essential amino acid supplementation, did not (mean and standard deviation, -0.90 ± 0.39 kg; $p = 0.0205$ vs. -0.33 ± 0.36 kg; $p = 0.3606$).[22] The lower rate of malnutrition and broader variety of lower severity injuries in that study population may account for these differences. Significant muscle loss is known to occur after orthopedic trauma and immobilization secondary to injury.[7,11,12] Similarly, the Baltimore hip studies found loss of lean body mass occurring up to 2 months after injury in a cohort of female geriatric hip fracture patients.[23] Comparatively, this study demonstrated greater loss of muscle mass persisting up to six months after injury. (Figure 2.) Higher injury severity, longer periods of immobilization and greater metabolic demand for wound healing potentially account for these differences in body composition changes between the high energy trauma population in the current study, compared with studies of older fragility fracture populations. This is the first study to assess muscle loss specifically in a high energy trauma population. It is reasonable to assume these more severe injuries would incur a greater energy demand for wound healing which could underline greater loss of muscle mass.

Patient-reported physical function after high energy musculoskeletal trauma is poor.[15,24-29] Among geriatric hip fracture patients, loss of skeletal muscle mass is substantial, and has been shown to correlate with a worsening recovery of physical function after hip fracture.[4,23,30] Hoogervorst et al. assessed functional outcomes in a high energy lower extremity fracture population (Mangled Extremity Severity Score (MESS) ≥ 7) and found only 7% of subjects achieved good functional recovery at two-year follow-up. The rate of achieving good functional recovery was zero among patients undergoing amputation at the time of injury.[24] Similar results were demonstrated in the Lower Extremity Assessment Project (LEAP), the largest prospective cohort studies of high energy lower extremity injuries. At 7-year follow-up investigators found nearly 50% of patients had substantial physical disability as indicated by a Sickness Impact Profile score >10.26 Similar outcomes of poor physical disability and function have been reported among military populations from the Military Extremity Trauma Amputation/Limb Salvage (METALS) Study for both lower and upper extremity injuries.[15,16] The present study found no significant recovery in patient-reported physical function after high energy trauma. This may be accounted for by the limited follow-up and the small sample cohort as well as the higher severity of injuries in this patient population. Overall, there is a need for studies evaluating changes in muscle mass, and their relation nutrition deficiencies, to also explore functional outcomes in order to translate biological changes into clinical outcomes applicable to patient care.

The prevalence of baseline protein insufficiency found in this high energy trauma population (n=5/20) is similar to rates of malnutrition seen among general orthopedic trauma patients, ranging from 17%-42% overall.[32-34] Complications after orthopedic trauma are also common[35] but there is heterogeneity in how the influence of nutrition status on clinical outcomes, such as surgical site infections, medical complications, non-union, mortality and hospital length of stay, has been evaluated in the literature.[10,33,34,36,37] Among geriatric patients malnutrition is a known predictor of increased hospital length of stay, mortality, poor functional recovery. Much of the evidence examining the influence of nutrition status, on these outcomes after orthopedic trauma is limited to these older more frail populations.[4,10,23,30,35,37-42] Hendrickson et al. and

Lee et al. demonstrated that malnutrition diagnosis was predictive postoperative complications among broader orthopedic trauma cohorts.[33,34] Hendrickson et al. also determined that dietician assessment was the strongest predictor of complications when comparing diagnostic methods of malnutrition.[33]

Limitations

There are limitations to the generalizability of the study results. This study was performed at a single Midwest Level 1 trauma center and the cohort consisted of majority Caucasian males. Future studies should aim to include patients from different geographical regions to capture a more diverse patient population with varying injury mechanisms. The small sample size, and survey completion limited comparisons between baseline protein malnutrition, complications, and changes in body composition. The often variable and limited follow-up among trauma patients poses challenges to assessing longitudinal outcomes. Because of these factors, the present study has limited detection of associations between inadequate protein intake and physical function. Future studies should include larger more diverse patient populations to further assess the relationships between loss of muscle mass, nutrition intake and functional recovery.

CONCLUSION

This observational cohort study found significant muscle loss and increases in percent body fat occurs after high energy trauma. Protein insufficiency and poor overall nutrition was common at baseline but did not impact changes in body composition or physical function. Larger scale investigations are needed to evaluate the influence of nutrition on body composition changes, functional and clinical outcomes among patients sustaining high energy orthopedic trauma. Future work should evaluate the effect of nutrition interventions to prevent muscle loss in this patient population.

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ORTHOPEDIC SURGERY RESIDENT EXPOSURE TO SLIDING HIP SCREW FIXATION FOR INTERTROCHANTERIC FEMUR FRACTURES: A MULTICENTER STUDY

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ABSTRACT

Background: This study aimed to determine the level of exposure to sliding hip screws amongst orthopedic surgery residents compared to intramedullary nail fixation for intertrochanteric femur fractures.

Methods: Data was collected from five orthopedic surgery residency programs through the case log system of the accreditation council for graduate medical education (ACGME) based on current procedural terminology codes (CPT). The rates of IMN for treatment of IT fracture (27245) were compared to SHS fixation (27244) for the period of 2017-2021. The location of the procedure was also logged as either a level one trauma center, non-trauma hospitals, and a veteran's affairs hospital (VA). Rates of SHS usage were compared by year and location type using multivariate logistic binary regression.

Results: 5,910 IT femur fractures were treated by orthopedic residents during the time period. IMN was utilized for 88.8% of cases. The highest usage of SHS was 15.6% in 2017 with a statistically significant decrease to 9.2% in 2021 ($p < 0.001$). SHS utilization was lowest at non-trauma centers (5.4%) and highest at level one trauma centers (11.7%).

Conclusion: Residents get limited experience with SHS compared to IMN in their training programs, and there is a significant trend toward fewer SHS implants being used by residents over the past 5 years. Residents' limited experience with SHS during residency may contribute for the trend toward IMN use. Surgeons at academic institutions ought to recognize this trend and strongly consider their implant choice when treating intertrochanteric femur fractures for fear of sliding hip screws becoming a lost art.

Level of Evidence: IV

Keywords: intertrochanteric fracture, resident education, intramedullary nail, sliding hip screw

INTRODUCTION

Intertrochanteric (IT) femur fractures are one of the most common injuries treated by orthopedic surgeons and account for an annual incidence of roughly 150,000 injuries.[1,2] Given the increasing elderly population of the United States, the rate of osteoporosis is expected to increase along with the rates of osteoporotic fragility fractures such as intertrochanteric femur fractures.[3,4] Due to the significant impact on patient mobility, surgery is most commonly indicated in those patients that are medically stable in order to decrease mortality and to limit the morbidity associated with bedbound patients, which includes pneumonia, deep vein thrombosis and pressure sores.[5-7] The mainstays of operative treatment remain intramedullary nail (IMN) or sliding hip screw (SHS) fixation, where the choice of implant often seems based on surgeon preference.[5] Prior studies comparing outcomes between the two treatment modalities have failed to demonstrate a significant difference with regard to outcomes, union rates or complication profiles.[8-11] That said, because of the internal buttress effect of the IMN, this implant is often indicated in the treatment of unstable intertrochanteric fractures, characterized by reverse obliquity orientation, subtrochanteric extension or posteromedial comminution.[12,13]

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Table 1. Proportion of Sliding Hip Screw and Intramedullary Nail by Year

Year	Total Cases	Sliding Hip Screw (27244)	Intramedullary Nail (27245)	P-Value	Odds Ratio [95% CI]
2017	1091	170 (15.6%)	921 (84.4%)	–	–
2018	1018	131 (12.9%)	887 (87.1%)	0.087	0.807 [0.63, 1.03]
2019	1192	124 (10.4%)	1068 (89.6%)	**< 0.001**	0.639 [0.50, 0.82]
2020	1201	104 (8.7%)	1097 (91.3%)	**< 0.001**	0.528 [0.41, 0.68]
2021	1408	130 (9.2%)	1278 (90.8%)	**< 0.001**	0.560 [0.44, 0.72]
Total	5910	659 (11.2%)	5251 (88.8%)	–	–

Statistical significance is shown with respect to 2017 as the reference value. P < 0.050 is considered significant, values are highlighted in bold.

Despite the lack of evidence demonstrating superiority of one implant over the other, there has been an evolving trend toward the preference of IMN over SHS for treatment of intertrochanteric femur fractures. Several studies have investigated Medicare, Veteran's Affairs, and ABOS part II databases with demonstration of an increase in the use of IMN for IT fractures from 3% in 1999 to 92.4% in 2017.[14-17] Several explanations have been proposed for why such a drastic trend exists, to include lack of exposure to SHS in orthopedic surgery training.[18,19] However, the data to demonstrate that orthopedic surgery residents are lacking operative experience with SHS have not been reported. Thus, the purpose of this study was to investigate if a similar trend toward IMN exists within U.S. orthopedic surgery training programs. The authors of this study hypothesized that a parallel trend exists, with residents gaining limited experience using SHS compared to IMN for intertrochanteric femur fractures.

METHODS

After review by institutional review board, this study was deemed exempt from full review. Data were then collected from five orthopedic surgery residency programs through the case log system of the accreditation council for graduate medical education (ACGME). These programs had a complement of 4, 5, 6, 8 and 8 residents annually for a total of 155 residents recording cases during the study period. Cases logged using current procedural terminology codes (CPT) 27244 and 27245 representing treatment of intertrochanteric femur fractures with plate/screw construct and intramedullary nail implant respectively were included in review and collected for the five year span from 2017-2021. No patient specific information nor trainee identifiable information was available through this database. In addition to code type, the location of the performed procedure was recorded. The location was described as an academic level one trauma center, a non-trauma designated community hospital, or veteran's affairs (VA) hospital. Each program rotated through a minimum of 1 level-one trauma center, 4 programs rotated through a non-trauma designated community hospital, and 4 programs rotated through a VA hospital.

Statistical analysis was performed using statistical package for social sciences (SPSS) (Version 24; IBM SPSS). Comparisons between SHS and IMN were made for both time over the five-year period from 2017 to 2021 and based on hospital type using multivariate logistic binary regression. 2017 was used as the reference value for the time comparison while the non trauma, community hospitals were used as the reference value for the hospital type comparison. Statistical significance was set to a p-value of < 0.5 and odds ratios were reported for each year and hospital location with respect to the reference.

RESULTS

Between the years 2017 and 2021, resident physicians at the 5 included programs recorded the treatment of 5,910 intertrochanteric hip fractures. Overall, SHS was utilized in 659 (11.2%) cases while IMN was utilized in 5251 (88.8%) of cases. The highest rate of SHS usage was recorded in 2017 with a rate of 15.6%. The rate of SHS use dropped to 12.9% in 2018, 10.4 % in 2019 and 8.7% in 2020. In 2021, SHS were utilized in 9.2% of IT fractures. The rates from 2019-2021 were significantly decreased compared to the reference rate in 2017 ($p < 0.001$). Table 1 further demonstrates the rates of SHS usage from all years included. (Table 1)

With regard to hospital type, 391 procedures were recorded at non trauma centers, 260 at VA hospitals and 5,263 at level-one trauma centers. SHS usage was lowest at the non-trauma hospitals with a rate of 5.4%. SHS were utilized at a significantly higher rate in both VA hospitals (9.6%; $p = 0.041$). and at level one trauma

Table 2. Proportion of Sliding Hip Screw and Intramedullary Nail by Hospital Type

Hospital Type	Total Cases	Sliding Hip Screw (27244)	Intramedullary Nail (27245)	P-Value	Odds Ratio [95% CI]
A)	391	21 (5.4%)	370 (94.6%)	–	–
B)	260	25 (9.6%)	235 (90.4%)	**0.041**	1.874 [1.03, 3.43]
C)	5259	613 (11.7%)	4646 (88.3%)	**< 0.001**	2.33 [1.49, 3.64]
Total	5910	659 (11.2%)	5251 (88.8%)	–	–

A) Community non-trauma hospital; B) Veteran's Affair's Hospital Systems; C) Level 1 trauma center.
Statistical significance is shown with respect to a community non-trauma hospital as the reference value. P < 0.050 is considered significant, values are highlighted in bold.

centers (11.7%; p < 0.001) when compared to non-trauma hospitals. Table 2 further outlines the rate of different implant usage by location of treatment. (Table 2)

DISCUSSION

Intertrochanteric femur fractures are frequently encountered by orthopedic surgeons and are expected to grow in frequency given the aging population and increased rates of osteoporosis in the United States.[1,3,20] Treatment of IT fractures with a sliding hip screw or intramedullary nail often depends on surgeon preference, as no studies have demonstrated superiority of one implant over the other.[8-11] Recent literature has demonstrated a significant trend toward increased IMN usage, with suggestions that the trend may be in part due to surgeon experience during surgical training.[15,18,19] The results of this study confirm the suggestions that orthopedic surgical residents are getting less exposure to SHS fixation during their residency training, which may contribute to the trend seen.

The trend toward use of IMN for IT fractures was first noted by review of the American Board of Orthopedic Surgeons (ABOS) part 2 examination database in 2008 by Anglen et al. and later confirmed by Smith et al. in 2021.[15,16] This trend seemed to suggest that younger surgeons favored IMN over SHS. Further study of the Medicare beneficiary database by Forte et al. demonstrated preference for use of IMN was associated with younger age of the surgeon and teaching hospital status. They further suggested that rates of IMN fixation would increase as surgeons continue to have less exposure to SHS through residency training.[21] Through use of questionnaires of current practicing orthopedic surgeons, Murray et al. and Mellema et al. similarly demonstrated that preference for IMN over SHS was associated with less surgeon experience as well as exposure during residency.[18,19] The present study's further affirms these prior investigations. The present study, however, highlights changes that are fundamental beyond practice trends: without the appropriate training of residents now, we may not be able to safely affect practice patterns, even if desired, for decades. The orthopedic residents included in this study demonstrated limited exposure to SHS fixation for intertrochanteric fractures with a trend of overall rates of SHS use declining over the course of the included study period.

The current study also found that residents were more likely to encounter the use of SHS at level one trauma centers as opposed to a non trauma center. These findings seem to agree with a prior study by Niu et al., who performed a web based survey of members of the American Academy of Orthopedic Surgeons. Through this, the investigators demonstrated that staff surgeons were more likely to utilize SHS if they worked at an academic hospital, were traumatology trained or supervised residents. These surveys also demonstrated that familiarity with technique was frequently cited as the reason for the choice of implant used.[22] Although it seems promising to resident education that surgeons who train residents are more likely to use a combination of SHS and IMN, the current study demonstrates orthopedic residents are encountering SHS use at a significantly decreasing rate.

Although outcomes following the use of IMN for IT fractures have demonstrated high union rates with low complication rates,[23,24] this trend toward IMN is not without consequence. The financial impact of this trend is particularly alarming as several studies have demonstrated a stark increase in cost associated with the use of IMN over SHS. Casnovsky et al. retrospectively reviewed all intertrochanteric fractures at their institution over a 5-year period and estimated cost of care with a time-driven activity-based costing. They found the average cost of care for patients undergoing treatment with SHS was significantly lower than those treated with both long and short IMN ($17,077 versus $19,314 and $21,372).[25] In a similar fashion, Swart et al. evaluated the cost effectiveness of each implant type based on fracture stability and implant failure rates. This study demonstrated SHS remained more cost effective for all IT femur fractures aside from those with reverse obliquity.[26] Despite this

evidence for improved cost effectiveness, it may be that many orthopedic surgeons do not consider cost when making their implant decision. Interestingly, a previous study by McCarthy demonstrated that orthopedic surgeons accurately identified the price of implant in only 21% of cases.[27] Regardless of the reason, financial considerations for implant use ought to be considered, particularly when no clinical difference in outcomes is overwhelmingly evident.

In addition to cost, it is important to recognize that SHS is not only an appropriate treatment strategy for IT fractures but is also an important implant for the treatment of young patients with femoral neck fractures.[28] In fact, several studies have demonstrated lower failure rates among young patients with femoral neck fractures treated with SHS compared to cannulated screws.[29,30] Needless to say, the SHS remains an integral implant in the orthopedic surgeon's toolbox. Exposure to this implant during residency is of critical importance to the resident's ability to utilize it in future practice. The lack of exposure to SHS for the treatment of IT fractures could lead to limited comfort with the implant for treatment of femoral neck fractures as well.

This study has multiple limitations. First, the information gathered through the ACGME case log is dependent on accurate reporting of procedures by the residents involved. For this reason, the system is subject to over or under reporting as well as scenarios that involve multiple residents recording the same procedure. Secondly, the case logs do not include information on fracture pattern or stability, which is a critical factor in determining the appropriate implant. Finally, the results of this study represent the experiences of a small sample group of residents at 5 residency programs out of 210 in the United States. Thus, this limited study may not be applicable to all orthopedic surgery residents.

CONCLUSION

This is the first study to our knowledge to evaluate orthopedic surgery residents' experience using sliding hip screws versus intramedullary nails for the treatment of intertrochanteric femur fractures. Residents get a much more limited experience with SHS than they do IMN in their training programs, and there is a significant trend toward fewer SHS implants being used by residents over the past 5 years. Thus, the limited experience orthopaedic surgery residents have with SHS during residency may account for the increased trend toward IMN use that has been shown throughout the field of orthopedic surgery. Surgeons at academic institutions ought to recognize this trend and strongly consider their implant choice when treating intertrochanteric femur fractures for fear of sliding hip screws becoming a lost art.

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PATIENT REPORTED OUTCOMES FOR MAISONNEUVE FRACTURES USING PROMIS PHYSICAL FUNCTION SCORES

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ABSTRACT

Background: Limited research exits surrounding Maisonneuve fractures due to rarity. Additionally, even less data has been published evaluating the patient reported outcomes of surgically treated Maisonneuve fractures using the Patient-Reported Outcomes Measurement Information System (PROMIS) Physical Function (PF) and Pain Intensity (PI) score. The aim of this study was to put forth a cohort of patient reported outcomes using PROMIS PF and PROMIS PI

Methods: Maisonneuve fracture patients with minimum 12-month follow-up treated at a level-1 trauma center from 2006 to 2020 completed PROMIS PF and PROMIS PI tests. Medical records were reviewed to gather patient characteristics, mechanism of energy, operative variables, and complications.

Results: The final cohort consisted of 28 patients with a mean follow up of 59.6 months with a mean time between injury and primary operation of 7.9 days. The mean PROMIS PF and PROMIS PI scores of the cohort were 56.3 (SD 10.8 [95% CI 15.9, 171.0] and 40.9 (SD 7.5 [95% CI 36,44]) respectively. The mean Foot and Ankle Ability Measure (FAAM) Activities of Daily Living (ADL) and FAAM Sports were 90.4 (15.4 [95% CI 84, 109] and 75.2 (SD 28.9 [95% CI 62, 91] respectively. Thirteen patients received syndesmotic screws only, nine received plate + syndesmotic screw, three received suture-button devices only, and three patients received syndesmotic screws + suture-button device. When the methods of syndesmotic fixation were divided into three groups, (1- syndesmotic screws only, 2-plate + syndesmotic screw, 3- suture-button device only and syndesmotic screw + suture-button device), the PROMIS PF scores for each treatment group was 60.2 (SD 8.5 [95% CI 54, 66]], 46.5 (SD 9.7 [95% CI 41, 53]), 62.8 (SD 9.7 [95% CI 54, 77]), respectively. The treatment group of plate + syndesmotic screw has significantly worse PROMIS PF compared to the syndesmotic screw only group.

Conclusion: This study is the largest cohort utilizing PROMIS PF and PI to evaluate surgically treated Maisonneuve fractures. The resultant PROMIS PF an PI scores further demonstrate the favorable outcomes for surgical treatment of Maisonneuve fractures.

Level of Evidence: III

Keywords: maisonneuve fracture, pronation-external rotation, PROMIS, FAAM

INTRODUCTION

Maisonneuve fractures are typically the result of high energy mechanisms which cause a proximal fibula fracture with concomitant injuries to the tibiofibular syndesmosis and the medial malleolus. The insult to the medial malleolus often results in damage to the deltoid ligament or an avulsion fracture of the medial malleolus. Posterior structures of the tibiotalar joint are also often associated with this type of injury.[1]

The Maisonneuve fracture has generally been described using the AO (44C.1-3), Lauge-Hansen, and/or Weber classification systems.[2,3,4] Treatment for these injuries typically involves surgical fixation via open reduction with internal fixation. However, debate remains as to what type of syndesmotic fixation is most efficacious.[5] Additionally, some studies have been published of patients being treated conservatively without surgical management when clinicians decide certain clinical criteria are met.[5-8]

While the fracture pattern involved in the Maisonneuve fracture is well known, the actual occurrence is relatively uncommon with rate of only 5 percent of ankle fractures.[3] The rarity of the injury causes difficulty in accurately assessing outcomes of different types of treatment. Furthermore, publications of long-term out-

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comes in general have been limited with most outcomes being reported via case reports and other small-scale studies describing functional outcomes after surgical treatment.[3,5,10]

To date, very little data exists on patient reported outcomes for Maisonneuve fractures using Patient-Reported Outcomes Measurement Information System (PROMIS) as a mode of evaluating outcomes.[11,12] Thus, the main objective of this study was to contribute to the literature and provide a larger cohort of patient reported outcomes using PROMIS Physical Function (PF) and Pain Intensity (PI) for surgically treated Maisonneuve fractures. Additionally, we hypothesized that patients treated with plate-assisted syndesmotic fixation would demonstrate worse physical function and activity scores compared to those treated with syndesmotic screws alone or suture-button devices.

METHODS

A single-institution retrospective cohort study was performed. After Institutional Review Board (IRB) approval was obtained, a query was made to identify skeletally-mature patients with operative ankle fractures from January 2006 to February 2020. Radiographs for each patient were then reviewed to identify patients with Maisonneuve fractures. Exclusion criteria included any imprisoned patients, non-English speaking patients, and patients who died during the follow-up period. Forty-one Maisonneuve fractures were treated with definitive fixation and one fracture was treated non-operatively at our institution from January 2006 to December 2019. Of those, two patients were deceased, and one patient was imprisoned. Of the remaining eligible patients, twenty-eight (28/41) with at least one year follow-up postoperatively were contacted and agreed to complete the outcome scores (Figure 1).

From the electronic medical record, demographic data were gathered including age, gender, and mechanism of injury. End stage reconstruction was defined as either tibiotalar arthrodesis or total ankle arthroplasty. An IRB consent information packet was mailed to patients. Upon consent via mail, each patient was subsequently contacted by telephone or emailed a survey link to complete their PROMs. Patients were asked a series of questions that make up the PROMIS physical function (PF) and pain interference (PI) outcome measures. Each question relates to the patient's current level of function and/or pain and is answered in a Likert-type scale from "Without any difficulty" to "Unable to do." Scores range from 0 – 100 with higher scores indicating more of the domain, i.e higher function or more pain interference. Additionally, patients completed the Foot and Ankle Ability Measure (FAAM) score for both activities of daily living (ADL) and Sports. This measurement system asks questions related to the patient's current level of function and/or pain and the Likert-scale is from "not at all [difficult]" to "unable to do" or N/A if the patient felt the question was not suitable for their current injury. For the FAAM, raw scores range from 0 – 84 on the ADL scale and 0 to 32 on the Sports scale. These raw scores are then transformed to percent scores (0 – 100%) with higher scores indicating higher function. Patients were also asked if they had undergone any subsequent surgeries on the ankle after permanent fixation or if they had ever had a surgical site infection on the affected ankle.

Statistical Analysis

Patient demographics and fixation characteristics were analyzed with descriptive statistics. A multivariate analysis of variance with a Fisher's Least Significant Difference post-hoc test examined the differences in PROMIS PF, PROMIS PI, FAAM ADL, and FAAM SPORT across fracture fixation methods. Confidence intervals of 95 percent were also calculated for the mean of each outcome measure. Age, gender, and patients CCI score were controlled for in the model. The model met the assumptions for homogeneity, normality, and variance. No analysis was possible of medial malleolar fixation as the data failed to satisfy the assumptions for a multivariate model. Hypothesis testing was based on an alpha level <0.05. All statistics were completed with SPSS 28 (IBM, New York, United States).

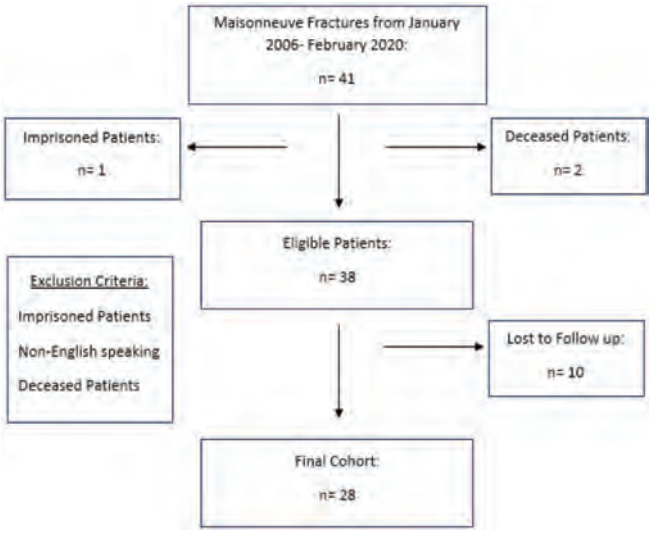

Figure 1. Illustration of how the final cohort size was obtained after patients were excluded from the study and/or lost to follow up.

Table 1. Demographics and Injury Classifications of the Patients with Maisonneuve Fractures Who Were Managed Surgically

Variable	(N=28)
Sex	
F	7 (25%)
M	22 (75%)
Age	
Mean (SD)	41.5 (15.6)
Range	(18, 70.0)
Mechanism	
Ground level fall	8 (31.0%)
Fall from height	2 (6.06%)
MVC/MVA/MCC	2 (6.9%)
Other	10 (30.30%)
Open Fracture	0 (0%)

RESULTS

Our final cohort consisted of 28 patients with a mean follow up of 59.6 (range, 12.4-113) [95% CI, 15.9, 171.0] months and a mean time between injury and primary operation of 7.9 (range, 0-55) days [95% CI 40.5-119.9]. The average patient age was 41.5 (range, 18-70) [95% CI 44 -55] (Table 1). The mean and median, PROMIS PF scores of the cohort were 56.3 (SD 10.8 [95% CI 52.1, 60.5]) and 55.0, respectively. The PROMIS PI scores had a mean and median of 40.9 (SD 7.5 [95% CI 38.-, 43.8]) and 36.3, respectively. The mean and median scores for the FAAM ADL were 90.4 (SD 15.3 [95% CI 84.5, 96.3]) and 97, respectively. The mean and median of the FAAM SPORTS was 75.2 (SD 28.9 [95% CI 64.0, 86.4]) and 83, respectively (Table 2).

Methods of syndesmotic fixation included syndesmotic screws+/-plate and/or suture-button device. Thirteen patients received syndesmotic screws (SS) only, three received suture-button devices (SBD) only, and nine patients received SS with a plate. Additionally, three patients received SSs and a SBD (Table 3). When the methods of syndesmotic fixation were divided into three groups, (Fixation: 1- SS only, 2-plate+SS, 3- SBD only, and SS+SBD), the PROMIS PF scores for each treatment group was 60.2 (SD 8.5 [95% CI 54.1, 66.3]), 46.5 (SD 9.7 [95% CI 39.6, 53.5]), 62.8 (SD 9.7 [95% CI 55.9, 69.7]) respectively. Comparing the PROMIS PF, FAAM ADL, and FAAM Sport scores between the different treatment groups, syndesmotic screw with plate performed significantly worse than SS or suture button device (Table 4).

Table 2. Patient Reported Outcomes of the Patients with Maisonneuve Fractures Managed Surgically Using PROMIS PF, PROMIS PI, FAAM ADL, and FAAM Sports

Variable	(N=28)
PROMIS-PF	
Mean	56.3 (SD 10.8)
Median	55.0
PROMIS-PI	
Mean	40.9 (SD 7.5)
Median	36.3
FAAM ADL	
Mean	90.4 (SD 15.3)
Median	97
FAAM SPORTS	
Mean	75.2 (SD 28.93)
Median	83
Hardware Removal	13 (46.4%)
Infections	2 (7.1%)
Ankle Fusion	1 (3.6%)

Table 3. Subsets of Surgical Management for the Patients with Maisonneuve Fractures

Variable	(N=28)
Syndesmotic Fixation-	
Screw only	13 (46.4%)
Suture-button device only	3 (10.7%)
Plate + Syndesmotic Screw	9 (32.1%)
Screw + Suture-button device	3 (10.7%)
Medial Malleolus Management-	
Screw	10 (35.7%)
Deltoid repair	5 (17.8%)
Plate	1 (3.6%)
None	12 (42.8%)

Regarding medial malleolus management, fifteen of the twenty-eight patients had either avulsion fractures or medial clear space widening. Of the twenty-eight patients, ten patients received a medial malleolus screw, thirteen received no operative management of the deltoid ligament (DL) and five had DL repair via suture or suture anchor (Table 2). The mean PROMIS PF score of the nontreatment group was 53.4 (SD 9.4 [95% CI 47.7, 59.1]) and the deltoid repair group was 61.6 (SD 13.2 [95% CI 45.2, 78.0]) (p-value of 0.34). Hardware removal was completed in 42.8% (12/28) patients. Of those who

Table 4. Statical Analysis Using MANOVA Stats Controlling for Age, Gender, and CCI Score as Covariates for PRO of Different Syndesmotic Constructs

PRO Score	SS		Plate + SS		Suture-button device SS +SB	
PROMIS PF	60.2	(SD 8.5) 95% CI (54.1, 66.3)	46.5 *(SS)	SD 9.7 95% CI (39.6, 53.5)	62.8	SD 9.7 95% CI (55.9, 69.7)
PROMIS PI	40.4	SD 6.6 95% CI (35.7, 45.1)	43.0	SD 9.8 95% CI (36.0, 50.0)	39.0	SD 6.1 95% CI (34.6, 43.4)
FAAM ADL	96.2	SD 5.4 95% CI 92.3, 100.1)	79.5	SD 23.4 95% CI (62.8, 96.2)	93.2	SD 11.3 95% CI (85.1, 101.3)
FAAM Sport	84.7	SD 18.0 95% CI (75.4, 94.0)	54.3	SD 38.6 95% CI (26.7, 81.9)	89.2	SD 14.2 95% CI (79.0, 99.4)

* P=0.005; $ p =>0.001.

underwent hardware removal mean PROMIS PF and PROMIS PI was 56.8 (SD 8.3 [95% CI 51.5, 62.1]) and 41.7 (SD 7.8 [95% CI 36.8, 46.6]), respectively. For those who never underwent hardware removal PROMIS PF, PROMIS PI, was 57.3 (SD 12.1 [95% CI 50.8, 63.8]) and 39.7 (SD 7.4 [95% CI 35.8, 43.6), respectively.

DISCUSSION

Due to the relative rarity of the Maisonneuve fracture, limited research exists about the topic. The present study is the largest cohort of patient reported outcomes utilizing PROMIS for surgically managed Maisonneuve fractures. The injury entails a proximal fibular fracture along with the failure of the deltoid ligament or medial malleolus and diastasis of the distal tibiofibular syndesmosis.[13] The high energies required for syndesmotic injury in addition to the proximal fibular fracture results in a severely unstable ankle fracture.[14,15] As a result, nearly all Maisonneuve fractures are treated surgically, and post-surgical outcomes have generally been reported as good.[1,11,12,16]

PROMIS Physical Function scores have been validated as reliable and responsive tools for assessing outcomes in patients with lower extremity trauma, including ankle fractures.[17] The findings of this study are largely consistent with those reported by Sanchez et al., which also emphasized the impact of demographic factors, comorbidities, and radiographic findings on PROMIS scores.[12] The present study further supports the generally favorable outcomes of surgical management of Maisonneuve fractures. We found the mean PROMIS PF, PROMIS PI to be 56.3(SD 10.8) and 40.9 (SD 7.5), respectively. Franovic et al. established a population average for PROMIS PF of 52.9 (SD 7.6) and PROMIS PI of 43.6 (SD 7.6) for people >40 years old.[18] Our results further demonstrate the favorable outcomes of surgical management of Maisonneuve fractures, as most patients within the current cohort returned to a level of function similar to that described for the general population.

FAAM has also been validated as a reliable measure of foot and ankle outcomes.[6,19,20] Lambers et al. published FAAM outcomes for a cohort of forty-four patients who underwent surgical fixation of Maisonneuve fractures using syndesmotic screws only.[21] Within Lambers et al.'s study, the mean FAAM score was 94, with no distinction being made between the FAAM ADL and FAAM SPORT. These results are similar to the FAAM ADL results presented in our present study of 90.4 (SD 15.3). Furthermore, Fox RS et al. published an abstract in 2020 with a cohort of patients with Maisonneuve fractures who were surgically treated with suture button devices.[22] The results of their study showed a mean FAAM ADL of 91.1 (vs 90.4 [SD 15.3] for our study) and a mean FAAM-Sports of 81.7 (vs FAAM sports of 75.2 [SD 28.9] for our study). These results appear to be consistent with the FAAM ADL scores within our current study of Maisonneuve fractures.

In evaluating syndesmotic treatment for Maisonneuve fractures, we found management with plate + SS to have significantly worse PROMIS PF compared to treatment with SS only, which may be a reflection of more severe injuries necessitating larger constructs. There was no significant difference between the SS only group and the SS+SBD group. While syndesmotic injuries are commonly treated with SS+plate, at the time of the literature review, we found no studies that directly compared the outcomes of syndesmotic injury treated surgically by SS vs SS+plate.[23] The consensus on the best treatment remains unclear and requires further investigation.[24] Nonetheless, comparable findings have been demonstrated in other studies evaluating the effectiveness between SS+/-plate and SBD in stabilization of syndes-

motic injuries.[25] Most notable, a randomized control trial between the two methods of syndesmotic fixation in the setting of pronation-external rotation ankle fractures was completed by Lehtola et al.[26] The results showed the mean Olerud-Molander Ankle Outcome Score (OMAS) to be 88 in the syndesmotic screw group and 78 in the suture button group (difference between means 7.1, 95% CI: -7.0-21.1, P = 0.32).

According to the results of the current study, reoperation rates were relatively high with 46.6% (13/28) undergoing reoperation, when compared to Andrew NS et al. which had a reoperation rate of 8.3% (2/24).[11] The most common reason for reoperation within our study was for symptomatic relief via hardware removal of syndesmotic screws. When PROMIS PF scores within our cohort were further subdivided into patients who underwent syndesmotic screw removal and those who did not the outcomes were nearly identical (56.8 [SD8.3] vs 57.3 [SD 12.1]). A 2021 systemic review and a 2021 meta analysis found the current literature to show no difference in function outcomes, complications rates, or pain scores for syndesmotic screw removal and concluded there is no evidence for the basis of routine removal of syndesmotic screws.[27,28] While our current study had no complications with the removal of the syndesmotic screws, infection is an obvious known complication.[27] Thus, as in our current study, we recommend that syndesmotic screw removal be assessed on a case-by-case basis with a patient focused conversation regarding potential benefits and risks of the procedure.

Medial malleolus ligamentous disruption is common in Maisonneuve fractures. However, the fracture pattern has been described without medial malleolus disruption.[8,29] With the main stabilizer of the ankle being the deltoid ligament, a Maisonneuve fracture with an intact deltoid ligament could be consider for nonoperative management.[30] Within our present study's cohort, fourteen of the twenty-eight patients had either avulsion fractures or medial clear space widening. Of the fourteen patients, twelve received no operative management of the deltoid ligament (DL) and five had DL repair via suture or suture anchor. The mean PROMIS PF score of the non treatment group was 53.4 (SD 9.4 [95% CI 47.7, 59.1]) and the deltoid repair group was 61.6 (SD 13.2 [95% CI 45.2, 78.0]), which is within one standard deviation mean score for the general population.[18] However, Guo et al. published a meta-analysis of 388 participants who experienced Weber type B or C fractures and found that the American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot scores were significantly better in patients who received deltoid ligament (DL) repairs.[9] Obvious limitations exist in comparing our present study to that of Guo et al.'s, as our study is specific to Maisonneuve fractures. None the less, our findings further support Guo et al.'s conclusion that more high-quality and prospective studies with long follow-up durations are needed to further evaluate the superiority of DL repair in ankle fractures.

Our study has limitations. While the cohort size is relatively large in comparison to the other patient reported outcome studies, the actual cohort size is small. As a result, statistical analysis within the cohort is limited. Because of the retrospective design with a longer catchment period, some patients were lost to follow up. None the less, the follow up percentage for the study was nearly 70%, which is in accordance with other retrospective orthopedic trauma studies.[31] The mean post operative follow up for our study was nearly 5 years, with some responses occurring nearly a decade after surgery; as such, the data may not accurately reflect early patient reported outcomes. Furthermore, the study was conducted at a single institution and our results may not translate well to other centers.

In conclusion, our current study puts forth the largest cohort utilizing PROMIS PF and PI to evaluate surgically treated Maisonneuve fractures. The resultant PROMIS PF and PI scores further demonstrate the favorable outcomes for surgical treatment of Maisonneuve fractures. Additionally, treatment of the syndesmotic injury with plate+SS showed significantly worse PROMIS PF scores compared to the SS only group. These results may help counsel patients about prognosis. However, much research still is needed to further evaluate these rare injuries.

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UTILIZATION OF A LATERAL BASED FEMORAL DISTRACTOR FOR CALCANEUS TUBEROSITY REDUCTION IN DISPLACED INTRAARTICULAR CALCANEUS FRACTURES: SURGICAL TECHNIQUE AND CASE SERIES

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ABSTRACT

Background: Displaced calcaneal fractures present significant challenges in achieving optimal reduction and fixation while minimizing complications. The traditional extensive lateral approach provides excellent exposure but is associated with high rates of wound complications, including infection and dehiscence. The sinus tarsi approach has gained popularity as a less invasive alternative, offering direct access to the posterior facet. However, it is limited in its ability to directly access and mobilize the calcaneal tuberosity, which is critical for restoring the height, length, and alignment of the calcaneus. This study describes a surgical technique with short term outcomes in which the sinus tarsi approach is combined with a laterally based femoral distractor which aids in manipulation and alignment of the calcaneal tuberosity.

Methods: This retrospective study included 28 patients with displaced intra-articular calcaneal fractures (OTA/AO 82 C1-C3; Sanders type II-IV) treated at a level I academic center between 2020 and 2022. All fractures were managed using a combination of the sinus tarsi approach and a laterally based femoral distractor. Complications were recorded as well as comparison radiographic parameters both pre-and post-operatively..

Results: Complications included one case of superficial skin necrosis and two cases of implant removal due to pain. There were no instances of deep infection requiring unplanned return to the operating room. No loss of tuberosity reduction or subfibular impingement was observed at the final follow-up (mean follow-up 14 months).

Conclusion: The combination of the sinus tarsi approach with femoral distractor use offers a method for reduction of displaced calcaneal fractures. This technique demonstrated appropriate restoration of hindfoot anatomy with reconstruction of height, length, width, and alignment in our patient cohort. This technique may potentially minimize the risk of complications compared to traditional methods, though further studies are needed to confirm these benefits and compare this technique with established approaches.

Level of Evidence: IV

Keywords: displaced calcaneal fractures, sinus tarsi approach, femoral distractor, hindfoot reconstruction, minimally invasive surgical techniques

INTRODUCTION

Due to wound healing complications associated with the extensile lateral approach (ELA) for displaced calcaneus fractures, less invasive surgical techniques have been developed and subsequently refined.[1-6] The sinus tarsi approach provides visualization and direct access to the posterior facet, middle facet, and anterior process of the calcaneus and the calcaneocuboid joint. However, direct access to the body and calcaneal tuberosity is limited. Reducing a shortened, varus calcaneal tuberosity can be difficult utilizing this approach due to limited visualization which necessitate indirect reduction methods. Described techniques for tuberosity reduction include manual manipulation with or without Schantz pins (e.g. Essex-Lopresti maneuver), percutaneous application of clamps, elevators, or joystick-type maneuvers, and medial-based external fixation.[2-8] Manipulation of fragments with Schantz pins can be cumbersome due to the loosening of pin(s) resulting from multiple reduction attempts, often requires a surgical assistant to provisionally stabilize the reduction, and difficulty with maintaining the reduction achieved. Medial based external fixation can be difficult in the lateral position and significantly increase the implant related cost. This article describes a surgical technique to mobilize and reduce the calcaneal tuberosity and body utilizing a laterally based femoral

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distractor through percutaneous techniques which facilitates the treatment of displaced calcaneus fractures using a sinus tarsi approach.

METHODS

A retrospective review of displaced intra articular calcaneus fractures (OTA/AO 82 C1-C3 injuries) treated utilizing a lateral femoral distractor with a sinus tarsi approach was performed. All procedures were performed at a level-one academic trauma center between 2020-2022. Injury, intra-operative fluoroscopic, and post operative images were reviewed for injury classification, measurement of calcaneal alignment parameters, and assessment of union. The electronic health record was reviewed for patient complications and return to the operating room.

Surgical Technique

The patient is positioned in the lateral decubitus position on a radiolucent operating table with the ipsilateral extremity on a radiolucent ramp positioned anterior to the uninjured side. The fluoroscopic machine is positioned anterior to the patient, approaching at a 45-degree angle to obtain a Harris axial view of calcaneus in addition to lateral and Broden's views. The planned sinus tarsi incision is drawn with a surgical marker. Using fluoroscopy to localize, separate stab incisions over the talar neck and the calcaneal tuberosity are drawn on a lateral view for placement of Schantz pins. The first 5.0 mm x 170 mm Schantz pin is placed into talar neck through a longitudinal stab incision. The pin should be perpendicular to the tibio-talar axis determined on the Harris axial view (Figure 1a). The second Schantz pin is placed into the displaced calcaneal tuberosity fragment perpendicular to its axis through a second longitudinal stab incision (Figure 1a). Next, the femoral distractor is constructed and applied. The sliding carriage is placed upside down as the holding sleeve on the sliding carriage requires close proximity to the holding sleeve on the end piece with the double joint during the reduction (Figure 2). The distractor vector should be set for medial and distal translation, as well as restoring the length of the body to appropriately position the tuberosity in space - thereby reversing the typical fracture deformities (Figure 3). Once the desired reduction vector is set, the pin in the calcaneal tuberosity is mobilized to parallel the talar pin (which acts as a stationary anchor) to correct the

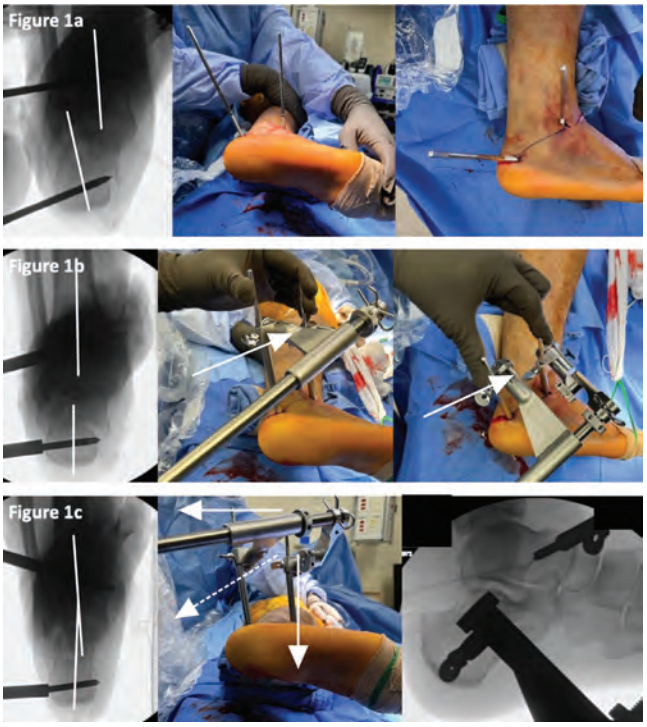

Figure 1A to 1C. Series of images demonstrating fluoroscopic images and corresponding clinical images to demonstrate the technique. Figure (1A) showing femoral distractor pin placements. Note divergent pin placement with distractor pin in calcaneus perpendicular to calcaneus axis with subsequent varus correction in figure (1B) by converging two distractor pins. Vector of distractor is highlighted in figure (1C) with white dotted arrow to distract tuberosity to medial and distal direction.

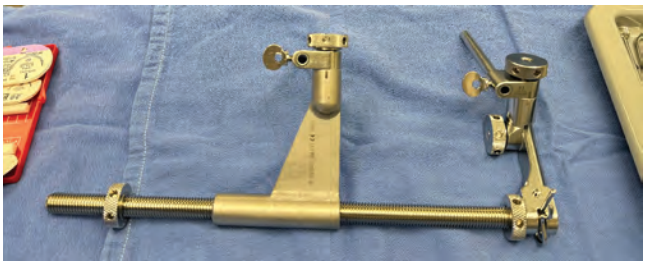

Figure 2. Distractor set up with reversed sliding carriage.

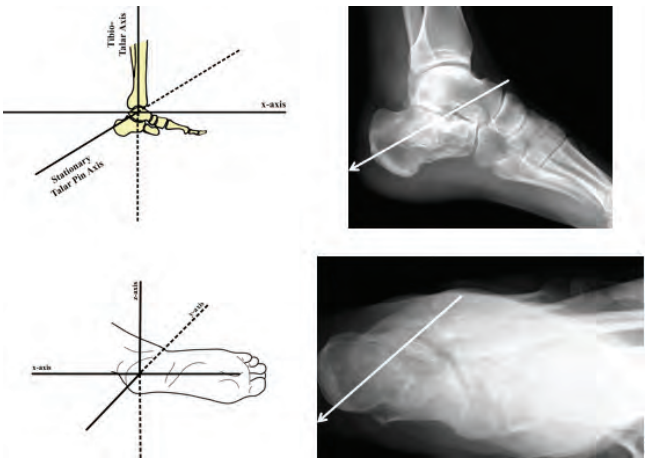

Figure 3. Vector of distractor is set based on fracture morphology. Distracting tuberosity based on stational talar pin axis and Y axis, the vector is set to medial and distal translation of tuberosity.

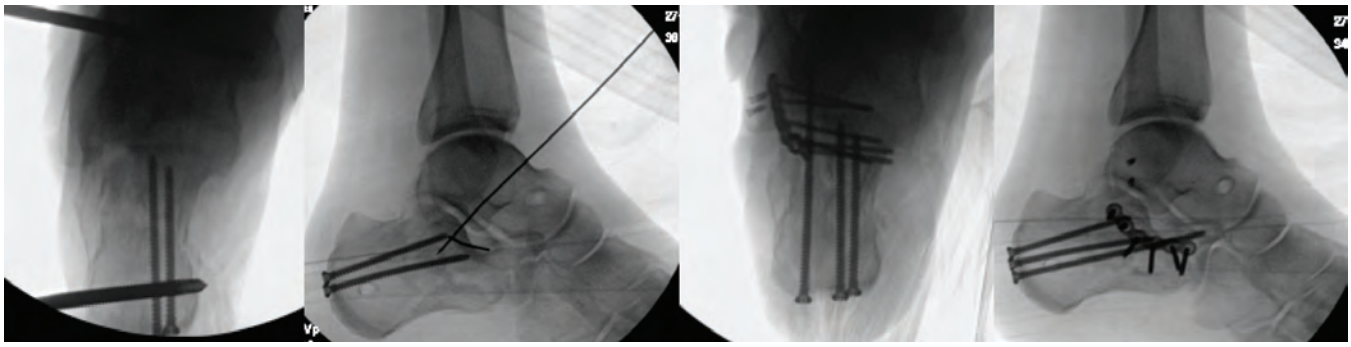

Figure 4. Intraoperative images showing sequential percutaneou screw fixation of distaplced tuberosity fracture after reduction was achieved using femoral distractor and sinus tarsi approach after tuberosity is addressed. Note that medial screw fixation of tuberosity to avoid fixation into depressed posterior facet fracture present in lateral half of posterior facet.

varus deformity (Figure 1b). After varus correction is confirmed on the Harris axial view, the sliding carriage is lengthened by dialing the distractor until the tuberosity reduction is achieved. This is judged by viewing the relationship between the constant fragment and the medial wall of the calcaneus in the Harris axial view and calcaneal length in the lateral view (Figure 1c).

Next, a stab incision is made on the posterior-medial aspect of the heel, and two 3.5 mm cortical screws are placed from the medial tuberosity toward the middle and anterior facets (Figure 4). 2.0 mm k-wires are placed in addition to the screws to further secure the reduction of the tuberosity. It is important not to place wires or screws laterally as they will hinder the posterior articular fracture reduction, which often is present laterally. After adequate provisional fixation is performed, the distractor can be removed, freeing up access to make a lateral approach to the articular facets. The stab incisions are irrigated and closed with non-absorbable sutures. The sinus tarsi approach is then made, the posterior facet is directly visualized, and articular reduction is performed under direct visualization. Fixation can then be performed per surgeon discretion and the needs of the fracture pattern. Next, a stab incision is made to the posterior-lateral aspect of the heel, and a 3.5 mm cortical screw is placed from the lateral tuberosity towards the calcaneal cuboid joint to finalize fixation of the tuberosity to the anterior calcaneus. Care is taken not to violate the calcaneal cuboid joint. The closure is performed with an absorbable suture in the subcutaneous layer and a non-absorbable suture for the skin.

RESULTS

Twenty-eight patients with displaced intra-articular calcaneal fractures were treated with open reduction internal fixation utilizing a sinus tarsi approach and lateral based femoral distractor by four fellowship trained orthopaedic trauma surgeons and were include. The injuries included 16 Sanders type II, eight type III, and four type IV injuries.[9] Postoperative follow-up ranged from 12 to 24 months (mean 14 months). Patient age ranged from 18 to 72 years (mean 42 years). There was one superficial skin necrosis of the sinus tarsi incision unrelated to the distractor pin site which was successfully treated with local wound care. There were no deep infections leading to unplanned return to the operating room. Two patients required implant removal due to pain related to screws placed in the tuberosity. At the final follow up, there was no evidence of loss of tuberosity reduction or subfibular impingement leading to secondary malunion corrective procedure (Table 1, Figure 5).

DISCUSSION

Treatment goals for calcaneus fractures include restoring the architecture of the hindfoot, reducing the articular surfaces, and ultimately returning to normal shoe wear. Much of the long-term outcomes of these potentially devastating injuries are dependent on the restoration of the length, height, width, and correcting varus malalignment that is often present with these fractures.[10] The hindfoot malalignment is predominantly due to tuberosity displacement. Therefore, it follows that correcting the position of the tuberosity is an important factor in the treatment of displaced intraarticular calcaneus fractures. Commonly, the tuberosity is displaced superiorly and laterally, resulting in a short, wide, flat, and varus hindfoot.[11,12] Bohler's angle should be evaluated and carefully restored intra-operatively to the normal range of 20-40 degrees, with comparison to the contralateral side often useful.[12,13]

The vulnerable soft tissue envelope of the lateral heel must be considered when treating calcaneal fractures surgically.[14] For years, the ELA to the calcaneus was the workhorse approach as it provides excellent exposure of the calcaneus, including the body, tuberosity, and posterior facet articular surface, allowing for direct

Table 1. Radiographic Calcaneal Measurements

	Pre-operative (mean)	Immediate Post-operative (mean)	Final Follow up
Bohler angle (degrees)	5.7	23.9	22.3
Height (mm)	34.5	49.2	48.4
Length (mm)	70.2	76.2	75.7
Heel varus angle (degrees)	18.2	5.9	5.4

Radiographic parameters of calcaneal alignment measured at three time points: injury radiographs, intra-operative fluoroscopy (immediate post-operative measurements), and final follow-up radiographs. Bohler's angle and heel varus angle are reported in degrees, while calcaneal height and length are measured in millimeters.

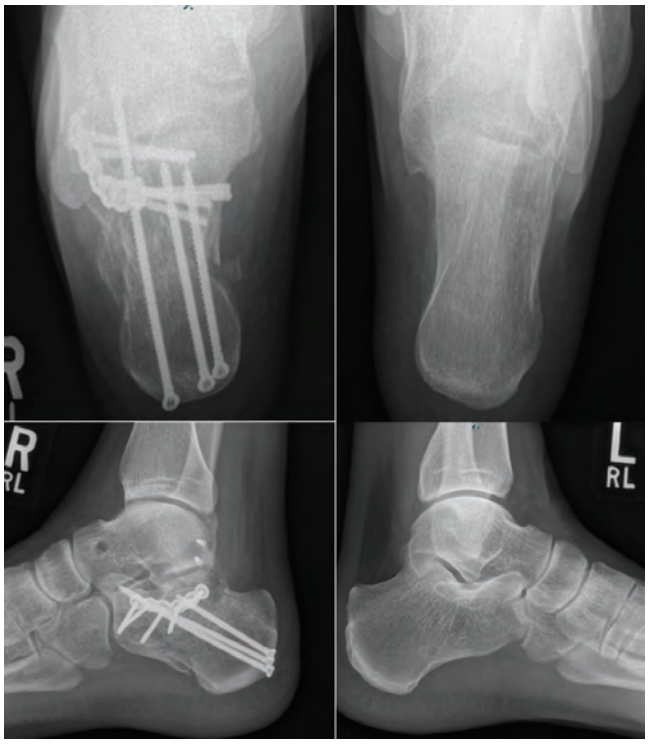

Figure 5. Post operative images of calcaneus fracture comparing to no injured side demonstration restoration of both height and length of calcaneus.

reduction and fixation.[9,15-17] However, high rates of complications, including wound dehiscence and infection, have been reported with this approach.[15,18-21] In order to avoid these complications, the sinus tarsi approach (STA) has become increasingly popular. Proponents of this less invasive approach argue that it provides ample exposure to perform adequate articular reduction of the posterior facet and has been shown to have lower rates of wound complications and no difference in functional outcomes when compared to intra-articular calcaneal fractures treated utilizing the ELA.[1,22-28] Joseph et al. recently found no difference in rates of wound necrosis, deep infection, secondary operations, or functional outcomes in 139 patients with calcaneal fractures treated with either the STA or ELA, but found that increasing Sanders type, smoking, and increasing BMI were more predictive of complications.[29] Busel compared the reduction quality between fractures treated with STA and ELA and found that no difference in reduction was observed with Sanders type II injuries, but did observe a trend toward improved reduction quality with ELA for type III injuries.[30] Ultimately, surgeons should weigh patient factors, fracture pattern, soft tissue integrity, and his/her own experience level when deciding which approach to utilize in the treatment of displaced intra-articular calcaneus fractures.

Regardless of exposure choice, the tuberosity must be manipulated for hindfoot reduction. Benirschke and Sangeorzan reported the results of 80 fractures treated with an ELA and their surgical technique. Via this open approach, they utilize a lateral to medial Schantz pin in the tuberosity fragment to restore length, height, width, and valgus alignment with a three-vector force, relying on indirect reduction and fluoroscopic confirmation of medial wall reduction.[16] In either percutaneous or laterally based open approaches, reduction of the medial wall requires indirect assessment. Some authors have described success with medial based open approaches for direct assessment of this, however this typically requires dual surgical approaches as well as proximity to the posterior tibial neurovascular bundle.[31-33]

In the absence of an open exposure, indirect reduction techniques utilizing distractors and external fixators to restore calcaneal height, length, and the longitudinal axis have previously been described.[34-37] These techniques often involve initial external fixation followed by a planned return to the operating room for staged open reduction internal fixation and/or involve placement of tibial and medial based calcaneal threaded pins, which can be challenging to perform or cumbersome to work around with the patient positioned laterally. Baumgartel et al. first described used of a medial based external fixator as part of staged treatment for displaced intra-articular calcaneal fractures.[34] This technique involves placement of a 5 mm Schanz pin from medial to lateral in the calcaneal tuberosity perpendicular to the long axis of the calcaneus followed by a second 5 mm Schanz pin placed from medial to lateral or nearly anterior to posterior in the distal 1/3 of tibia shaft. The pins are then connected with an external fixator bar and clamps and distraction is carried out to correct the varus deformity

and restore the length and height of the calcaneus under image intensification. Patients would then return to the operating room when the soft tissues were amenable, and an open approach was performed to address remaining posterior facet articular depression and to perform internal fixation. Githens et al. presented a modification to this technique to also include placement of a medial based cuneiform Schanz pin in addition to the calcaneus and tibial pins.[35] After correction of the varus deformity and restoration of height is achieved and stabilized with the tibiocalcaneal bar, a second bar is placed between the calcaneal and cuneiform pins and distraction in this plane provides restoration of length. DeWall et al., described their results of percutaneous versus open reduction of calcaneus fractures. Their percutaneous technique includes use of a large corkscrew from the posterior-lateral heel to manipulate and reduce the tuberosity fragment, followed by provisional stabilization with k-wires and ultimately screw fixation.[2] Conceptually, the described technique also relies on percutaneous manipulation of this fragment from the same vector. However, by utilizing the femoral distractor and building off the stable base of the talus and sustentacular fragment, a controlled, or "dialed-in" reduction can be achieved, and, importantly, held hands-free while provisional stabilization is performed. This potentially requires fewer assistants in the operating room and allows for a more relaxed transition from reduction to provisional stabilization. Once the tuberosity fragment is secured to the anterior calcaneus, the lateral distractor is removed, which allows uninhibited access to the lateral skin for the open reduction of the articular surfaces.

This clinical series demonstrates low overall wound healing complications, infection, and hardware removal rates. This technique achieved an appropriate restoration of hindfoot anatomy with reconstruction of height, length, width, and alignment. The technique, however, should be used cautiously in fractures with displaced sustentacular fragments which is reported up to 42%[38] as the technique requires a constant medial fragment to reduce the displaced tuberosity back to. At a minimum of one year follow up, no loss of reduction was observed. The use of a laterally based femoral distractor for indirect reduction of the hindfoot alignment in combination with a sinus tarsi approach for direct reduction of the articular fragments represents an additional option for surgeons to treat these challenging injuries.

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REVISION RATES FOR ACUTE VERSUS DELAYED TOTAL HIP ARTHROPLASTY AFTER ACETABULAR FRACTURE

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ABSTRACT

Background: Total hip arthroplasty (THA) has demonstrated utility in expediting return to function in the management of acetabular fractures. Despite its increased utilization, optimal timing to minimize complications and need for revision remains controversial and is often left to surgeon discretion. This study seeks to determine if timing, acute versus delayed (>30 days) THA for the management of acetabular fracture impacts rate and indications for revision arthroplasty.

Methods: Retrospective review identified 165 patients undergoing primary THA for an acetabular fracture at a Level I Academic Trauma Center from 1997 to 2020. Patients were stratified by performance of acute versus delayed (>30 days) THA. Charts were reviewed for rates and indications for revision arthroplasty. Statistical analyses were performed with $\alpha \leq 0.05$.

Results: THA following acetabular fracture had an overall revision rate of 10.9 % (n=18), with an insignificantly increased rate associated with delayed THA (n=15, 13.0%) compared to acute THA (n=3, 6.0%). Prosthetic joint infection (PJI) was the most common indication for revision in delayed THA (n=9, 60.0%) and instability for acute THA (n=2, 66.7%). Patients undergoing acute THA had a higher rate of fracture dislocation (54.0% versus 25.2%, p=.0003) on presentation and increased mean age at time of injury (66.21 ± 10.38 vs 45.43 ± 15.41 years, p <0.0001) and arthroplasty (66.23 ± 10.8 vs 52.54 ± 12.73 years, p<0.0001).

Conclusion: THA timing following acetabular fracture remains equivocal with an insignificant difference in revision rate between acute and delayed THA.

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INTRODUCTION

Acetabular fractures have an estimated incidence of 40 fractures/100,000/year in the United States and have been linked to increasing age and comorbidities at time of injury, thus significant attention had been directed towards the application of total hip arthroplasty (THA) in acetabular fracture management to optimize patient mobility and minimize morbidity.[1-7] The role of THA in the treatment of acetabular fractures has continued to expand in the orthopaedic trauma community with a reported 16.5% increase in THA utilization in comparison to a 21.5% decrease in acetabular open reduction internal fixation (ORIF) from 2010-2020, a trend which has been most notable in older and middle aged populations.[3-8] THA in this population facilitates function while addressing pain and mechanical symptoms following acetabular fracture given the inherent risk of posttraumatic osteoarthritis and avascular necrosis with previous studies referencing rates of 12 to 56% and 6 to 10% respectively.[9-12] THA combined with ORIF is shown to decrease time to full weightbearing, lead to higher functional outcome scores, decrease length of stay, and minimize rates of pneumonia and respiratory complications linked to immobility, as well as, have decreased revision rates in comparison to ORIF alone.[9,13-15] Despite this, THA for acetabular fractures remains a practice specific decision with no consensus regarding the ideal timing of arthroplasty and patient selection.

Acetabular fractures present arthroplasty challenges in both the acute and delayed setting, clouding decisions regarding timing of THA. Surgeons may be faced with challenges regarding acute fracture stability, the need for concomitant ORIF, stability of acetabular components in the setting of poor bone stock/comminution, possible nonunion, pre-existing fixation, heterotopic ossification (HO) and scar tissue complicating sciatic nerve management on exposure.[2,3,7,16] These technical challenges pose the risk for increased complication and need for revision surgery.[4,5,10,14,17-19] Matched studies have referenced increased risk for all complications with THA in

the setting of acetabular fractures, including increased rates of prosthetic joint infection (PJI), longer operative times, increased blood loss, and rates of transfusion in comparison to patients undergoing THA for non-fracture indications.[20,21] Complication and revision rates for THA following acetabular fractures have been found to range from 12.2 to 26.9% and 4.3-18.2% respectively adding pause to the ubiquity of THA for acetabular fractures.[5,10,14,17,18]

Through retrospective review of patients undergoing THA for acetabular fractures at our institution, this study seeks to determine whether timing of arthroplasty following acetabular fractures in the form of acute and delayed THA (>30 days) impacts revision rates, while identifying indications for revision and patient selection within these treatment populations.

METHODS

A retrospective review was performed of patients who underwent a total hip arthroplasty for the primary indication of acetabular fracture at our institution from 1997 to 2020. Patients were stratified by acute and delayed THA with acute THA defined as patients undergoing arthroplasty less than or equal to 30 days from date of initial fracture, while delayed arthroplasty was defined as greater than 30 days from time of injury.

Demographic information including patient age at date of injury and date of THA in years were tabulated along with age difference in years from time of injury to arthroplasty. Time in days from injury to THA was recorded. Injury specific data was collected including presence of fracture dislocation, Letournel acetabular fracture classification, method of initial intervention including open reduction internal fixation versus nonoperative management, and time of most recent follow-up expressed in months since injury.[22]

Table 1. Age and Time with Respect to Injury, Total Hip Arthroplasty (THA), Follow-Up

	n	Mean+/- Standard Deviation	Lower Quartile	Median	Upper Quartile
Age at time of injury (years)	165	51.73 ± 17.01	40.28	53.38	63.48
Age at time of THA	165	56.69 ± 13.59	47.91	56.80	65.29
Age Difference from injury to THA	165	4.96 ± 8.50	0.02	1.17	5.96
Most Recent Follow-up from THA	165	39.21 ± 44.44	10.00	24.00	51.00

Rates of revision THA were identified for patients undergoing delayed and acute THA, while further stratifying by primary indication for revision arthroplasty including categories of instability, aseptic loosening, prosthetic joint infection, periprosthetic fracture, and metallosis.

SPSS statistics was utilized to perform all statistical testing. Descriptive statistics of all quantitative reported demographic, injury, and outcomes data. Chi square tests, Fisher Exact and Wilcoxon testing were performed for all patient/injury characteristics and THA outcomes reported. All statistical analyses were performed with an $\alpha<0.05$. Variables were analyzed between the acute and delayed THA groups, along with a subgroup analysis for patients who did and did not undergo revision surgery.

RESULTS

Retrospective review identified 165 patients who underwent arthroplasty at our institution after sustaining an acetabular fracture with an overall average age at time of injury of 51.73 ± 17.01 years and 56.69 ± 13.59 years at time of arthroplasty (Table 1). Average follow-up for the cohort overall was 39.21 ± 44.44 months. Of these patients, 56 (33.94%) were characterized as having an acetabular fracture dislocation. Through the analysis of patient fracture patterns by the Letournel classification, posterior wall fractures accounted for the most common pattern in the cohort (42.4%) followed by transverse posterior wall (17.6%), both column (13.9%), and T-type fractures (6.7%) (Table 2). In the cohort, nine patients were labeled with an unknown fracture pattern (Table 2).

Table 2. Cohort Acetabular Fracture Pattern Distribution

Fracture Pattern	Total Fractures	Percentage of Total Cohort
Posterior Wall	70	42.4%
Transverse-Posterior Wall	29	17.6%
Both Column	23	13.9%
T-Type	11	6.7%
Unknown	9	5.5%
Transverse	8	4.8%
Anterior Column	6	3.6%
ACPHT	4	2.4%
Anterior Wall	2	1.2%
ACPHT+PW	1	0.6%
PCPW	1	0.6%
Posterior Column	1	0.6%
Total	165	

ACPHT-anterior column posterior hemi transverse, PW-posterior wall, PCPW-posterior column posterior wall.

50 patients (30.3%) underwent acute THA, while 115 (69.7%) underwent delayed arthroplasty. Through the study period, no acute THA was performed prior to 2008 and 45 of the recorded cases were performed after 2010. A similar trend was seen with delayed THA with 96 of the arthroplasty procedures taking place after 2010. Patients undergoing acute THA were noted be significantly older at time of injury (p<0.0001) and at time of THA (p<0.0001) (Table 3). Patients undergoing acute THA had a significantly higher rate of fracture dislocation at the time of initial injury in comparison to those undergoing delayed THA with proportions of 54% and 25.2% respectively (p=0.0003) (Table 3). The most common fracture patterns for patients undergoing acute THA were posterior wall (46%), transverse posterior wall (20.0%), and both column fractures (12%) (Table 3). Similarly, the most common patterns for the delayed THA group included posterior wall (40.9%), transverse posterior wall (16.5%), and both column (14.7%) (Table 3). For patients undergoing delayed THA, the majority of patients underwent ORIF (80.0%) as part of initial management, while 16.4% initially underwent an initial course of nonoperative management (Table 3). Two patients in the acute THA cohort underwent ORIF, while a

Table 3. Acute and Delayed Total Hip Arthroplasty (THA) Cohort Demographics, Injury Characteristics and Initial Management

	Acute THA (n=50)	Delayed THA (n=115)	P-Value
Age at Injury (years)	66.21 ± 10.38	45.43 ± 15.41	<0.0001*
Age at THA (years)	66.23 ± 10.38	52.54 ± 12.73	<0.0001*
Days from Injury to THA	5.10 ± 5.19	2597.7 ± 3437.5	<0.0001*
Age Difference (years)	0.01 ± 0.01	7.11 ± 9.41	<0.0001*
Fracture Dislocation	27	29	0.0003*
Follow-up (months)	29.32 ± 32.59	43.50 ± 48.19	0.0167*
Fracture Classification			
ACPHT	2	2	
ACPHT+PW	1	0	
Anterior Column	2	4	
Anterior Wall	1	1	
Both Column	6	17	
PCPW	0	1	
Posterior Column	0	1	
Posterior Wall	23	47	
T Type	2	9	
TPW	10	19	
Transverse	3	5	
Unknown	0	9	
Initial Management			
ORIF	2	92	
Nonoperative	1	19	
ORIF+Girdlestone	0	1	
PAO	0	1	
External Fixation	0	2	

ACPHT-anterior column posterior hemi transverse, PW-posterior wall, PCPW-posterior column posterior wall, TPW- transverse posterior wall, ORIF-open reduction internal fixation, PAO-periacetabular osteotomy.
*Denotes statistical significance (α<0.05).

Table 4. Comparison of Demographics, Injury Characteristics, and Initial Management for Patients with and Without Total Hip Arthroplasty (THA) Revision

	Revision (n=18)	No Revision (n=147)	P-Value
Age at Injury (years)	48.88 ± 17.21	52.07 ± 17.01	.4254
Age at THA (years)	51.90 ± 15.32	52.27 ± 13.30	.1448
Age Difference (years injury to THA)	3.02 ± 4.26	5.20 ± 8.86	.7380
Fracture Dislocation	3	53	.1011
Follow-up (months)	94.72 ± 77.21	32.41 ± 33.13	<0.0001*
Fracture Classification			
ACPHT	1	3	
ACPHT+PW	0	1	
Anterior Column	0	6	
Anterior Wall	1	1	
Both Column	2	21	
PCPW	0	1	
Posterior Column	0	1	
Posterior Wall	3	67	
T Type	3	8	
TPW	3	26	
Transverse	0	8	
Unknown	5	4	
Initial Management			
ORIF	11	83	
Nonoperative	5	62	
ORIF+Girdlestone	0	1	
PAO	1	0	
External Fixation	1	1	

ACPHT-anterior column posterior hemi transverse, PW-posterior wall, PCPW-posterior column posterior wall, TPW- transverse posterior wall, ORIF-open reduction internal fixation, PAO-periacetabular osteotomy.
*Denotes statistical significance (α<0.05).

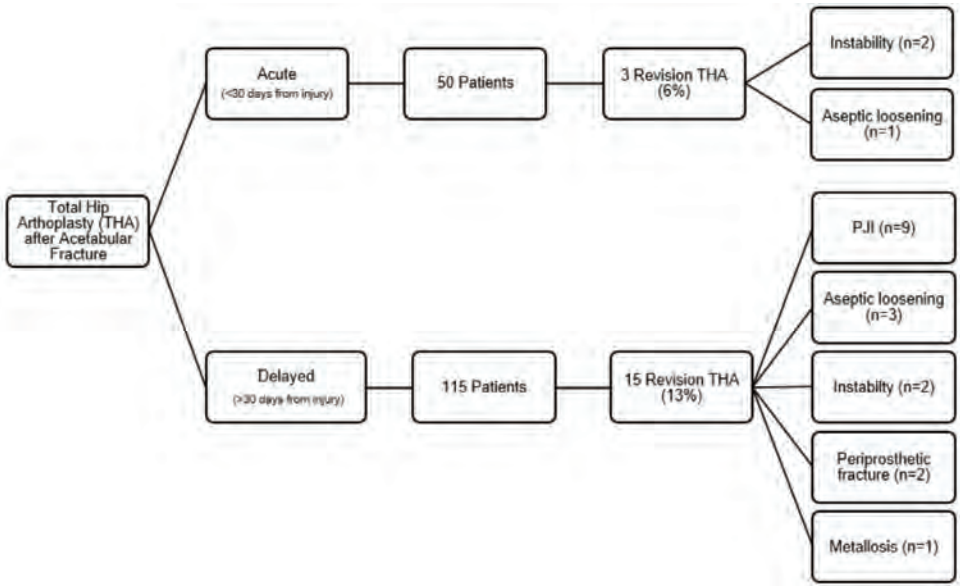

Figure 1. Flow diagram of revision rates and indications for acute and delayed total hip arthroplasty.

single patient had an attempted course of nonoperative management (Table 3). Patients undergoing delayed arthroplasty had a statistically increased length of mean follow-up (43.50 ± 48.19 months) in comparison to acute THA (29.32 ± 32.59) (p=0.0167).

Our cohort had an overall revision rate of 10.9% with 18 patients requiring revision arthroplasty following THA for an acetabular fracture (Table 4). Patients undergoing delayed THA had a higher revision rate of 13.0% in comparison those undergoing acute THA with a rate of 6.0%, however this was found to be a statistically insignificant difference (OR 2.35, 95%CI: 0.65-8.51, p=0.1933) even when adjusting for age at time of injury (OR 2.35, 95%CI: 0.54-10.17, p=0.9968) (Figure 1). Overall, PJI was the most common indication for revision arthroplasty (50%) followed by instability (22.2%), aseptic loosening (22.2%) with two cases of acetabular loosening, one case of femoral loosening with prior acetabular revision, periprosthetic fracture (11.1%), and metallosis (5.6%) (Figure 1). In the acute THA group, instability was most common (66.7%) indication followed by aseptic loosening of the acetabular component (33.3%). PJI was the most common indication for revision in the delayed arthroplasty group with a rate of 60% followed by aseptic loosening (20%), instability (13.3%), periprosthetic fracture (13.3%), and metallosis (6.7%).

Patients undergoing revision surgery had a significantly longer mean length of follow-up in comparison to patients with no revision (p=<0.0001) (Table 4). No statistically significant difference was observed between the revision and non-revision group for age at time of injury, age at arthroplasty, days from injury to arthroplasty, age difference between time of injury and time of arthroplasty, or presence of fracture dislocation at initial injury (Table 4). Of patients undergoing revision 61.1% underwent ORIF, while 11.1% initially underwent nonoperative management (Table 4). While most were noted to have an unknown fracture morphology (27.8%), posterior wall (16.7%), t-type (16.7%), and transverse posterior wall (16.7%) fractures were the most common morphologies in patients undergoing revision (Table 4).

DISCUSSION

With the demonstrated benefits of providing early weightbearing, improved functional outcomes, and minimizing risks of osteoarthritis, total hip arthroplasty for the management of acetabular fractures has continued to gain attention from the trauma community.[3-18] Considering this growing popularity, it is essential to understand the rates and indications for revision arthroplasty especially in regard to operative timing.

The overall revision rate for all patients undergoing THA for an acetabular fracture at our institution was 10.9%, which falls within the range of 4.3% to 18.2% revision rates previously documented.[5,10,14,17,18] These rates are unsurprising, with one insurance database matched study by Manirajan et al. demonstrating THA for fracture as having increased rates of revision, infection, and complications in comparison to primary arthroplasty.[20] Stratifying our revision cases by timing of arthroplasty identified a revision rate of 13.0% for delayed THA versus 6.0% for acute THA. While not statistically significant, the trend of delayed THA having a higher revision rate has been seen across multiple studies.[23,24] In a review of

121 patients undergoing THA for acetabular fracture by Sermon et al. delayed THA was noted to have a revision rate of 22%, while early THA a rate of 8%.[23] Similarly, Gracia et al. found no significant different in return to OR with primary survivorship free from reoperation of 91% and 82% for acute and delayed THA respectively.[24] This trend was further corroborated in a systematic review by Liang et al., noting a revision rate of 17.1% for delayed THA and 4.3% for acute THA.[25]

Multiple factors may contribute to the need for revision arthroplasty such as HO, instability, implant loosening and prosthetic joint infection.[4,5,21,26] Within our cohort PJI was found to be the most common indication for revision overall with all cases occurring in the delayed arthroplasty cohort. The high risk of PJI in delayed arthroplasty is supported in a matched study by Rezaie et al. who found a PJI rate of 6.9% for patients undergoing THA conversion for post traumatic arthritis (PTOA) in comparison to 0.5% for patients undergoing primary THA.[21] One possibility for the increased risk of infection is the presence of implants from prior ORIF. O'Driscoll et al. found a higher complication rate in THA patients with prior ORIF with a revision rate of 9.7% and infection rate of 3.6%.[10]

In comparing the roll of initial management prior to THA, Garcia et al. demonstrated a higher risk of complication for patients undergoing prior ORIF as opposed to initial nonoperative management.[27] Moon et al. also noted an 83.4% survival rate free from revision for THA following acetabular ORIF with patients undergoing THA conversion for PTOA and nonunion having an increased rate of THA clinical failure.[28] THA has also been shown to have dislocation rates of 12% following failed ORIF.[29]

Aside from infection and the possible role of prior ORIF on revision, our study found aseptic loosening and instability to be the next most common indications for revision overall. Instability in the form of dislocation was the most common reason for revision in the acute total arthroplasty group followed by aseptic loosening, while aseptic loosening and instability were the second and third most common revision indications in the delayed arthroplasty group. The similar distribution found for these categories in acute and delayed THA has been seen in the literature with no significant differences in rates of aseptic loosening.[6] Understanding the associated indications for revision for THA following acetabular fractures, can help surgeons educate patients on the risks and benefits associated with arthroplasty for acetabular fracture, while also help guide the timing of THA.

Given, that many acetabular fractures require osseous stabilization prior to arthroplasty, combined hip procedures (CHP) involving ORIF with simultaneous acute arthroplasty are often necessary for providing a stable THA in the acute setting and may confound arthroplasty timing decisions.[9,12,15-19,30,31] While only two of our patients in the acute arthroplasty cohort underwent acute ORIF preventing any valuable analysis, CHP has been demonstrated to have a ten year survivorship of 85.7% in comparison to 45.8% with ORIF alone with revision rates of 12.5% and 25% respectively.[15] CHP patients have been shown to have more marginal impaction, higher rate for femoral head fractures, as well as, higher ASA (American Society of Anesthesiology) scores and Charlson comorbidity index in comparison to ORIF.[15] CHP has been found to have lower operation times, earlier return to full weightbearing, and higher Harris Hip scores at two months in comparison to acute ORIF.[13] ORIF in the setting of acute THA has further demonstrated better Oxford Hip Scores in comparison to ORIF with delayed THA with similar operative times and LOS between groups.[32] Acute THA in the form of CHP may offer a means of minimizing revision risks associated with prior ORIF and improve patient reported outcomes with acute total hip arthroplasty by allowing surgeons to plan THA and fixation concurrently, while avoiding complications of fixation implants in the delayed setting.

Patients undergoing THA were significantly older in comparison to delayed THA at both time of injury and age at time of arthroplasty at approximately 66 years old for both categories. This is consistent across the literature with Sermon et al. noting patients in the early THA group having an average age of 78 years in comparison to 58 years for the delayed group.[23] Liang et al. demonstrated similar findings with the delayed cohort having an age of 64.3 years versus 73.3 years in the acute.[25] Even when accounting for combined hip procedures with ORIF and acute arthroplasty, patients were noted to be older in comparison to delayed arthroplasty with mean ages of 81 and 75 years respectively.[32] These trends highlight the tendency for surgeons to avoid arthroplasty in a younger population which may be secondary to the high function in young patients and the risk of revision associated with longevity of THA implants. Our practice is often directed towards delaying THA in young patients who do not demonstrate significant arthritis at time of injury and are noted to have a stable hip with good secondary congruence with the anatomic opportunity for a functional hip. This would explain why patients undergoing delayed arthroplasty in our cohort had a substantially decreased age at time of injury and at THA of 45 and 52 years respectively with a mean time to conversion of approximately 7 years.

Patients undergoing acute THA were further noted to have a higher rate of fracture dislocation at time of injury which may serve as a proxy for underlying instability and fracture patterns prone to PTOA warranting

acute arthroplasty. Both acute and delayed total hip arthroplasty demonstrated similar fracture patterns with posterior wall being the most common pattern, followed by transverse posterior wall, and both column injuries. In a systematic review of 270 patients undergoing acute THA with simultaneous ORIF in displaced acetabular fractures, Giustra et al. identified anterior column posterior hemi transverse as the most common fracture pattern at 30.6% followed by both column injuries at 15.9%, and posterior wall at 11.8%.[17] The differences in fracture distribution may be explained by the difference in age at time of injury, with our cohort having an overall younger population accounting for all ages, while Giustra et al. primarily evaluated geriatric patients > 60 years old.[17] In a retrospective review evaluating factors for conversion to THA following an acetabular fracture in 685 patients by Cichos et al., 27% had a transverse posterior wall fracture, 23% T type, 15% posterior column, posterior wall, and 12% posterior wall.[33] Risk factors for conversion to THA included transverse posterior wall fracture pattern, protrusion, hip dislocation, increased age, increased BMI, presence of infection, and dislocation following ORIF.[33] These findings suggest that the current tendency for surgeons at our institution and the trauma community leans towards performing acute THA in patients with inherent instability at time of injury in conjunction with fracture patterns linked to high rates of PTOA, as well as, being in a group suitable for a total hip where longevity of implants is less of a concern.

The results of this study should be carefully considered in relation to a few limitations. The retrospective nature of this study limits the ability to link timing of THA with rate of revision and further presents the risk for missing/incomplete data and accuracy of the electronic medical record. Given the nature of trauma, loss to follow-up outside of our institution is a limitation as this may have led to an underestimation of true revision rates and complications for patients that may have received care elsewhere following their index surgery. The lack of patient reported outcome measures further limits insight into the impact of THA timing on functional outcomes and the identification of patients that may have subclinical complications that serve as a harbinger for future revisions. In the context of the existing literature, variability exists regarding the definition of acute versus delayed total hip arthroplasty, with some studies defining acute as less than 3 weeks in comparison to our study of 30 days.[18] This study may also be susceptible to selection bias with healthier and more functional patients undergoing acute THA which may confound revision rates. The timeline (1997-2020) and multiple surgeons involved in this study further presents heterogeneity in the implants and techniques used in our data set which may play a role in revision rates. This study was unfortunately underpowered to truly assess statical differences in revision indications and injury characteristics. Despite these limitations, this study adds a substantial cohort of patients to the existing body of data used by trauma surgeons to help make informed decisions regarding the use of THA in the management of acetabular fractures.

The results of this institutional study suggest that timing of THA following acetabular fracture remains equivocal with respect to revision risk and may offer a safe option in the acute setting especially for patients with a fracture dislocation as a means of reducing pain and limiting disability from prolonged immobilization. Long-term follow-up studies and patient reported outcome measures are needed to help further guide and optimize the application of arthroplasty for acetabular fractures.

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IMPORTANCE OF NON-PHARMACOLOGIC INTERVENTIONS IN OSTEOPOROSIS MANAGEMENT: A CASE SERIES FINDING VALUE IN NUTRITION AND EXERCISE COUNSELING BY A FRACTURE LIAISON SERVICE

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ABSTRACT

Background: Bone mineral density (BMD) warrants attention given its role in secondary fracture prevention and pre-surgical optimization in orthopaedic surgery. While fracture liaison services (FLS) offer expertise in the management of osteoporosis medications that are known to increase BMD, these resources further coordinate the prescription of vitamin D supplementation and provide nutritional counseling to include adequate amounts of dietary calcium and protein, along with recommendations of intentional exercise to improve a patient's overall bone health and decrease fall risk. This case series describes patients who experienced increase in bone mineral density with these non-pharmacologic interventions.

Methods: Retrospective review was performed to identify patients experiencing an increase in BMD on dual-energy x-ray absorptiometry (DXA) scan after presenting to the bone health clinic of a level one academic trauma center since January 2020. Patients prescribed an osteoporosis medication were excluded. Each patient's prior bone health history, comorbidities, prior injuries, DXA data, and laboratory values were recorded. Bone health interventions including nutrition optimization, to include adequate daily dietary intake of calcium and protein, intentional exercise, as well as vitamin D supplementation were noted.

Results: 12 patients experienced an increase in bone mineral density with non-pharmacologic interventions. Average age of the series was 64.8 years (range 51-76 years) and seven were female. 75% were referred by orthopaedic subspecialty services with 50% being referred after sustaining a fracture. All 12 patients experienced an increase in total hip BMD with and average increase of 3.7% (range 1.0-6.8%), while spine BMD was seen to increase in 10 patients for an average increase of 6.0% (range 1.4-10.5%). Increases in femoral neck BMD were only seen in eight patients with an average increase of 1.5% (range 0.6% - 2.8%). Interval time between initial DXA and repeat DXA was 21.7 months (range 12.2-47.4 months).

Conclusion: Incorporation of vitamin D supplementation along with a nutrient dense diet to include adequate dietary intake of calcium and protein, along with exercise counseling may provide a method of improving bone mineral density in orthopaedic patients. These findings highlight the importance providing additional non-pharmacologic interventions for patients treated by the FLS.

Level of Evidence: IV

Keywords: bone mineral density, DXA, nutrition, supplementation, protein, calcium, vitamin d, exercise, fracture liaison service, bone health

INTRODUCTION

Optimization of bone mineral density (BMD) and secondary fracture prevention has become a core component of orthopaedic practice nationwide through the efforts of the American Orthopaedic Association's Own the Bone and the International Osteoporosis Foundations Capture the Fracture® initiatives directed at improving osteoporosis care.[1-5] Bone mineral density has been demonstrated to be inversely proportional to fracture risk and continues to be a tangible metric by which dual x-ray absorptiometry (DXA) can be used to assess efficacy of bone health interventions.[6,7] While many efforts have been targeted at pharmaceutical administration for management of osteoporosis and the maintenance of BMD, the role for nutrition and regular exercise programs remains understated.

At our institution, the bone health program receives referrals across all orthopaedic service lines for the purposes of secondary fracture prevention after sustaining fragility femur fractures, improving BMD prior to elective joint arthroplasty and spine surgery, as well as, managing osteoporosis medications. One of the hallmarks of our program is the focus on patient education on nutrition and exercise as a basis of improving patient bone health. This includes the routine prescription of

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vitamin D, and recommending adequate dietary calcium, and protein for all patients. Through implementation of this practice, a series of patients were noted to experience increases in BMD on serial DXA scans with nutritional and exercise interventions alone in the absence of osteoporosis medications.

This case series presents 12 patients who followed in our institution's outpatient bone health clinic and experienced increases in BMD through nutritional and exercise interventions without the aid of osteoporosis medications. Through the presentation of these 12 patients this case series aims to 1) demonstrate the capacity for quantitative improvements in BMD on DXA scans with nutritional and exercise interventions, 2) summarize the heterogenous characteristics of patients experiencing increases in BMD, and 3) highlight nutritional and exercise counseling as a low demand and high yield method of improving BMD in any orthopaedic practice.

METHODS

Retrospective review for all patients presenting to our institution's bone health clinic from its inception in January 2020 to August 2024 was performed. Patients who experienced an increase BMD on DXA with diet and exercise alone were included in the case series for analysis. Patient charts were queried for age at time of presentation, indication for referral to bone health clinic, referring service, and details regarding injuries associated with fragility fractures that led to referral. All patient comorbidities, prior bone health interventions (i.e. vitamin D, calcium, protein supplementation), presence of prior of bone health evaluation, 12-month fall history, and substance use status were noted. Laboratory markers including calcium (Ca), parathyroid hormone, free and total testosterone, 25-hydroxy (OH) vitamin D were recorded if obtained for each bone health visit within the study period. DXA data including BMD and t-scores were recorded for the femoral neck, total hip, and lumbar spine if performed. All interventions and recommendations provided by the bone health clinic were included for each patient case. Plans at the time of last follow-up were included for each patient.

All statistics were performed in Microsoft Excel (Redmond, WA). Descriptive statistics were performed for continuous variables. Percent change for BMD was calculated as the difference between the most recent BMD and initial BMD divided by initial BMD. Trends for changes in laboratory values were similarly assessed by percent change. No formal comparative statistics were performed for this study due to the lack of statistical significance inherent to the size of this series.

This study was classified as quality improvement by the institutional review board (IRB) and was exempt from further review (IRB ID # 202402300). All patients included in this case series signed written consent granting permission to share their data for publication and academic discussion.

RESULTS

Retrospective review of all patients evaluated in our institutions bone health clinic identified 12 patients who experienced increases in bone mineral density without osteoporosis medications. Of these patients seven were female and five were male with an overall average age of 64.8 years. Nine patients were referred from orthopaedic subspecialty services, one was a self-referral, and two were referred by a primary care provider (PCP) (Table 1). Indications for referral were variable with six patients being referred for bone health optimization in the setting of fracture, four referred after receiving an osteoporosis or osteopenia diagnosis, and two referred after undergoing elective surgery (Table 1). Four patients had a prior fragility fracture, five had at least one fall in the 12 months prior to bone health presentation (Table 1). Only three patients had a prior bone health evaluation, however, seven were on Vitamin D supplementation at baseline, three on calcium supplementation, and two on over the counter (OTC) protein shake supplementation (Table 2). All 12 patients presented with calcium levels within normal limits with an average of 9.4 mg/dL (normal: 8.5-10.5 mg/dL) (Table 2). 25-OH Vitamin D levels at presentation were variable with a range of 16 ng/mL to 107 ng/mL with an average of 44.6 ng/mL (normal: 20-80 ng/mL) (Table 2). PTH (parathyroid hormone) levels at presentation ranged from 27 pg/mL to 68 pg/mL with an average of 44.1 pg/mL (normal: 15-65 pg/mL) (Table 2). PTH was not collected at presentation for one of the patients.

For bone health interventions, all patients were counseled on the importance of nutrition, encouraging a calcium rich diet in addition to consuming at least 30 grams of protein three times per day. This was in addition to all patients receiving oral Vitamin D supplementation ranging from 1000 IU to 5000 IU daily based on their nutritional needs and prescribing an oral 400 mg calcium supplementation three times daily (Table 3). With respect to protein supplementation, one patient used only dietary changes to meet protein needs, while nine patients were advised to consume an OTC protein shake with eight being recommended to consume the 30-gram protein shake daily, two consuming the 20-gram formulation three times daily, and one consuming the 25-gram formulation three times daily (Table 3). No patients were prescribed osteoporosis medications in this case series primarily as a result of shared decision making and patient preference to trial non-pharmacologic management.

Table 1. Patient Bone Health Referral Context and Comorbidities

Case #	Age at Presentation (Years)	Referring Service	Reason for Referral	Prior Fragility Fracture	# of Falls in 12 Months	Comorbidities
1	51	Ortho Spine	L1 Compression Fracture	No	1	Asthma, Skin Cancer
2	58	Primary Care	Osteopenia	Yes	0	Hypertension
3	75	Self-Referral	Osteopenia	No	0	Hyperlipidemia, Cardiac Arrythmia, Breast Cancer s/p lumpectomy, radiation/chemotherapy on anastrozole
4	67	Foot and Ankle	Post-Surgery	Yes	2	Hypertension, Hyperlipidemia
5	63	Ortho Trauma	Vitamin D Deficiency, Scapula Fracture	No	1	Hyperlipidemia, Hypertension, Metabolic Syndrome
6	76	Foot and Ankle	Talus Stress Fracture	Yes	0	Left Ventricular Hypertrophy, Hypertension, Hypothyroidism
7	69	Ortho Trauma	Periprosthetic Distal Humerus Fracture Nonunion s/p ORIF	Yes	1	Systolic Heart Failure, Atrial Fibrillation, Cirrhosis
8	61	Ortho Trauma	Distal Clavicle Fracture	No	1	None
9	60	Ortho Hand	s/p Ulnar Shortening Osteotomy	No	0	Sjogren's, Cerebral Vascular Accident, Chronic Obstructive Pulmonary Disease, Vulvar Cancer s/p chemotherapy/radiation
10	76	Sports Medicine	Osteoporosis	No	0	Hypertension, Hyperlipidemia, Atrial Fibrillation
11	57	Primary Care	Osteoporosis	No	0	Celiac Disease, Lactose Intolerance
12	65	Ortho Trauma	Tibial Plateau Fracture	No	0	Hypertension, Hyperlipidemia

S/p-status post, ORIF-Open Reduction Internal Fixation.

Table 2. Summary of Prior Bone Health Interventions and Baseline Laboratory Values

Case #	Prior Bone Health Evaluation	Prior Bone Health Interventions	Calcium at Presentation (mg/dL)	25OH-Vitamin D at Presentation (ng/mL)	Parathyroid Hormone at Presentation (pg/mL)
1	No	None	9.3	40	66
2	Yes	10,000 IU Vitamin D3 Daily, Citracal 650 mg BID	10.0	107	33
3	Yes	OTC Protein Shake, OTC Calcium/ Phosphate Supplements, 1000 IU Vitamin D3	9.6	41	34
4	Yes	OTC Calcium Supplement	9.0	25	N/A
5	No	None	9.4	16	45
6	No	3000 IU Vitamin D3 Daily	9.3	45	27
7	No	2000 IU Vitamin D3 Daily	9.0	34	68
8	No	600 IU Vitamin D3 Daily	9.2	27	48
9	No	OTC Protein Supplement Daily	9.4	41	36
10	No	5000 IU Vitamin D3 Daily	9.6	54	30
11	No	5000 IU Vitamin D3 Daily	9.4	54	58
12	No	None	9.6	51	40

IU-International Units, BID-Twice Daily, OTC-Over the Counter.

All patients included in the case series had a DXA at the time of initial evaluation. A follow-up DXA scan was completed, at the same facility, at a mean of 21.7 months (range 12.1-47.4 months) following the initial DXA to assess progress. For this case series, total hip BMD was the most common increase seen with all 12 patients demonstrating an increase in total hip BMD with an average percent increase of 3.7% (Table 4). Spine BMD was the second most common increase seen with 10 patients experiencing an increase for an average percent increase of 6.0% (Table 4). Femoral Neck BMD was the least seen increase with eight patients demonstrating an average percent increase of 1.5% (Table 4). One patient demonstrated no change in femoral neck increase (Table 4). Eight patients experienced BMD increases or no change in all three anatomic points, while three experienced increases in two of three anatomic points, and only one experienced an increase at a single anatomic point (Table 4).

Based on the findings of the available DXA data, one patient was offered Denosumab to help further increase BMD, however, the patient declined pursuing pharmacologic treatment and elected for follow-up in two years (Table 3). Five patients were scheduled for follow-up with a repeat DXA in two years, while three patients were scheduled for routine follow-up without DXA for repeat labs at a range of one to two years (Table 3). One patient was permitted to follow-up as needed with no set follow-up plan (Table 3).

DISCUSSION

The value of nutritional supplementation, diet, and exercise is frequently overshadowed by pharmacotherapy in the care of orthopaedic patients for the management of osteoporosis and bone health optimization. This 12 patient case series demonstrates the capacity for patients to experience increases in bone mineral density without osteoporosis pharmacotherapy, offering a potential solution to improving access to bone health care for practices without expertise in the prescription of osteoporosis pharmacotherapies. Patients in this series demonstrated an average 3.7% increase in total hip BMD, 6.0% average increase in spine BMD, and 1.5% average increase in femoral neck BMD. While the positive relationship between nutrition and bone mineral density is hardly novel, this cases series provides quantifiable data from patients frequently encountered across orthopaedic service line in need of bone health care.[8-22] This series further outlines a nutritional supplementation regimen that could be easily implemented across orthopaedic service lines with demonstrated efficacy in improving BMD.

Pharmacotherapy provides a reliable means of increasing bone mineral density with average increases in BMD ranging from 3-13%.[23-25] While, these increases are variable according to medication prescribed and location of DXA BMD, the BMD values obtained for total hip and spine BMD from this cases series fall within the range of expected gains yielded from osteoporosis pharmacotherapies.[23-25] Similar to pharmacotherapy, lumbar

Table 3. Patient Level Bone Health Interventions Provided by Bone Health Clinic

Case #	Vitamin D3 Supplementation	Calcium Supplementation	Recommended Protein Supplementation	Follow-up Plan
1	2000 IU PO Daily	400 mg PO TID	OTC Shake 30 g Daily	DXA in 2 years
2	2000 IU PO Daily	400 mg PO TID	None/Diet Only	DXA in 2 years
3	1000 IU PO daily (summer) 2000 IU PO daily (winter)	400 mg PO TID	OTC Shake 30 g Daily	Follow-up 18-24 months
4	5000 IU PO daily	400 mg PO TID	OTC Shake 20 g TID	Follow-up 2-3 years
5	5000 IU PO BID	400 mg PO TID	OTC Shake 30 g Daily	None
6	3000 IU POD daily	400 mg PO TID	OTC Shake 25 g TID	Denosumab Deferred, Follow-up 2 years
7	2000 IU PO daily	400 mg PO TID	OTC Shake 30 g Daily	DXA in 2 years
8	1000 IU PO daily	400 mg PO TID	OTC Shake 30 g Daily	DXA in 2 years
9	2000 IU PO daily	400 mg PO TID	OTC Shake 20g TID	DXA in 2 years
10	5000 IU PO Daily	400 mg PO TID	OTC Shake 30g Daily	Follow-up 1 year
11	5000 IU PO Daily	400 mg PO TID	OTC Shake 30g Daily	Add Calcium Citrate 500 mg BID, DXA in 1 year
12	4000 IU PO Daily (winter) 2000 IU PO Daily (summer)	400 mg PO TID	OTC Shake 30g Daily	Increase Protein Shake to 2 per day, DXA in 1 year

IU-International Units, BID-Twice Daily, TID-Three Times Daily, OTC-Over the Counter, DXA-Dual X-Ray Absorptiometry, PO-By Mouth.

Table 4. Changes in Bone Mineral Density for Initial and Follow up DXA Scan

Case #	Initial DXA BMD			Follow-up DXA BMD			Interval Time (Months)
	Femoral Neck g/cm^2	Total Hip g/cm^2	Lumbar Spine g/cm^2	Femoral Neck (% change) g/cm^2	Total Hip (% change) g/cm^2	Lumbar Spine (% change) g/cm^2	
1	0.759	0.954	0.950	0.764 (0.7%)	0.991 (3.9%)	1.024 (7.6%)	12.3
2	0.789	0.907	1.959	0.802 (1.6%)	0.934 (3.0%)	0.927 (-3.3%)	25.8
3	0.698	0.792	0.839	0.702 (0.6%)	0.843 (6.4%)	0.927 (10.5%)	47.4
4	0.997	1.114	1.367	0.880 (-11.7%)	1.136 (2.0%)	1.465 (7.2%)	33.2
5	0.897	1.075	1.286	0.910 (1.4%)	1.132 (5.3%)	1.360 (5.8%)	25.0
6	0.631	0.731	0.974	0.627 (-0.6%)	0.751 (2.7%)	1.051 (7.9%)	12.3
7	0.667	0.825	1.034	0.630 (-5.5%)	0.853 (3.4%)	1.028 (-.6%)	24.6
8	0.533	0.773	0.755	0.533 (0%)	0.781 (1.0%)	0.778 (3.0%)	12.3
9	0.677	0.844	1.017	0.691 (2.1%)	0.869 (3.0%)	1.071 (5.3%)	25.9
10	0.528	0.672	1.033	0.542 (2.7%)	0.692 (3.0%)	1.047 (1.4%)	15.8
11	0.595	0.690	0.744	0.610 (2.5%)	0.737 (6.8%)	0.772 (3.8%)	13.1
12	0.644	0.847	0.833	0.662 (2.8%)	0.884 (4.4%)	0.894 (7.3%)	12.2

DXA-Dual X-Ray Absorptiometry, BMD-Bone Mineral Density.

spine BMD experienced the largest increase in our case series with a range of 1.4% to 10.5%. Despite these large increases, positive lumbar BMD changes remain difficult to interpret due to the confounding effect of degenerative disk disease on inflating BMD values, despite practice changes of performing DXA evaluations higher in the lumbar spine to mitigate these effects.[26,27] However, there is evidence suggesting higher protein intake may have a protective effect on lumbar spine BMD.[28] The increases seen in the total hip BMD for all patients included in this study is more reassuring, as this is the DXA metric our institution routinely utilizes as a barometer of a patient's bone health status and is likely most reflective of the benefits of vitamin D supplementation and increased dietary calcium and protein.

This study has multiple limitations, primarily related to the retrospective nature of this case series. Due the retrospective nature of this study BMD changes cannot be directly attributed to nutrition and exercise, as causation and confounding variables were not controlled for. Due its retrospective nature there is the risk for incomplete data and unknown factors such as care from outside institutions that may not be accounted for that contributed to changes in BMD. Furthermore, this study does not account for adherence to the recommended and prescribed exercise regimen which may refute the conclusion that increases in BMD were attributed to the bone health interventions implemented in this series. The generalization of findings from this case series to other orthopaedic practices may further be limited, as all bone health care in this series was provided by a health care professional with extensive experience osteoporosis management. This series also does not identify patients who may experience decreases in BMD with only diet and exercise, which may limit the impact of the findings of this study. Error associated with deviation in DXA acquisition for studies obtained at our institution and other studies also cannot be accounted for which may confound the increases seen in this study, for acceptable precision for DXA scans had been previously estimated to be 1.9%, 1.8%, and 2.5% error for the lumbar spine, total hip, and femoral neck respectively, as suggested by Choplin et al.[29] This series is also underpowered and thus did not have a sample size sufficient for formal statistical analysis or determination of whether the increases in BMD are representative of a minimal clinically important difference (MCID). Future research should be directed towards identification of patient specific factors that may be associated with BMD increases without osteoporosis medications, as well as, identifying the MCID for BMD to justify deferring initiation of osteoporosis pharmacotherapies.

This case series highlights the added value of non-pharmacologic therapies including nutrition optimization and intentional exercise in improving BMD for orthopaedic patients. Pharmacotherapy remains an essential component of osteoporosis management, but our findings highlight the importance of including nutrition and exercise counseling as a part of the FLS treatment plan. Future research should determine the added benefit of nutrition and exercise interventions in addition to pharmacologic therapies for older adults with osteoporosis.

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