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IOWA ORTHOPEDIC JOURNAL
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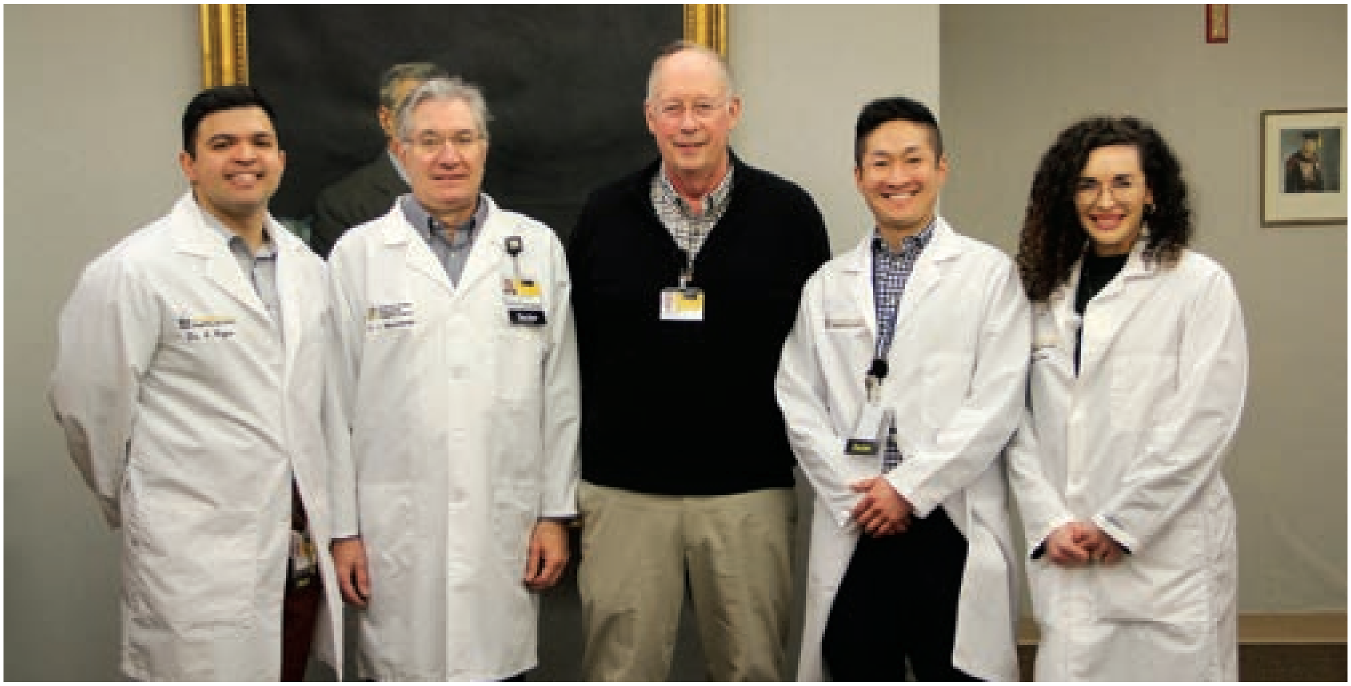
2024 IOJ EDITORS' NOTE



From left to right: Drs. Edward Rojas (Resident Editor), Jose Morcuende (Staff Advisor), J. Lawrence Marsh (Staff Advisor), Connor Maly (Resident Editor), and Sarah Ryan (Resident Business Manager and Editor).

We are pleased to present the 44th 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. Due to the continued success of the IOJ, we are fortunate to continue the tradition of publishing a Fall electronic issue for a fifth consecutive year.

We would like to recognize our graduating class of senior residents: Drs. Olivia O'Reilly, Samuel Swenson, Jacob Henrichsen, James Hall, Burke Gao, and James Cardinal. 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.

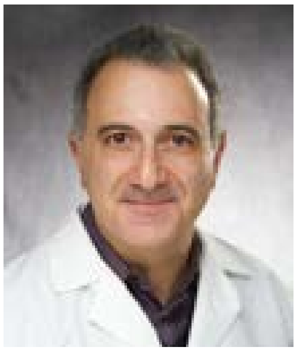
We would also like to thank several key individuals without whom the publication of the IOJ would not be possible. We would like to thank Angie Poulsen, who was instrumental in the organization and preparation of this year's IOJ. We thank Dr. Sarah Ryan for her efforts to coordinate corporate sponsors. 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. Burke Gao as Resident Reviewer of the Year for the exceptional 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.

Connor Maly, MD
Edward Rojas, MD
Sarah Ryan, MD
Editors-in-Chief
Iowa Orthopedic Journal
University of Iowa Hospitals and Clinics
Department of Orthopedics and Rehabilitation

2024 DEDICATION OF THE IOWA ORTHOPEDIC JOURNAL

Connor J. Maly, MD, Edward O. Rojas, MD, Sarah E. Ryan, MD



Cassim Igram, MD

The editors of the Iowa Orthopedic Journal (IOJ) dedicate the 2024 edition of this storied publication to Dr. Cassim M. Igram. It is these young "docs" pleasure to help compose this tribute to Dr. Igram, who has been a model leader, outstanding educator, and valued mentor to both faculty and residents alike throughout his career and tenure at Iowa.

Dr. Cassim M. Igram was born in Iowa City, IA at Mercy Hospital and spent his formative childhood years in Cedar Rapids, IA. He attended Washington high school, where he actively participated in track, wrestling, and marching band. His journey as a Hawkeye began when he enrolled at the University of Iowa for his undergraduate studies, and he remained a spirited Hawkeye by participating in the University of Iowa marching band throughout college. He subsequently stayed in Iowa City to pursue his medical education at the University of Iowa Carver College of Medicine. Staying in Iowa City for his medical education proved one of the best decisions he ever made for several reasons. First and foremost, during his 3rd year of medical school he met his wife Julie on a blind date at the Iowa River Power Company. They were married one week before he started residency, and have three wonderful children together, Alex (32), Sarah (31), and Taylor (26). It was also during medical school that he met several faculty members and lifelong mentors James Nepola, Stu Weinstein, Larry Marsh, and John Albright. Inspired by their guidance and support, he decided to pursue a career in orthopedics and matched for residency at the University of Illinois Chicago. After completing his residency training in the Windy City, he relocated to New Orleans, LA to complete a spine fellowship at LSU. Dr. Igram then returned to the Hawkeye state and settled in Des Moines, IA where he worked as a spine surgeon at Mercy Hospital for over 20 years. He was then recruited back to the University of Iowa by our very own Dr. Nepola, who initially offered him the job on the back of a McDonalds French fry box. As such, when discussing writing this year's dedication with faculty, Dr. Nepola had countless thoughts to share. Fortunately, we were able to review, select and approve them before publication to ensure there was still room for actual manuscripts in this year's edition. The following captures only some of Dr. Nepola's accolades about Dr. Igram.

"It is well-deserved and fitting that the Iowa Orthopedic Journal is dedicated to Dr. Igram this year, as he truly embodies what it means to be an Iowa Hawkeye. I have known Dr. Igram since he was a medical student, and what was clear to me then and remains true of him to date is how much he cares about patients, residents, and colleagues. Every medical student says they get

Dr. Igram and company at his eldest son Alex's wedding.

Left to Right: Dr. Olinger, Dr. Lindsay, Dr. Weinstein, Dr. Pugely, Dr. Kesler, Dr. Igram, Dr. Eisenberg, and Dr. Found at Senior Resident's Dinner 2022.

Dr. Igram showing one of his senior residents, Dr. Rojas, relevant anatomy intraoperatively as always.

Dr. Igram with the Iowa orthopedic resident representatives Dr. O'Reilly, Dr. Wilkinson, and Dr. Swenson in Washington D.C. at the National OrthoPac meeting.

Dr. Igram and his wife Julie with Dr. Nepola and his wife Cathy on Capitol Hill during the National Orthopaedic Leadership Council Meeting 2023.

into medicine to help people, but only a special few outwardly embody this sentiment and are born doctors. Let me tell you what, Cass Igram was born a doctor. In Latin, the word doctor means teacher, and that is a large part of who Dr. Igram has been for students, residents, and faculty alike throughout his career. I have seen his entire career unfold in front of me, and since mentoring him through his residency application process, it always struck me how his mindset was always about helping patients. This never wavered, and I will never forget the look on his face when he told me he matched at the University of Illinois Chicago for orthopedic surgery, and how happy I was for him to carry out the vocation he was born to do. Residency took him off to Chicago, and fellowship took him away to New Orleans, but as I suspected his path brought him back to the Hawkeye state, and I was thrilled he could serve the people of Iowa because Iowa is where he belongs.

Beyond his clinical practice, Dr. Igram has remained an active leader in the orthopedic community for over twenty years. He has served on the American Academy of Orthopaedic Surgeons (AAOS) board of counselors, is a member of the AAOS Now Editorial Board, sits on the AAOS committee on Professionalism, remains an active member of the Iowa Orthopedic Society (IOS), and serves as the treasurer of the OrthoPac. Throughout the nation, he is recognized as Iowa's representative for the orthopedic community. His involvement, reputation, and status within the political community have even caught me by surprise. Most recently at a National Orthopedic Leadership Council meeting this past fall, where all my political friends not only know him by name but know him well. He is a doctor first, colleague, outstanding professional, and orthopedic leader in my eyes, whom we are lucky to have in this department. It is wonderful to see how well-regarded and respected he has become throughout his career. His reputation and influence with government leaders through his advocacy work for the orthopedic community now extend from Capitol Hill in Washington D.C. to the Governor's Mansion on Terrace Hill in Des Moines. Everyone knows and makes sure to listen when Dr. Igram is speaking.

For all the great things Dr. Igram has accomplished, he does have his vices. As a former member of the Des Moines Golf Club and an avid duffer, he rarely turns down a Sunday morning break of dawn tee time with me. Well, unless his children are in town, or he's committed to another family activity with his lovely wife Julie. Family duties have always trumped my attempts to pull him away for a good game of golf, unlike myself. Cass is and will always be a dedicated family man who has successfully balanced his career and commitment to his family. Even while successfully establishing this work-life balance, I saw how Dr. Igram's commitment to his patients and for Iowa never faltered, which is why I recruited him when we had the opportunity to add a new spine staff a decade ago. All it took was one fancy, impromptu lunch at McDonald's for me to confirm that he would be an excellent fit in Iowa City. He was still the same patient-centered doctor whom I met as a medical student. On top of it all, it was obvious that he could not resist the opportunity to return to his alma mater in Iowa City and finish out his career as a faculty member for The University of Iowa, again exemplifying how he is a Hawkeye through and through.

Bringing Dr. Igram into the department has been a fantastic addition on multiple levels. He has brought a wealth of experience and knowledge that he has constantly shared with faculty and residents. He has remained true to our shared core value of helping patients, which is what we are here to do. We may fix bones, fuse spines, and replace joints, but if we haven't made the patient better, then we've failed, and Cass does not allow for failure. I have heard it from residents and for myself; he will only operate if he thinks it will help make the patient better. He doesn't operate on imaging studies; he operates on people. He continues to teach residents how to understand patients and their problems, in the context of their imaging, and put it all into perspective for the patient to make the right decision. Now wouldn't it be excellent if all of us could gain such wisdom from the time we spend with him? He always does the right thing, as all of us should. Iowa is better thanks to people like him being here. He cares about everyone; he is a giver, he is a doctor, and he personifies my vision for where I hope to leave this department in the future. Thank you, Cass; we are fortunate to have you here, and honored to dedicate the IOJ to a true Hawkeye!"

Similarly, when speaking with residents, both past and present, two words always come up when describing Dr. Igram: support and mentorship. He embodies these qualities to the fullest, not just for residents, but for faculty as well. Any resident who has rotated through the spine service has heard the other faculty say, "I have to run this by Igram," when they have a challenging case, and he has always answered the call to help his fellow faculty with his extensive experience and intuition. This type of supportive presence is one every young faculty member hopes to have when starting their career and should aspire to become. Likewise, Dr. Igram's innate drive to mentor residents and help them succeed in any way he can is exemplary. Even if you don't aspire to become a "lowly spine surgeon," Dr. Igram always has your back and will support you without you even realizing it. One such example was shared by one of the IOJ editors, Dr. Rojas:

"From my time as a medical student to this day as a senior resident, Dr. Igram has been a constant support and mentor in my career. As a medical student, he helped set me up for success with an away rotation at the University of Illinois, Chicago, where he did his residency. He reached out to their residency director to put in a good word for me before I ever stepped foot in Chicago, and thanks to that, I had an excellent experience there. During the residency application process, he was a huge advocate for me to match at Iowa. Now as a resident, it brings me so much joy to hear him tell me how proud he feels that he supported my application, especially with how he has seen me grow as a resident. Even during the fellowship interview trail, he was always interested to know how things were going for me. I had several instances during interviews where I would show up and find out during the interview day that he had already reached out to a program to put in a good word for me, without me ever knowing. This type of constant, unwavering support is who he is and how he just always cares. Now I just hope to keep making him proud of what he has invested in me by paying it forward to others throughout my career."

However, Dr. Igram's impact has always stretched beyond our interactions with him in the hospital. As graduates like Dr. Kyle Kesler and Dr. Josh Eisenberg share—He was more than a mentor; he was a guiding presence, caring about our well-being both personally and professionally. His fireside chats during journal club sessions at his home were cherished moments where discussions about orthopedic spine articles seamlessly blended with conversations about life and medicine. It was always heartwarming to see how all the residents would show up regardless of their interest in spine because we always ended up talking about so much more than that. Gathered around his fire pit, we found ourselves immersed in discussions ranging from spine surgical techniques to advice on how to survive a career in medicine. Through these gatherings, Dr. Igram taught us the significance of excelling in our field while maintaining a balanced personal life. He instilled in us the belief that being a skilled surgeon also meant being a compassionate and well-rounded individual, leaving an enduring impact on our journey through training.

No number of words can do justice to Dr. Igram's impact on countless residents and faculty through multiple avenues of education, support, and mentorship, his contributions to the orthopedic community through political advocacy, and his conscientious care for the people of Iowa through his clinical practice. However, we hope the 2024 Iowa Orthopedic Journal Dedication serves as a start. Finally, Dr. Nepola insisted on being the one to close out this tribute, and if you know Dr. Nepola, there is no changing his mind. So here is his year's IOJ dedication closing thoughts.

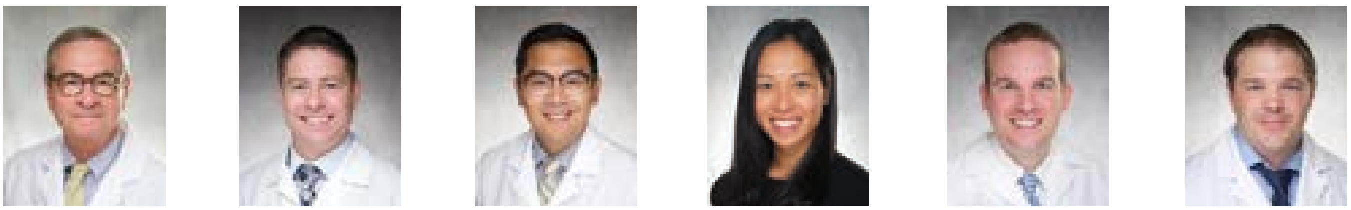
"Every medical school applicant knows to recite the necessary phrase that they are going into medicine because they want to help people, and they may all mean it at that time. Yet, unlike many who lose that drive through the trials and tribulations of their career, Dr. Igram meant it then and continues to live it to this day. We, his students, are grateful to him for reminding and teaching us through his actions every day, not only to talk the talk, but ALWAYS walk the walk. There have been many notable orthopedic surgeons who have come through the University of Iowa in our storied history, and you stand among them as the consummate Iowa Hawkeye, whose career has never been about yourself, and instead always about those you could help in any way possible along the way. Thank you, Doctor Igram."

We couldn't say it any better ourselves and are honored to dedicate this edition of the Iowa Orthopedic Journal to you Dr. Igram.

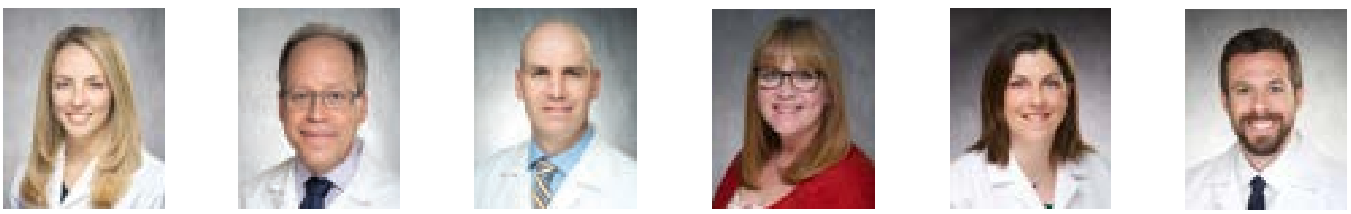
-The IOJ Editors

DEPARTMENT OF ORTHOPEDICS AND REHABILITATION FACULTY 2023-2024

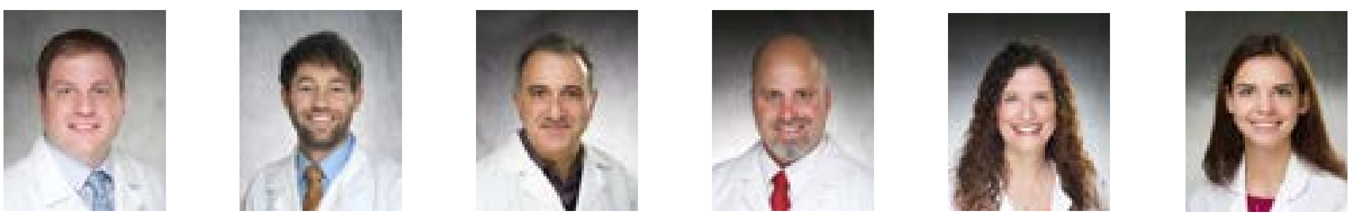
Dr. Donald Anderson | Dr. Adam Arendt | Dr. Eric Aschenbrenner | Dr. Rahul Bijlani | Dr. Heather Bingham | Dr. Matthew Bollier



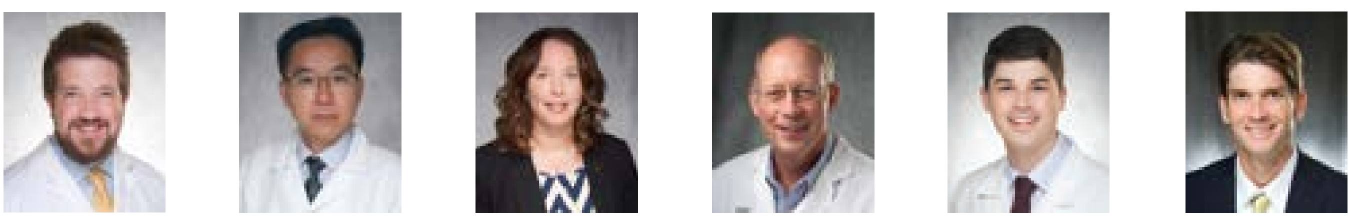
Dr. Joseph Buckwalter IV | Dr. Joseph Buckwalter V | Dr. Philip Chen | Dr. Bopha Chrea | Dr. Kyle Duchman | Dr. Jacob Elkins



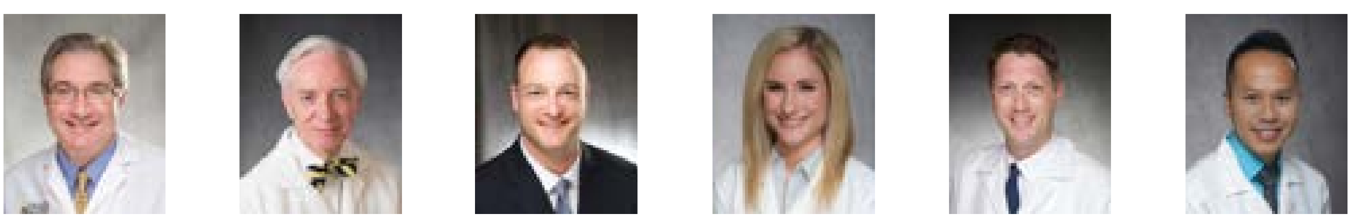
Dr. Ashlee Enzinger | Dr. John Femino | Dr. Joseph Galvin | Dr. Kara Gange | Dr. Jessica Goetz | Dr. Mederic Hall



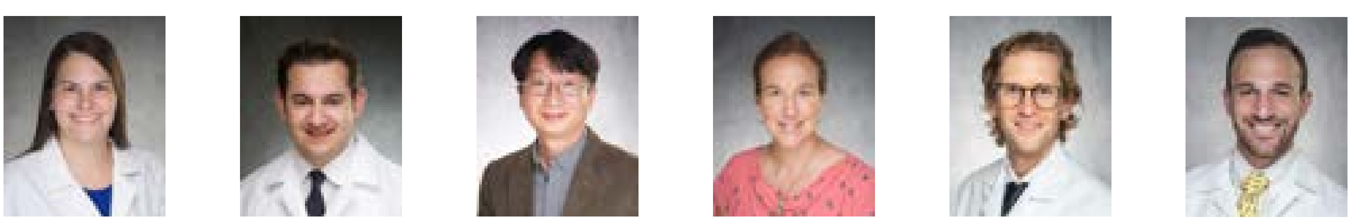
Dr. Matthew Hogue | Dr. Joshua Holt | Dr. Cassim Igram | Dr. Matthew Karam | Dr. Valerie Keffala | Dr. Heather Kowalski



Dr. Ryan Kruse | Dr. Hongshuai Li | Dr. Megan Lundstrom | Dr. J. Lawrence Marsh | Dr. Ryan McLoughlin | Dr. Benjamin Miller



Dr. Jose Morcuende | Dr. James Nepola | Dr. Nicolas Noiseux | Dr. Catherine Olinger | Dr. Brendan Patterson | Dr. Than Pham



Dr. Sarah Polk | Dr. Andrew Pugely | Dr. Dong Rim Seol | Dr. Jennifer Rogers | Dr. Brett Rosauer | Dr. Andrew Schwartz


Dr. Kathleen Vonderhaar

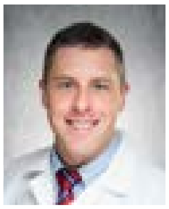

Dr. Ling Wang


Dr. Stuart Weinstein

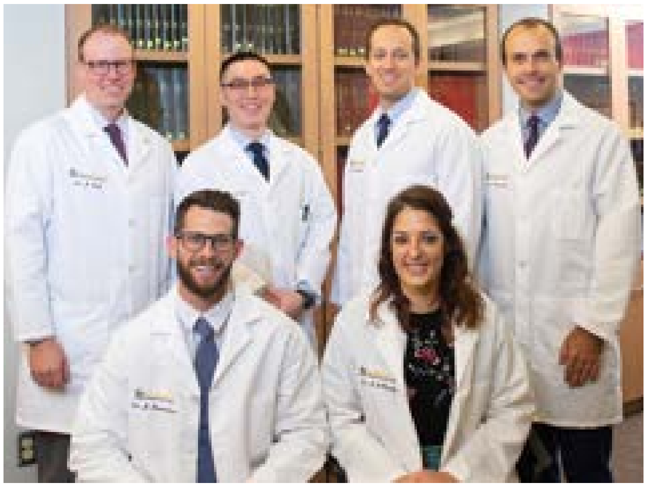

Dr. Robert Westermann


Dr. Michael Willey

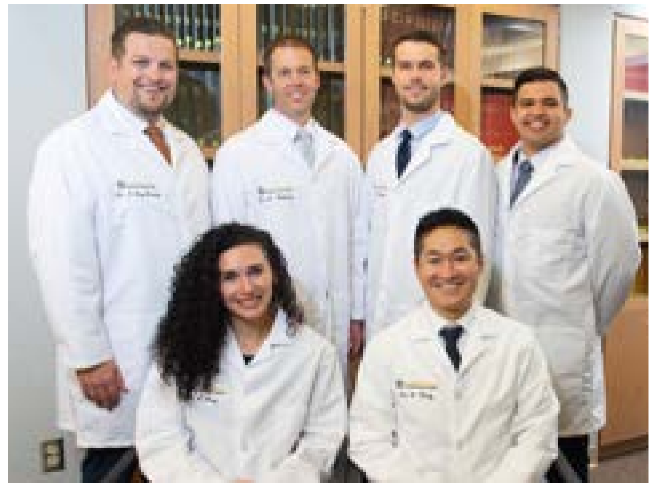

Dr. Brian Wolf


Dr. Steven Zehring

DEPARTMENT OF ORTHOPEDICS AND REHABILITATION RESIDENTS 2023-2024



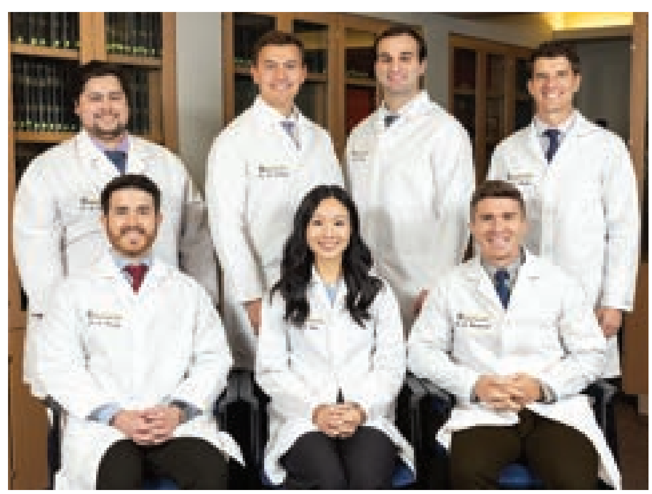
PGY5-Class of 2024. Back row (left to right): Drs. James Hall, Burke Gao, James Cardinal, and Samuel Swenson. Front row (left to right): Drs. Jacob Henrichsen and Olivia O'Reilly.



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. Steven Leary, Austin Benson, and Arianna Dalamaggas. Front row (left to right): Drs. Hannah Korrell, Alex Demers, 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.

2024 GRADUATING ORTHOPEDIC RESIDENTS

James Cardinal, MD

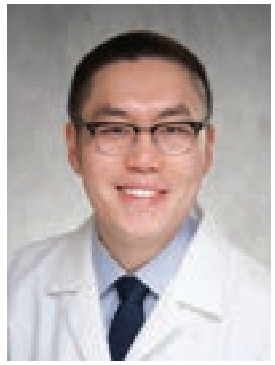
James grew up in Bountiful, Utah with his parents and four siblings. From elementary to high school, he enjoyed many activities including athletics, scouting, and skiing. He played lacrosse and rugby for his high school team.

James initially went to Brigham Young University to study accounting with the intent of pursuing a career in finance. After his freshman year, he delayed his studies two years to complete a volunteer service mission in Mongolia. His experiences working with the poor and underserved people of Mongolia led him to change career paths. With a desire to have a more service-oriented career he decided to study medicine.

While applying to medical school, James worked in finance for Intermountain Healthcare. He spent his free time working with an international team of trauma surgeons to introduce and propagate the Advanced Trauma and Life Support training program in Mongolia.

These experiences exposed him to the myriad of problems modern healthcare faces and has guided his research interests towards developing models for medical education in low-income countries and maximizing operating room efficiency. He is currently working with Dr. Buckwalter on using 3-D modeling to better understand optimal screw placement for scaphoid fracture fixation with the hope this will lead to a low-cost training model for resident and fellow education.

After residency, James plans to obtain further training in a hand and upper extremity fellowship at the University of Arizona. He and his wife plan on returning to the Mountain West with their three kids. He hopes to continue to his volunteer work in international surgical education. He is grateful for the support he has received from the team, especially Dr. Steven Long while completing this current project. He is grateful for the continued mentorship he has received from the faculty at the University of Iowa, especially the current and past members of the hand division Drs. Lawler, Fowler, Buckwalter, and Caldwell. Most of all, he is grateful for unwavering support he has received from his wife and family.



Burke Gao, MD

Burke Gao was born in Overland Park, Kansas. He grew up in a loving home with his parents and older sister Raisa. He began playing the violin at 6 years of age and continued this passion throughout grade school. Outside of school, he played with the Kansas City Youth Symphony Orchestras. His efforts culminated in multiple all state orchestra selections and several years with the KC Youth Symphony's highest level flagship orchestra.

Inspired to help heal others, it was always a dream of his to become a doctor. When Brown University offered him an opportunity to join their 8-year medical program, it was without hesitation that he enrolled at Brown.

At Brown, Burke found a passion for economics and its use of statistics in answering social questions as well as its ability to model human behavior and incentives. His senior thesis analyzed 10 years of archival data in Geneva, Switzerland from the WHO's smallpox eradication program to investigate the role of trust in building public health efficacy. His work won Brown's Samuel Lamport Prize and a Watson Institute Fellowship Award. At Brown, he was also an econometrics tutor and a minority peer counselor. In those roles he found great joy in teaching and promoting the personal growth of others in areas surrounding diversity and social responsibility.

While in medical school, Burke was heavily involved with sports medicine research with Dr. Brett Owens and Dr. Aristides Cruz. Both Dr. Owens and Dr. Cruz helped to inspire in him a love for orthopedic surgery. While at Iowa, Burke became interested in-patient education and worked on a number of publications regarding the quality of online patient education materials.

Dr. Gao is incredibly humbled and grateful for the opportunity to train at Iowa's storied orthopedic surgery program. At Iowa, he has gained clinical and life lessons from skilled, caring, and thoughtful surgeons. The mentorship and guidance of Dr. Buckwalter V—as well as Iowa's past hand surgeons, Dr. Lawler, Dr. Caldwell, and Dr. Fowler—were instrumental in his development and eventual choice to apply for a fellowship in hand surgery. He hopes to follow in their footsteps and become an academic hand surgeon.

Burke would like to thank his parents and sister for their support, love, and guidance over the years. He would like to thank the innumerable mentors and attendings that have helped him during residency, and Dr. Karam and Dr. Marsh for offering him a spot in the best residency program in the country. Finally, he would like to thank his five co-residents for being the best people to laugh, train, and grow with.

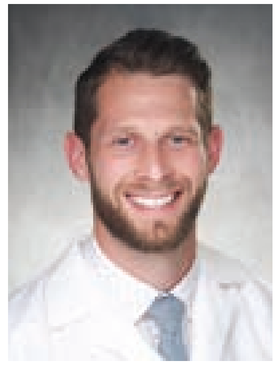
James Hall, MD

James Hall grew up in Bettendorf Iowa, the son of John and Kay Hall. Growing up on the banks of the Mississippi river, James became interested in the sport of rowing in high school. This led to several national championships and the opportunity to continue his participation in the sport at the University of Pennsylvania on the men's heavyweight rowing team. After suffering a back injury while training, he transferred to the University of Wisconsin, Madison, where he continued to compete in the sport. Unfortunately, his rowing career was cut short by the injury, but he was very fortunate to meet his wife while studying in Madison. After completing his degree in Economics, James moved to the suburbs of Chicago where he began working in real estate sales before moving into medical device sales. It was his experience as a sale representative with NuVasive that exposed him to medicine and the operating room. This experience helped him realize he desired a greater purpose in life, something that caring for patients through medicine would offer. This compelled him to pursue his post-baccalaureate pre-medicine courses,

while working full-time and he ultimately left the comfortable sales life in 2012, completing a master's degree in 2014 before beginning medical school in 2015. Along the way, James married his wife Jonna and has been blessed with three children – Harper (10yrs), Hudson (9yrs) and Harrison (6yrs).

James was exposed to clinical research as a medical student and continued his exploration during residency. He has researched a variety of topics including the lasting impact of smoking cessation in joint arthroplasty, return of scapulothoracic rhythm after reverse total shoulder arthroplasty, efficacy of smoke evacuation devices in spine surgery and the efficacy of a machine learning algorithm in determining survival in metastatic tumors of the spine. His experience in spine clinic with socially disadvantaged patients was the catalyst of his senior research project, where he tries to determine how socioeconomic status affects patient reported outcomes and complications in spine surgery.

After graduating from residency, James will be pursuing a fellowship in spine surgery at Norton Leatherman Spine in Louisville, KY. He is grateful for all the faculty and co-residents who have helped to make his time at Iowa so enjoyable. There is not room to name them all, but he is especially grateful to the spine faculty who helped to develop his interest in the field, especially Dr. Weinstein, Dr. Pugely, Dr. Igram and Dr. Olinger. He would also like to thank his amazing and spectacular wife, Jonna. Without her support and devotion, he would not be where he is today. Although she is aware, he wanted to make sure everyone else knew how much she has contributed to his success. He also wants to thank his mother and father for all their love and support.



Jacob Henrichsen, MD

Jake grew up in a smaller community in southern Utah, just outside Zion National Park. Growing up he spent a great deal of time outdoors, riding motorcycles, hunting, fishing, and competitive swimming. He completed his undergraduate studies at the University of Utah, and medical school in Michigan at William Beaumont School of Medicine.

His mother was a nurse growing up, and her experiences opened Jake's mind to a career in medicine. His aspirations were confirmed while working in an emergency department in Salt Lake City. He has dragged his wife Ashley of 13 years and their two kids Nixon (11) and Harlow (8) around the country chasing his dreams. He enjoys spending time outdoors with family, friends, and his dogs.

Research has been a part of Jake's training beginning just prior to medical school. He worked as a research assistant for Intermountain Healthcare, focusing on improving the value of healthcare. He then transitioned his research to the specialties he was most interested in, including otolaryngology, urology, and finally orthopedics. During residency his primary focus has been young adult hip and he worked closely with mentors Dr. Westermann and Dr. Willey.

Throughout residency Jake found that he thoroughly enjoyed several subspecialties and had a very difficult time trying to decide what subspecialty to pursue. Additionally, he and his family are small town people at heart, and ultimately made the decision to pursue a career in general orthopedics. Jake has accepted a job in Southern Arizona where he'll take over a practice in a smaller community. He looks forward to the patients he'll treat and the outdoor adventures he and his family will embark on, not to mention the sunny, warm weather.

Olivia O'Reilly, MD

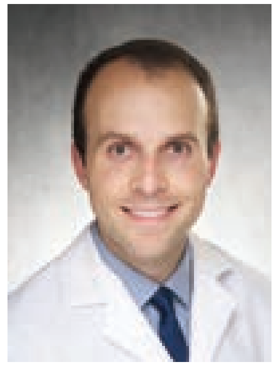
Olivia came to Iowa from a small town in Northwest Ohio, spending her early years in the dugout of a baseball diamond. She attended Sylvania Southview High School, graduating as a scholar athlete. She attended THE Ohio State University, where she walked on to the softball team and earned four varsity letters, a position as the starting pitcher, and eventually an athletic scholarship. She received her undergraduate degree in Biology with Honors distinction, and graduated magna cum laude as an Academic All-American. She was accepted to medical school in her senior softball season, after spending hours studying on the team bus between games.

Olivia attended the University of Toledo College of Medicine and Life Sciences, where she became interested in orthopedics. She was fortunate to find a lifetime mentor in Dr. Patrick Siparsky and published often in the field of sports medicine research. She received the Ruth Jackson-Steindler Orthopedic Clerkship in her fourth year of medical school, which brought her to the University of Iowa Hospitals and Clinics. Spending a month with the trauma team was all it took to confirm that Iowa was the right place for her.

Olivia's interest in orthopedic research flourished in medical school. She worked as research assistant at the University of Pennsylvania Perelman School of Medicine in the McKay Orthopedic Research Laboratory under the direction of Robert L. Mauck, PhD. She started residency on a high note when she was named Featured Author of the American Journal of Sports Medicine as an intern in March 2020. In residency, she explored both basic science and clinical research across multiple subspecialties. She received multiple grants for her work, including the Orthopedic Research Education Foundation Resident Research Grant and the Ruth Jackson Orthopedic Society Jacquelin Perry Resident Research Grant, both for her part in creating a randomized controlled trial exploring telerehabilitation following shoulder arthroplasty.

After residency, Olivia will complete her sports medicine fellowship training at Duke University. She plans to practice academic medicine and work as a team physician, giving back to the athlete population. She is thankful for the research mentors she has gained in her time at Iowa, especially Dr. Maria Bozoghlian, Dr. Brendan Patterson, and Dr. Robert Westermann. She is grateful for her classmates and coresidents, who make the residency journey worth it. Olivia is most grateful for her family, especially her father Mike and her late mother Barb, who inspired her to enter the medical field.

Samuel Swenson, MD



Sam spent his childhood in western Washington state where his plans to pursue a career in orthopedics took shape in his early childhood. By age 5, he enjoyed hearing about orthopedic cases from his father, a general orthopedist, and playing with implants and Sawbones his father brought home. He attended Monroe High School, where his senior year career planning project was on orthopedic surgery. Free time was spent playing golf, snowboarding, and hiking the Cascade Mountain backcountry.

Sam received his undergraduate degree in microbiology at Brigham Young University. Following his freshman year, he spent two years as a missionary in Chicago, where he learned to speak Spanish, a skill he uses frequently to communicate with patients. After graduation, he and his wife were married, and they now have four children. He attended medical school at George Washington University in Washington, DC.

His first exposure to research occurred as an undergraduate student, where he spent time in a basic science microbiology lab studying antimicrobial peptide resistance in Yersinia pseudotuberculosis. In medical school, Sam was involved with testing an augmented reality-based system for pedicle screw placement. During residency, he became interested in spine surgery, with a particularly formative experience in Dr. Weinstein's clinic, learning the indications for bracing in adolescent idiopathic scoliosis. Sam welcomed the opportunity to collaborate with Drs. Weinstein, Holt, and Dolan to develop a study aimed at increasing adherence to brace prescriptions.

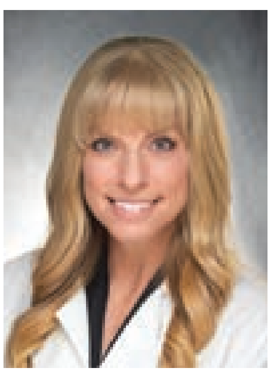
After graduation, Sam plans to obtain further training with a spine fellowship at the Indiana Spine Group. He plans to look for a private practice job in the western US. He is grateful for the support of the team who has been instrumental in bringing the present project to fruition, particularly Dr. Dolan, who has enrolled patients, collected, and analyzed data, and negotiated with the IRB. He would also like to thank those mentors who have inspired and facilitated his pursuit of a career in spine surgery: Drs. Weinstein, Pugely, Igram, Holt, and Olinger. Most importantly, he is grateful for the constant support from his family, and especially his wife.

2024 GRADUATING FELLOWS

Mohamed Abdelaziz Elghazy, MD, MSc, PhD

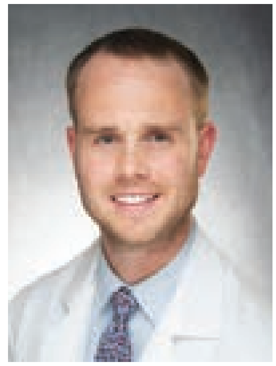
Mohamed is the current foot and ankle fellow. He grew up in Mansoura, Egypt. He earned his medical degree from Faculty of Medicine at Mansoura University. He did his orthopedic residency at the same institution and successfully completed a Master-degree in Orthopedic Surgery. After residency training, he was awarded a grant for Excellence in Scientific Achievement, allowing him to complete his PhD research project at Massachusetts General Hospital-Harvard Medical School. After completing the PhD degree, he worked as a Lecturer of Orthopedic Surgery at Faculty Medicine, Mansoura University, Egypt.

Mohamed came to Iowa for his foot and ankle fellowship with Dr. Femino and Dr. Chrea. He is thankful for the entire Foot and Ankle team for being welcoming and creating an amazing learning experience. After graduation, Mohamed will be going to Hospital of Special Surgery at New York for a Limb Lengthening and Complex Reconstruction fellowship, but he will always remember the Iowa experience as one of a kind, with great resources for training and research. He will always be proud to be part of this amazing family.



Lisa Frantz, MD

Lisa Frantz is the current hand surgery fellow. She received her medical degree from the University of Kansas in Wichita, Kansas and completed Orthopedic Surgery residency at the University of Kansas in Wichita. Prior to attending medical school, Lisa worked as a physician assistant in orthopedic surgery for 9 years. She is married with 2 sons and plans to return to Kansas after fellowship to work in private practice. Lisa is grateful for her training here at the Iowa Hand Fellowship as well as the mentorship and dedication of sharing time and knowledge from Dr. Buckwalter. Being able to perform hand surgery at the Iowa VA with Dr. Buckwalter IV has also enhanced the experience of the fellowship. The rich history and tradition of orthopedic surgery at the University of Iowa makes it a special place to complete training.



J. Adam Driscoll, MD

Adam is the current Adult Hip and Knee Reconstruction Fellow at the University of Iowa. He received his undergraduate degree in Biology at Calvin College in Grand Rapids, MI. He went on to medical school at Michigan State University College of Human Medicine. Following medical school, he relocated to the Detroit suburbs where he completed his orthopedic surgery residency at Beaumont Health, Royal Oak. He is joined by his wife, Chelsea, daughter Eleanor and son Owen. He will return to Michigan at the completion of fellowship to begin practice in academic orthopedic surgery at Bronson Hospital and Western Michigan University in Kalamazoo, MI.

Adam is incredibly grateful for the excellent training he has received at the University of Iowa. He has grown tremendously as a clinician and a surgeon through the thoughtful mentorship of Dr's Elkins, Noiseux, Schwartz, Willey and Westermann. He has found the University of Iowa to be an exceptional place to train, with a rich history and passion for teaching. He is confident this fellowship has set him on a path to a successful career in hip and knee reconstruction.

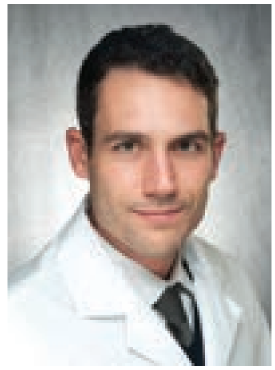
Dheeraj Makkar, MD

Dheeraj is the current Orthopedic Oncology fellow at the University of Iowa. He is from India, hailing from Amritsar, renowned for hosting largest community meals in the world. Following his roots, he completed his orthopedic training at Government Medical College, Amritsar, where he laid the foundation for his career.

Seeking to broaden his expertise, Dheeraj ventured to South Korea to gain exposure in arthroscopy. Upon returning to India, he dedicated himself to practice mainly trauma cases and passed the MRCS and FRCS part 1 exams to enhance his proficiency.

However, a fortuitous encounter with Dr. Miller reshaped his professional trajectory. Expressing his gratitude for Dr. Miller's mentorship and the invaluable opportunity to expand his knowledge in orthopedic oncology under his guidance, he pursued and was privileged to receive a fellowship at the University of Iowa.

Dr. Miller's mentorship has been a transformative force in his professional journey, imbuing him with the knowledge and confidence needed to excel in orthopedic oncology. Dr. Miller's expertise, coupled with his compassionate approach, has deepened his understanding of the field, and instilled in him a profound sense of gratitude for the privilege to learn from such a distinguished surgeon. He is greatly appreciative of Dr. Miller's guidance and remains committed to honoring his legacy by striving for excellence in patient care and furthering the advancements in orthopedic oncology especially pelvis, pediatrics, and spine.



Bruno Butturi Varone, MD

Bruno is the current Orthopedics Sports Medicine Fellow at the University of Iowa.

He completed his medical training, orthopedic residency, and knee surgery fellowship at the University of São Paulo, in Brazil. Now, he is currently finishing his Sports medicine Fellowship at the University of Iowa.

Bruno is truly thankful to Dr. Wolf, Dr. Westermann, Dr. Bollier, and Dr. Duchman for all the mentorship and training that made this year a special lifetime opportunity. Coming from a knee surgery background, he is grateful for extending his arthroscopic expertise to shoulder and hip.

The Hawkeye experience with the Football team coverage was the icing on the cake, with additional experience in the training room and on the sideline.

He would also like to thank the whole Orthopedics department and Iowa City for welcoming him with open arms. The University of Iowa will be forever his pride.

NEW ORTHOPEDIC FACULTY

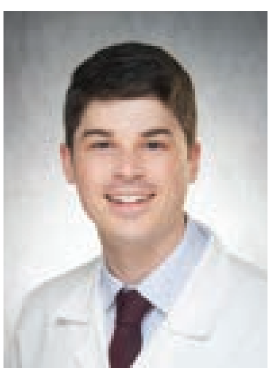
Bopha Chrea, MD

Dr. Bopha Chrea is an Assistant Professor in the Department of Orthopedics and Rehabilitation at the University of Iowa. Prior to joining UI, Dr. Chrea served at Oregon Health and Science University, where she was responsible for foot and ankle trauma coverage.

Dr. Chrea earned her BA from University of Western Ontario, her MD from Trinity College, University of Dublin Ireland, her residency at University of Mississippi Medical Center, the only level one trauma center in Mississippi, and she completed her fellowship at Hospital of Special Surgery in New York. Recently she completed the Health Care Leadership Program with The University of Utah.

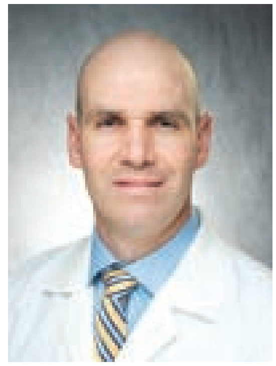
At the University of Iowa, Dr. Chrea is starting a new research program focusing on better understanding prognostic factors that lead to the development of post-traumatic ankle arthritis. As she transitions into her role as Co-Director of the UIOWA Orthopaedic Functional Imaging Research Laboratory, she will be exploring the use of the CurveBeam HiRise weight bearing CT scanner to obtain baseline images that enable us to better characterize problematic injury patterns, as well as the diagnostic dilemma associated with isolated fibula fractures.

Dr. Chrea lives with her husband Thomas and their 2 children, Arlo and Liv in Iowa City, Iowa.



Ryan McLoughlin, MD

Dr. Ryan McLoughlin is a Clinical Assistant Professor in the Department of Orthopedics and Rehabilitation. He works at the university inpatient rehabilitation hospital as a general physiatrist. He grew up in Long Island, NY where he spent most of his time sitting in traffic. He completed his medical education at the State University of New York in Brooklyn and residency in Physical Medicine and Rehabilitation at the University of Pennsylvania. In addition to his primary role at the inpatient rehabilitation center, he has a clinical and research interest in the treatment of testosterone deficiency. In his free time, he enjoys lifting weights and spending time outside.

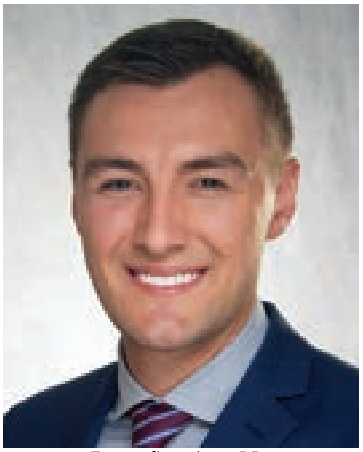


Joseph Galvin, DO, FAAOS

Dr. Joseph Galvin grew up in Redwood City, California. He received his undergraduate degree in Mechanical Engineering from the United States Military Academy at West Point. Following West Point, he served as an Army airborne Ranger infantry officer in the 82nd Airborne Division and deployed for 1 year to Eastern Afghanistan (2005-2006) as a platoon leader where he was awarded the Bronze star. Following his transition from the Infantry to medicine, he completed medical school and then orthopaedic surgery residency at Madigan Army Medical Center in Tacoma, Washington. Following residency, he was stationed at Blanchfield Army Community Hospital, Fort Campbell, Kentucky for 2 years as a general orthopaedic surgeon and deployed to the North Sinai, Egypt. Then he transitioned to the Harvard Shoulder and Elbow Fellowship in Boston and as a part of this spent 3 months in France and Switzerland with international shoulder experts. He then returned to Madigan as a shoulder and elbow surgeon and Associate Residency Program Director for the past 4 years. During this time, he deployed again to Afghanistan on a forward surgical team. He moved to Iowa City with his wife and 4 children. He has a special interest in researching clinically relevant biomarkers to aide in the diagnosis, prognosis and treatment of shoulder and elbow conditions.

The 2024 Michael Bonfiglio Award for Student Research in Orthopaedic Surgery

The 2024 Iowa Orthopaedic Society Medical Student Research Award for Musculoskeletal Research



Peter Sanchez, M4
Michael Bonfiglio Recipient

Sophia Xiao, M2
IOS 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 $500 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.

The Iowa Orthopaedic Society Medical Research 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 $1000 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 Peter Sanchez, M4, receive the 2024 Michael Bonfiglio Student Research Award. Peter's award was based on his project, "Dynamic Changes of the Neuromuscular Junction After Peripheral Nerve Compression and Decompression." His advisor was Dr. Joseph Buckwalter V.

The selection committee recommended that the 2024 Iowa Orthopaedic Society Medical Student Research Award be given to Sophia Xiao, M2, for her research titled "Course of Carpal Tunnel Syndrome Management in Diabetic Patients." Her advisor was Dr. Joseph Buckwalter V.

The Michael Bonfiglio Award and the Iowa Orthopaedic Society Medical Student Research 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

A CROSS-SECTIONAL STUDY OF GENDER-SPECIFIC INFLUENCES OF ORTHOPEDIC SUBSPECIALTY SELECTION

Katelyn T. Koschmeder, BFA[1]; Amelia C. Hurley-Novatny, BS[1,2,3]; Alex A. Marti, BA[1]; Kathryn M. Sharp, BA, BS[1]; Shannon E. Linderman, BS[1]; Alex R. Coffman, BS[4]; Catherine R. Olinger, MD[4]

ABSTRACT

Background: Per the American Academy of Orthopaedic Surgeons, 6.5% of practicing orthopedic surgeons are female and a majority subspecialize in pediatrics, hand, and foot and ankle surgery. The study purpose is to evaluate influences of orthopedic subspecialty selection, specifically factors such as perceived strength, lifestyle, and mentorship influence on subspecialty decisions and to identify if gender plays a role in these perceptions.

Methods: An IRB approved cross-sectional study was conducted via email distribution of a REDCap™ survey to U.S. licensed orthopedic surgeons. Data regarding demographics, professional degree, training and current practice location, and perceptions regarding orthopedic surgery was obtained using Likert rating scales. Data was analyzed using descriptive statistics with two-tailed student's t-tests (α=0.05).

Results: The survey yielded 282 responses (182 females and 100 males). Overall, the distribution of residents (28%), fellows (6%), and attendings (66%) correlates well with the prevalence of each respective physician category in the field of orthopedic surgery. The study demonstrated no difference in subspecialty choice based on mentorship, work-life-balance, career advancement, subspecialty culture, salary potential, family planning, or schedule. However, a statistically significant difference exists regarding stereotypes, perceived strength required, and perception of discrimination from pursuing a specific orthopedic subspecialty. 27% of females and 10% of males reported discouragement from any subspecialty ($p<0.05$). Adult reconstructive and oncology were most frequently discouraged. Women reported not choosing a subspecialty because of perceived physical demands more often than men ($p<0.001$). Women reported an increased use of adaptive strategies in the operating room ($p<0.001$). Women were also more likely to report feeling discouraged from pursuing a subspecialty due to their gender ($p<0.001$). Both men and women reported mentorship as the most influential factor in subspecialty selection.

Conclusion: Women and men reported different factors were important in their decision of subspecialty. Women were more likely to be discouraged from a subspecialty and experience discrimination based on their perceived strength compared to male peers. Residents, fellows, and attending surgeons valued mentorship as the most influential in their subspeciality choice. This study suggests intrinsic and extrinsic influences that may differentially affect male and female orthopedic surgeons when they choose a subspecialty.

Level of Evidence: III

Keywords: subspecialty selection, women in orthopedics, gender, influences, mentorship, subspecialty, physical strength

INTRODUCTION

Despite the increasing percentage of female medical students and residents, orthopedic surgery remains the least gender-diverse specialty.[1-3] The American Academy of Orthopaedic Surgeons cited that only 6.5% of orthopedic surgery members identify as female.[4-6] This is a significantly lower female proportion compared to other surgical subspecialties. To improve gender disparity and diversity within orthopedics, it is essential to identify the etiology of this discrepancy. Previous studies have attempted to evaluate why orthopedic surgery remains a male-dominated field. These studies have shown that students of racial, gender, and cultural minority backgrounds without exposure to orthopedics were more likely to perceive orthopedics as less diverse and

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inclusive than their student counterparts.[7] Following their clerkship exposure, numerous minority medical students perceived orthopedics as being more inclusive compared to their initial pre-exposure assessment.[7] A survey of 628 medical students identified that both male and female students perceived orthopedics as a competitive, male-dominated field with intense work hours.[1] Female respondents in the study rated the requirements for physical strength and the male-dominated status as significantly higher than male respondents. Female respondents perceive orthopedics as highly male-dominated, associating it with a requirement for high physical strength, while male respondents perceive lower strength requirements and less male dominance in the field.[1] Rohde et al., found that women reported not pursuing orthopedics due to perceived poor work-life balance, high physical strength required, and a lack of available mentorship.[8]

Despite these preconceived biases, the prevalence of female orthopedic surgeons has increased since 2016 from 4% to 6.5% and female orthopedic residents increased from 13% to 15%.[2,8] Although this is a positive trend, orthopedics continues to lag behind compared to surgical subspecialities as a whole. The representation of all female surgical residents (orthopedic, neurosurgery, urology, otolaryngology, plastic surgery, and general surgery) is 33%, which is significantly higher than 15% of female orthopedic surgery specific residents.[9] Analyses of orthopedic gender trends estimate a 2% annual compound growth rate in the portion of female orthopedic surgeons.[10] With this estimated annual change rate, it will take over 200 years for orthopedic surgery to reach gender parity when compared to other medical specialties.[10] While there have been improvements to reduce the gender bias in orthopedics, the change is slow, warranting further study of gender disparities in orthopedics and intervention regarding identified factors. This rise in female trainees and attendings brings forward an opportunity to change the paradigm of orthopedic surgery as more female mentors develop, but we believe further understanding will enhance this change rate.

It is well recognized that there is further disparity between different orthopedic subspecialties. Women are underrepresented in subspecialties such as spine and adult reconstruction, whereas they are more represented in orthopedic pediatrics and hand surgery.[3] Fellowship match data from 2010-2014 identified that only 3% of orthopedic spine subspecialists identify as female, while 25% of pediatrics and 14% of foot and ankle subspecialties identify as female.[11] In 2020, Bratescu et al. conducted a survey study inquiring about the most important factors in female orthopedic surgeons' subspecialty choice. The results identified that personal satisfaction and intellectual stimulation were rated as the most highly influential factors.[12] Two additional studies found that females value mentorship and intellectual stimulation more highly than their male counterparts.[13-14] Although this data is an excellent first evaluation of the influences that drive orthopedic subspecialty selection, our study aims to explore the etiology of the gender discrepancies within orthopedic subspecialties further by including resident physicians' responses and inquiring about additional influential factors of lifestyle, perceived physical demand, and discouragement from specific subspecialties.

The purpose of this study was to evaluate influences of orthopedic surgery subspecialty selection in the United States. Stratified by gender, we evaluated multiple factors for their influence on subspecialty selection, including lifestyle, mentorship opportunities, and strength perception have on subspecialty selection. This study aims to identify key factors in subspecialty selection and interrogate perceived strength as a pervasive preconception potentially affecting gender discrepancies.

METHODS

This cross-sectional study was reviewed and approved by the University of Iowa Institutional Review Board. The survey was created using REDCap™ (REDCap version 14.4, REDCap Cloud). Inclusion criteria: a licensed orthopedic surgeon or trainee in the United States. Residents, fellows, and attending physicians were surveyed. Respondents were not required to be currently practicing.

The study aimed to survey all orthopedic surgeons in the United States. There is no formal way to distribute a national survey to all U.S. licensed orthopedic surgeons, so we distributed the survey to residency coordinators at U.S. orthopedic residency training programs to email to all current orthopedic residents and staff at their respective programs. We also distributed the survey through the Ruth Jackson Orthopedic Society listserv. The survey was available for completion from October 1st-31st of 2022. The survey collected demographic information, training and practice background, ratings of various influences on subspecialty choice, experiences of bias related to strength perceptions, and ratings of perceived level of physical demand per subspecialty (Supplemental Digital Content 1). The ratings of influences were on a Likert scale of 1 (very unimportant) to 5 (extremely important). The ratings of physical strength required for each subspecialty were on a scale of 1 (not at all physically demanding) to 10 (extremely physically demanding).

Statistics were performed using Microsoft Excel™

(Excel 2019, Microsoft Company). Data was separated into male and female-identifying respondents. A single non-binary respondent was surveyed. We regret excluding this data point from gender-specific analysis due to limited respondents in this gender group; however, the respondent was included for whole-population analysis. We acknowledge that there are other gender identities beyond binary genders, but for the sake of comparison to previous published studies, we decided to separate the cohort using binary genders as determined by the respondents. For questions requiring an answer from a range (e.g., 1-5), a Student's t-test was performed between male and female respondents with an α level of 0.05. For questions requiring a binary answer, a chi-squared analysis was performed with an α level of 0.05.

RESULTS

Demographics

A total of 282 responses were obtained (34% response rate); 181 female-identifying, 100 male-identifying, and one non-binary identifying physician completed the survey. The demographics of respondents are listed in Table 1 with a Caucasian predominance. The median age of respondents was 38 years with a non-normal distribution (25-89 years old) (Table 2). 28% respondents were residents, 6% fellows, and 66% attendings or staff physicians (Table 2). Location of medical training, residency training, and current practice was spread across the US, with California, Iowa, Tennessee, Minnesota, and New York being most highly represented. The three most highly represented subspecialties were pediatrics, sports medicine, and hand surgery (Table 3). The least represented subspecialties were spine, shoulder/elbow, and generalists.

Table 1. Racial Demographics of Survey Respondents

Demographic	Women	Men	P value
White, non-Hispanic origin	139 (77%)	94 (94%)	0.0002
White, Hispanic origin	13 (7%)	2 (2%)	0.06
Indigenous/Native American	1 (0.5%)	1 (1%)	0.7
Black	8 (4%)	2 (2%)	0.3
Asian	16 (9%)	2 (2%)	0.02
Other	4 (2%)	1 (1%)	0.5

Self-reported race on the basis of gender for all self-identified women (n=181) and men (n=100) survey participants.

Table 2. Training Level Demographics of Survey Respondents

Demographic	Women (n=181)	Men (n=100)	P value
Training Level			0.2
Resident	42 (24%)	34 (34%)	
Fellow	12 (7%)	5 (5%)	
Attending/Staff	126 (69%)	62 (62%)	
Average age (range) *	40 (25-85)	43 (26-89)	0.04

Level of orthopedic surgery training and age of all survey participants on the basis of gender.

Factors affecting subspecialty decision

To evaluate the importance of various contributing factors to subspecialty selection, respondents were asked to rate 11 factors on a Likert scale of 1 (completely unimportant) to 5 (extremely important) on how that factor affected their subspecialty selection. Figure 1 reports the average rating for each factor stratified by gender. The most remarkable difference between male and female respondents was the importance of perceived discrimination based on gender and having faculty and trainees of the same gender within that subspecialty. On average, women rated discrimination based on gender significantly higher than men ($p < 0.0001$). Similarly, women rated choosing a subspecialty with faculty and trainees of the same gender as significantly higher than men ($p < 0.0001$). Other factors that females rated more important than their male counterparts were choosing a subspecialty with faculty and trainees of a similar cultural background ($p<0.01$), strength required or physical demands of the subspecialty ($p<0.01$), and

Table 3. Subspecialty Demographics of Survey Respondents

Subspecialty	Women (n=181)	Men (n=100)
Undecided	19 (10%)	11 (11%)
Foot/ankle	12 (7%)	6 (6%)
General	2 (1%)	3 (3%)
Hand	29 (16%)	12 (12%)
Adult reconstructive	15 (8%)	12 (12%)
Oncology	11 (6%)	7 (7%)
Pediatrics	41 (23%)	14 (14%)
Shoulder/elbow	4 (2%)	5 (5%)
Spine	4 (2%)	9 (9%)
Sports Medicine	22 (12%)	15 (15%)
Trauma	15 (8 %)	4 (4%)
Other	7 (4%)	2 (2%)

Breakdown of declared orthopedic subspecialties for all survey participants on the basis of gender. "Other" refers to any practice not classified by the commonly noted subspecialty types.

the culture or typical personalities of the subspecialty ($p<0.01$). Notably, the factors with meaningful differences in importance between men and women included the overall four lowest rated influences.

Exposure to subspecialty during residency, available mentorship, available career development, salary potential, work-life balance, typical schedule, and family planning did not differ between genders. The three most highly influential factors overall were exposure to subspecialty, available mentorship, and subspecialty cultures and personalities. Two main themes were apparent in subspecialty selection: available training or mentorship during residency and personal preferences of subspecialty culture. Altogether, this data suggests that some factors affecting subspecialty selection differ between men and women, these factors were not reported to be highly influential.

To further explore the role of mentorship in subspecialty selection, we asked respondents if they had been discouraged or encouraged to pursue any subspecialty, and if so, which one(s). Women were significantly more likely to report being encouraged to pursue a given subspecialty compared to their male counterparts, with 38% of women and 23% of men reporting that they had received encouragement (Figure 2A). The most common subspecialties women were encouraged to pursue were hand (18%, $p<0.001$), pediatrics (18%, $p<0.001$), and spine (6%, $p<0.01$). All other subspecialties had no significant difference. When asked about being discouraged from pursuing a given subspecialty, 27% of women and 10% of men reported receiving this advice ($p<0.01$) (Figure 2B). Women were significantly more likely than men to be discouraged from pursuing adult reconstructive (12% versus 0%, $p<0.01$) and oncology (4% versus 0%, $p<0.01$).

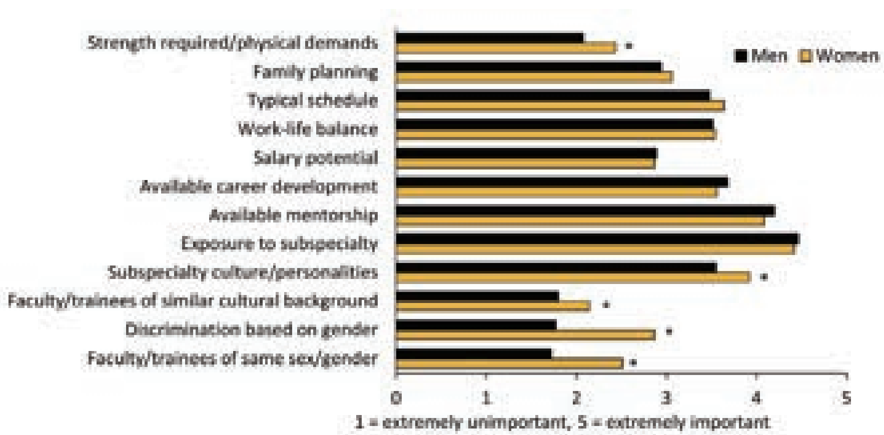


Figure 1. Personal values affecting subspecialty selection. Survey respondents were asked to rate the importance of 11 factors influencing subspecialty selection on a scale from 1 to 5.

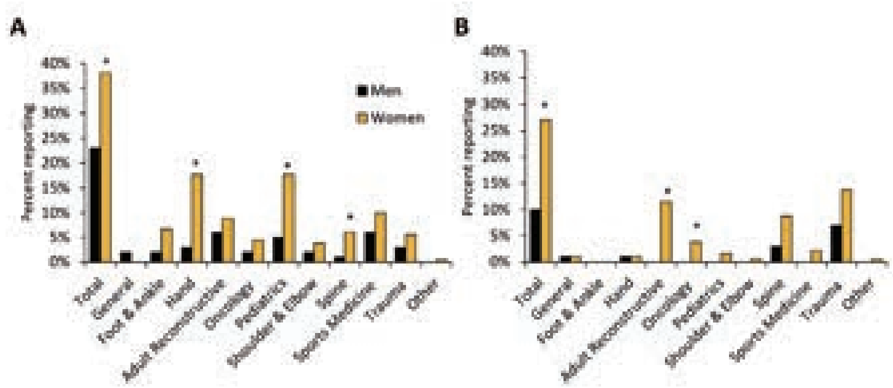


Figure 2A to 2B. Rates of encouragement (2A) and discouragement (2B) from pursuing a given subspecialty experienced by men and women during their training. Survey respondents were asked if they had ever been encouraged or discouraged from pursuing a given subspecialty, and if so, which subspecialties(s).

Strength perceptions within orthopedics

It is a common misconception that physical strength is an essential attribute of an orthopedic surgeon, and thus it has been hypothesized that this is a deterrent to women entering orthopedics. We sought to understand the validity of this hypothesis, as well as evaluate the role of physical perception of strength with subspecialty selection. When asked how frequently respondents were unable to accomplish a task in the operating room (OR) due to physical inability, women most commonly reported “seldom” whereas men most commonly reported “never” (Figure 3A). When asked if they used adaptive techniques in the OR, women were significantly more likely than men to use adaptive techniques overall (171% versus 60%, respectively, p<0.001) (Figure 3B). Additionally, women reported using adaptive techniques for positioning patients, gripping tools, and reaching the OR table more often than their male counterparts (p<0.0001 for all). 78% of women reported experiences in which colleagues assumed they were physically incapable of performing a skill, compared to only 13% of men (p < 0.001) (Figure 3C). Additionally, women received this discrimination from colleagues at all levels of training. The discrimination came from other support staff including attending physicians, fellows, senior residents, junior residents, allied health professionals, and administrators. Discrimination from advisors was notably low and did not reach a statistically significant difference between men and women.

Finally, we sought to understand how these experiences affected subspecialty selection. Women more strongly agreed that the level of influence anticipated physical demands played a role in subspecialty selection than men (p<0.001) (Figure 3D). To further understand the interplay between anticipated physical demands and subspecialty selection, respondents were asked to rate the different subspecialties in terms of how physically demanding they are (Figure 4). There were

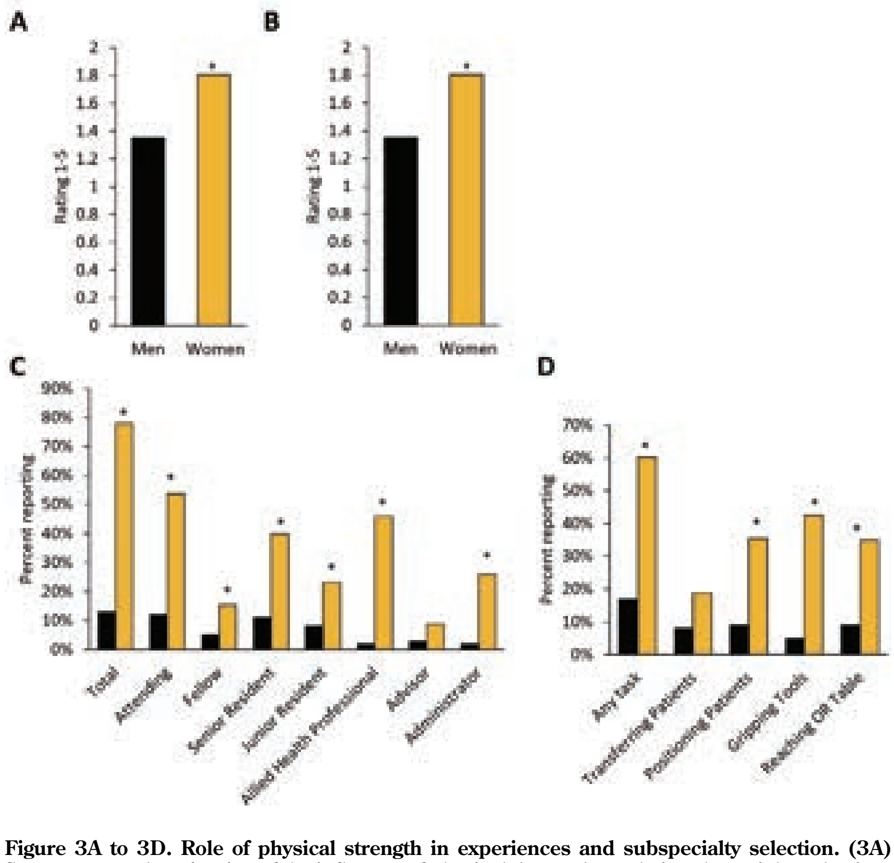


Figure 3A to 3D. Role of physical strength in experiences and subspecialty selection. (3A) Survey respondents’ rating of the influence of physical demands on their subspecialty selection. (3B) Reported frequency of inability to accomplish tasks based on physical limitations. (3C) Percentage of survey respondents reporting a colleague assuming they would be physically unable to complete a task in the OR. (3D) Percentage of respondents reporting using assistive techniques in the OR.

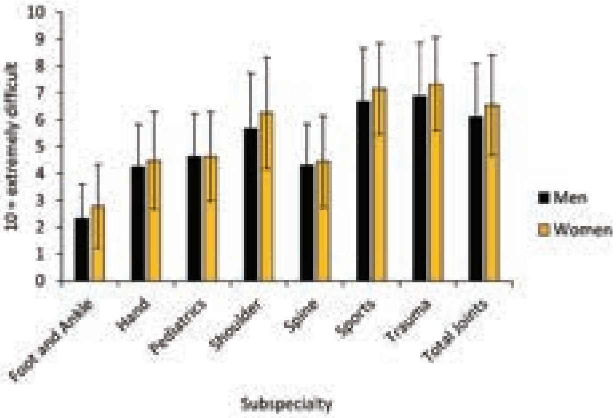


Figure 4. Ratings of physical demand for each subspecialty. Rated from 1 (Not at all physically demanding) to 10 (extremely physically demanding).

significant differences in the male and female ratings for hand, spine, trauma, and total joint, but these absolute differences were small. We further wanted to understand if there was a correlation between average difficulty rating and percentage of women within that subspecialty. Linear regression models of both female representation within our study and data reported by Chambers et al. found a negative correlation between difficulty rating and percentage of women (Figure 1), but neither model was statistically significant.[3] Overall, these results indicate that strength perception is a pervasive belief affecting subspecialty selection.

DISCUSSION

Influences on Subspecialty Selection

Regardless of gender, respondents rated exposure to the subspecialty, available mentorship, work-life balance, and career development opportunities as the most highly influential factors on their subspecialty choice. When reviewing ratings of influences by gender, women were significantly more likely to rate perceived strength required, subspecialty culture, discrimination based on gender, and presence of faculty/trainees of the same sex or gender as having greater influence on their subspecialty selection than men. These results support previous studies suggesting similar factors influence orthopedic subspecialty choice.[1,8,12-14]

Female patient preference for a physician of the same sex as them is another driving force for increasing the female presence within orthopedics. According to the study by Dineen et al., the study orthopedic surgery patients commonly reported not having a preference of provider gender; if a preference was documented, it was most often a female patient requesting a female provider.[15] Another study of emergency room visits identified that most patients in the study preferred a same-sex physician in routine visits or sensitive visits.[16] This information provides important background regarding why increasing diversity within orthopedic subspecialities may enhance patient comfort and satisfaction. Overall, this study identified that gender appears to play a role in orthopedic surgery subspecialty selection, and study results suggest interventions are warranted to reduce this bias.

Mentorship

In this study, women were significantly more likely to be encouraged to pursue specific subspecialities by others than men. These subspecialities included hand and pediatric surgery. Women were significantly more likely to be discouraged from pursuing a subspecialty, most commonly adult reconstruction, and oncology. These influences may reflect levels of available mentorship or bias from mentors, both positive and negative.

Overall, mentorship appears to influence any person's selection of subspecialty.[17-18] It is known that fewer female orthopedic surgery mentors exists than male mentors.[19] Of note, it takes a first year medical student 9+ years to become a practicing orthopedic surgeon.[4-5] This timeline predicts that current mentorship data reflects changes made ten years ago rather than current day modifications. The rate of female orthopedic surgeons continues to increase each year, along with rising rates of females holding leadership roles.[20] Recent surveillance of academic orthopedic programs showed that females comprise 3% of chair positions, 8% of vice chairs, 11% of program directors, and 27% of assistant program directors.[21] This steady increase in percentage of female leaders in junior positions is promising for the rise of future senior leaders that can bridge the gap in female mentorship that orthopedics currently lacks. Mentorship appears to have a large influence on subspecialty selection amongst all orthopedic residents. Increasing available female mentors could potentially be among the most impactful first steps in reducing the gender disparities amongst orthopedic subspecialties. This idea is supported by existing data demonstrating that geographic areas with more existing female orthopedic surgeons tend to recruit more female orthopedic surgery trainees, with an overall potentiating effect on growth of gender parity within the field.[6]

Physical Abilities

It has been well-established that perceptions of physical strength influence female medical students'[1] decisions to apply into orthopedic residency, but it was unclear if physical strength influences female orthopedic surgeons' decisions of subspecialty.[1,12-14] This study found that perceived physical strength required had a more significant influence on women's subspecialty selection than men's. Women reported a higher rate of adaptive technique use in the operating room to aid in task completion. Women were remarkably more likely to experience assumptions on their physical ability by all members of the healthcare team than men.

Regarding physical capabilities, previous studies have found that male surgeons often have a greater hand grip strength, while female surgeons have greater hand dexterity.[22] Although females are more likely to require use of adaptive techniques to complete tasks, differences in physical characteristics based on gender have not been tied to differences in surgical outcomes.[22] Additionally, reviews of orthopedic resident performance demonstrated no difference between male and female resident performance.[23] A recent JAMA study by Satkunasivam et al., reported that female surgeons performing common elective surgical procedures have better postoperative outcomes than male surgeons.[24] This is not an orthopedic specific study, but it demonstrates that beyond the goal of increasing diversity within orthopedics, there is more to learn about gender-related outcomes within surgical fields such as orthopedics. Additional studies could aim to specifically identify if assumptions about physical ability made by other members of the healthcare team play a significant role in the perception of required strength.

Significance

It is known that orthopedic surgery is the least gender diverse medical subspecialty. In addition, it is also already a high-demand specialty with an expected continued increase in demand in the near future.[25-26] A recent study reported that over half of counties in the United States did not have a practicing orthopedic surgeon.[26] As the average lifespan continues to rise,[27] the demand for orthopedic surgical services will more than likely grow as well. This anticipated expanding demand necessitates increased recruitment of female surgeons not only to meet physical need, but also to improve patient care and outcomes. Attracting the most qualified and talented candidates is central to the success of any medical department. With that idea in mind, every effort must be made to identify and eliminate factors which may deter qualified candidates from pursuing a career in orthopedic surgery.

In order to shift the paradigm, we need to understand better what barriers and biases exist. We identified that female orthopedic surgeons value mentorship from the same sex/gender, and view subspecialty culture and perceived strength required as highly influential in their subspecialty choice. Current data shows that more females are entering orthopedics each year, and there is a slowly increasing rate of females in leadership positions. Increased available mentorship may influence more female orthopedic surgeons to pursue previously underrepresented subspecialties.

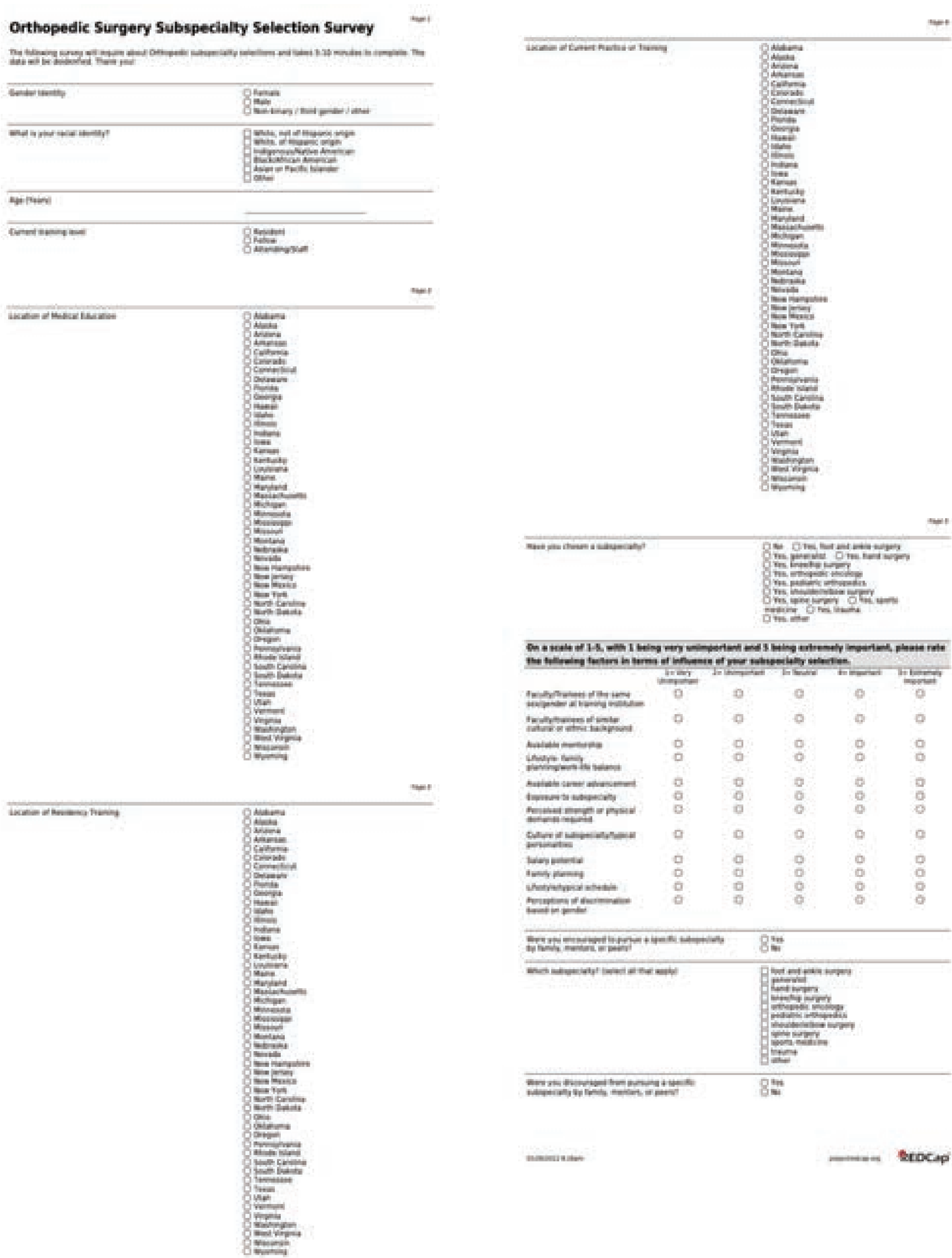
Limitations

The limitations of our study include limited generalizability to private orthopedic practices because our study population is predominantly in academic medicine due to our method of survey distribution. The data was collected via email survey and therefore response bias may exist. Female respondents are overrepresented in comparison to the current prevalence of female orthopedic surgeons due to the distribution to the Ruth Jackson Orthopedic Society. The response rate for the survey was low (<50%), which is a limitation. The methods of the study are limited to the gender binary, which excludes a population of individuals which is likely small but not unimportant, and likely has their own set of unique barriers/biases.

CONCLUSION

Identifying factors which may deter qualified candidates from pursuing a career in the field of orthopedic surgery is imperative for providing the highest quality of patient care and for the advancement of the field as a whole. Given the known disparity between the percentage of female trainees within medicine as a whole compared to orthopedic surgery, it is clear that barriers exist on the basis of gender. This study identified that women were significantly more likely to rate discrimination based on gender, perceived strength required, subspecialty culture, and presence of faculty/trainees of the same sex or gender as having greater influence on their orthopedic subspecialty selection than men. Both men and women ranked exposure to subspecialty, available mentorship, and subspecialty cultures and personalities as the most influential factors. Women were significantly more likely to be encouraged to go into certain subspecialties (pediatrics, hand, spine) and discouraged from going into other subspecialities (adult reconstructive and oncology) than men.

Future studies are needed to identify the subspecialties in which orthopedics mentors themselves were trained, and subsequently, the subspecialties those mentors recommended or discouraged to residents. This will help discern if a confounding factor exists. Subsequent studies aim to identify if others' assumptions about the resident's or attending's physical ability play a role in the perception of required strength. Lastly, future studies should continue to track gender trends in residency and subspecialty decisions to enhance the longitudinal data.


Orthopedic Surgery Subspecialty Selection Survey

The following survey will inquire about Orthopedic subspecialty selections and takes 5-10 minutes to complete. The data will be deidentified. Thank you!

Gender Identity
- Female
- Male
- Non-binary / third gender / other

What is your racial identity?
- White, not of Hispanic origin
- White, of Hispanic origin
- Indigenous/Native American
- Black/African American
- Asian or Pacific Islander
- Other

Age (Years)

Current training level
- Resident
- Fellow
- Attending/Staff

Location of Medical Education
- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

Location of Residency Training
- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

Location of Current Practice or Training
- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
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- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming

Have you chosen a subspecialty?
- No
- Yes, foot and ankle surgery
- Yes, generalist
- Yes, hand surgery
- Yes, knee/hip surgery
- Yes, orthopedic oncology
- Yes, pediatric orthopedics
- Yes, shoulder/elbow surgery
- Yes, spine surgery
- Yes, sports medicine
- Yes, trauma
- Yes, other

On a scale of 1-5, with 1 being very unimportant and 5 being extremely important, please rate the following factors in terms of influence of your subspecialty selection.

	1= Very Unimportant	2= Unimportant	3= Neutral	4= Important	5= Extremely Important
Faculty/Trainees of the same sex/gender at training institution	O	O	O	O	O
Faculty/trainees of similar cultural or ethnic background	O	O	O	O	O
Available mentorship	O	O	O	O	O
Lifestyle: family planning/work-life balance	O	O	O	O	O
Available career advancement	O	O	O	O	O
Exposure to subspecialty	O	O	O	O	O
Perceived strength or physical demands required	O	O	O	O	O
Culture of subspecialty/typical personalities	O	O	O	O	O
Salary potential	O	O	O	O	O
Family planning	O	O	O	O	O
Lifestyle/typical schedule	O	O	O	O	O
Perceptions of discrimination based on gender	O	O	O	O	O

Were you encouraged to pursue a specific subspecialty by family, mentors, or peers?
- Yes
- No

Which subspecialty? (select all that apply)
- foot and ankle surgery
- generalist
- hand surgery
- knee/hip surgery
- orthopedic oncology
- pediatric orthopedics
- shoulder/elbow surgery
- spine surgery
- sports medicine
- trauma
- other

Were you discouraged from pursuing a specific subspecialty by family, mentors, or peers?
- Yes
- No

REDCap

If yes, which subspecialties? (select all that apply)
- foot and ankle surgery
- generalist
- hand surgery
- knee/hip surgery
- orthopaedic oncology
- pediatric orthopaedics
- shoulder/elbow surgery
- spine surgery
- sports medicine
- trauma
- other

Do you feel that you have been discouraged from pursue certain subspecialties based on your gender?
- Yes
- No

If yes, which subspecialties were you discouraged from considering?
- foot and ankle surgery
- generalist
- hand surgery
- knee/hip surgery
- orthopaedic oncology
- pediatric orthopaedics
- shoulder/elbow surgery
- spine surgery
- sports medicine
- trauma
- other

Please answer the following questions regarding perceived physical demands/strength requirements for orthopedic surgery.

How frequently have you not been able to accomplish a necessary task in the OR due a lack of physical strength?
- Never
- Seldom
- Sometimes
- Often
- Always

Have you chosen not to pursue a subspecialty due to anticipated physical demands or strength?
- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

Has you ability or comfort with using certain techniques and instruments affected your subspecialty choice?
- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

Do you use any modifications or adaptations for any of the following tasks? (select all that apply)
- No
- Transferring patients
- Positioning patients during surgery to gain more leverage
- Gripping certain large tools
- Reaching the OR table

REDCap

During your training, did anyone ever made assumptions about your physical ability to perform a certain task? (select all that apply)
- No
- Yes, by an Attending Physician
- Yes by a Fellow
- Yes by a Senior Resident
- Yes by a Junior Resident/Intern
- Yes by an Allied Health Professional
- Yes by an Advisor/Mentor
- Yes by Administrative Staff

Rate the following subspecialties on their requirement for physical strength. (1 being not at all physically demanding, 10 being extremely physically demanding)

	1= not at all physically demanding	2	3	4	5	6	7	8	9	10= extremely physically demanding
Foot/Ankle Surgery	○	○	○	○	○	○	○	○	○	○
Hand Surgery	○	○	○	○	○	○	○	○	○	○
Pediatrics Orthopaedic Surgery	○	○	○	○	○	○	○	○	○	○
Shoulder/Elbow Surgery	○	○	○	○	○	○	○	○	○	○
Spine Surgery	○	○	○	○	○	○	○	○	○	○
Sports Medicine Surgery	○	○	○	○	○	○	○	○	○	○
Orthopedic Trauma Surgery	○	○	○	○	○	○	○	○	○	○
Knee/Hip Surgery	○	○	○	○	○	○	○	○	○	○
Orthopaedic Oncology Surgery	○	○	○	○	○	○	○	○	○	○

Figure 5. Copy of REDCap™ Survey Questionnaire. Questions asked of participants and rating scales.

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IMPROVING APPLICANT SATISFACTION IN ORTHOPAEDIC SURGERY RESIDENCY MATCHING: THE ROLE OF PREFERENCE SIGNALING

Lisa M. Tamburini, MD[1]; Annabelle P. Davey, MD[1]; James C. Messina, MD[1]; Francine Zeng, MD[1]; Lauren E. Geaney, MD[1]

ABSTRACT

Background: The orthopaedic surgery residency match is becoming increasingly more competitive with a disproportionate number of applicants to positions. As the residency application process has become more competitive, applicants have resorted to applying broadly to improve their chance of a successful match. Preference signaling was implemented for orthopaedic surgery for the 2022-2023 match cycle which allowed applicants to "signal" 30 programs of their choosing.

Methods: The purpose of this study was to assess the impact of preference signaling on orthopaedic surgery applicant experiences and outcomes in the 2023 residency application cycle and match. An anonymous electronically based survey study developed using Research Electronic Data Capture (REDCap) was send to 895 applicants to a single orthopedic residency program. 148 applicants filled out some portion of the survey for a 16.5% response rate.

Results: 51% of applicants applied to 61-100 programs. Applicants received more interview offers from programs they signaled compared to programs they did not signal. 50% of applicants responded that the number of allotted signals was "just right", with more applicants responding that the number of signals allotted was "too many" rather than "too few". 62% of applicants agreed that signaling increased his/her chances of receiving an interview offer at a signaled program, 66% were satisfied with the results of the match, and 50% thought signaling had a positive impact on the application process.

Conclusion: Overall, preference signaling was well received by applicants and may help to connect applicants with residency programs they are specifically interested in.

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Level of Evidence: III

Keywords: the match, residency, preference signaling

INTRODUCTION

Orthopaedic surgery is one of the most competitive surgical specialties with high standards for residency applicants and one of the lowest match rates among all specialties.[1] The disparity between the number of applicants and first year residency positions has increased over the years, with 1,425 applicants for 899 spots in 2023.[1,2] As the residency application process has become more competitive, applicants have resorted to applying broadly to improve their chance of a successful match.[1,4] Recent changes in the application process, including the switch to nonnumerical scoring of United State Medical Licensing Examination (USMLE) Step 1 and the widespread adoption of virtual interviews during the COVID-19 pandemic have caused the match process to become even more uncertain. As a result, applicants are applying to a greater number of programs to increase their chances of matching.[4,5] In recent years, the majority of orthopaedic surgery residency applicants applied to over 80 programs.[1] With increasing choices, it is possible applicants and programs could suffer from choice overload, thereby potentially decreasing satisfaction with their ultimate choice. The Jam study popularized the idea of choice overload after investigating how increasing the number of choices affected a customer's decision to make a jam purchase.[6] Since this study, the idea of choice overload has been investigated further with a recent metanalysis finding greater choice options produced more choice deferral, switching, as well as greater post-decisional dissatisfaction, regret, and uncertainty.[7]

As a result of the increasing numbers of applicants, orthopaedic surgery residency program directors are also faced with the task of sorting through a greater number of applications to determine which applicants should receive an interview. The increasing number of applications per applicant make it difficult to ascertain an applicant's genuine interest in a program. Preference signaling has already been adopted by other specialties including otolaryngology, urology, and dermatology, which affords applicants the opportunity to express specific interest in a program with the hopes of increasing the chance of receiving an interview at a signaled program as well as artificially limiting an applicant's choices.[8-11] Preference signaling may also benefit residency programs by revealing which applicants have a genuine interest in training at their program.[9]

The American Orthopaedic Association introduced preference signaling for the first time for the 2022-2023 orthopedic residency application cycle.[12] Applicants were allocated 30 signals to distribute to programs of their choosing. In a survey of orthopaedic surgery residency program directors prior to the 2023 Match cycle, signaling was expected to become one of the most important factors in evaluation of applicants.[13] Given the novelty of preference signaling, the aim of the present study is to assess the impact of preference signaling on orthopaedic surgery applicant experiences and outcomes in the 2023 residency application cycle and match.

METHODS

After obtaining Institutional Review Board (IRB) approval, e-mail addresses of all applicants to the orthopaedic surgery residency program at the investigating institution for the 2022-2023 application cycle were obtained from the Electronic Residency Application Service (ERAS). All applicants who completed the survey participated in the 2023 Match and orthopaedic surgery residency preference signaling. An anonymous survey was created in accordance with National Resident Matching Program (NRMP) guidelines. Information captured in the survey is outlined in Figure 1, which includes the survey that was sent to applicants in its entirety. Match results were released on March 17, 2023. Applicants were subsequently emailed with the invitation to complete the survey on March 20, 2023. A reminder email was sent after 2 weeks. The survey remained open for a total of 4 weeks, after which no further responses were collected.

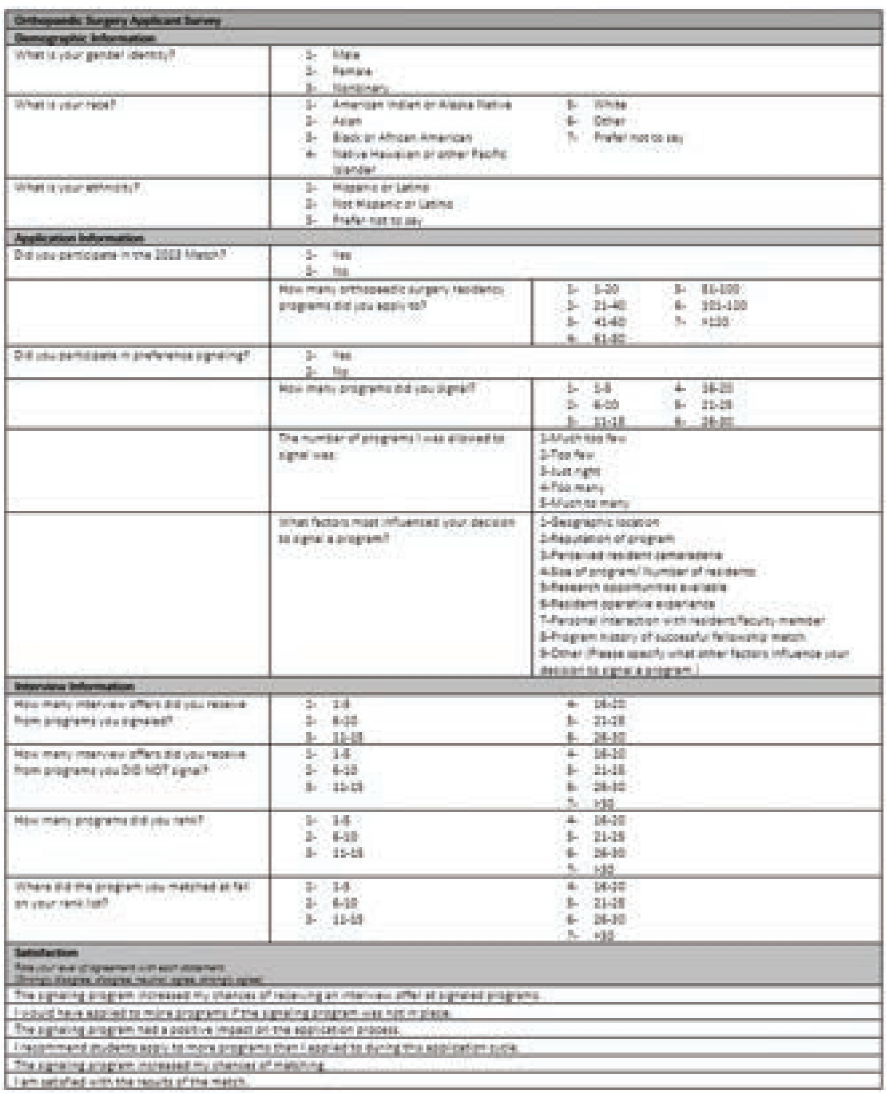

Figure 1. Copy of anonymous survey administered to medical students.

Study data was collected using Research Electronic Data Capture (REDCap) (version 13.1.27; Vanderbilt University, Nashville, TN, USA)[14] hosted at the investigating institution. All software is hosted locally and was approved by the local IRB and information security. This study was also approved by the local IRB (IRB# 23X-163-1). Descriptive statistics including proportions were calculated and are presented.

RESULTS

The survey was sent to 895 applicants. 148 applicants filled out some portion of the survey for a 16.5% response rate. Surveys that were partially completed were included in the results. Data presented is based on the number of responses to each question.

78% of survey respondents were male. 73%, 14%, 8% of survey respondents were white, Asian, and Black or African American, respectively. 7% of respondents were Hispanic or Latino.

A majority of applicants applied to between 61 and 100 programs, with 26 (18%) applying to 1-60 programs, 74 (51%) applying to 61-100 programs, and 46 (32%) applying to >100 programs. 96% of applicants signaled 26-30 programs with only 4 applicants signaling 1-5 programs. Fifty percent of applicants (71/142) felt that 30 program signals was "just right". 39% of applicants (55/142) felt the number they were allowed to signal was "too many" or "much too many" when compared to the 11% who thought the number was "too few" or "much too few" (16/142). (Figure 2)

Applicants received more interview offers from programs they signaled compared to programs they did not signal. 37% of applicants received greater than 10 interview offers from programs they signaled while only 5% of applicants received greater than 10 interview offers from programs they did not signal. (Figure 3)

Geographic location, reputation of program, and personal interaction with a resident or faculty member were the most common reasons that students signaled a program with 89%, 66%, and 61% of applicants selecting these options, respectively. Only 21% of applicants felt the research opportunities available influenced their decision to signal a program. Operative experience, perceived resident camaraderie, program history of successful fellowship match, and size of program were selected as influential factors by 58%, 53%, 38%, and 27% of applicants, respectively. Other factors included mentor connections to a program, DO or IMG friendly, and perceived chance to match at a program (Figure 4).

There was much variability in the number of programs applicants ranked with 70, 57, and 9 applicants stating they ranked 1-10, 11-20, and 21-30 programs, respectively. 85% of applicants (94/110) who answered the question matched at one of their top five ranked programs. (Figure 5) 62% of applicants (85/131) thought preference signaling increased their chances of receiving an interview offer at a signaled program. Similar number of applicants agreed (37%, 48/131) and disagreed (43%, 56/131) with the statement "I would have applied to more programs if the signaling program was not in place." Overall, 66% (87/132) of applicants were satisfied with the results of the match and 50% (65/131) thought the signaling program had a positive impact on the application process.

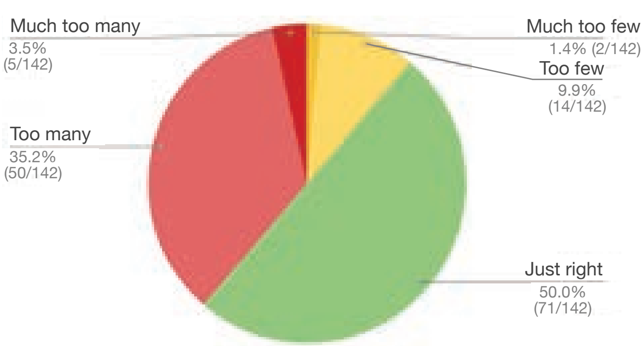

Figure 2. Summary of responses to questions: "The number of programs I was allowed to signal was...".

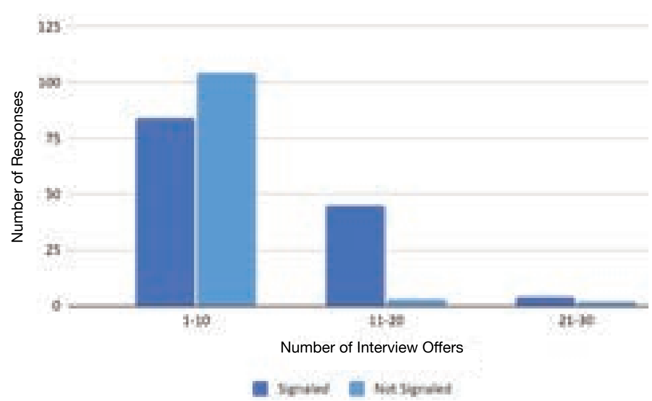

Figure 3. Number of applicants receiving number of interviews from programs they signaled vs. programs not signaled.

What factors most influenced your decision to signal a program?	
Geographic Location	131
Reputation of Program	98
Perceived Resident Camaraderie	78
Size of Program/ Number of Residents	40
Research Opportunities Available	31
Resident Operative Experience	86
Personal Interaction with Resident/ Faculty Member	90
Program History of Successful Fellowship Match	56
Other	14

Figure 4. Number of applicants indicating factors important to signaling a program.

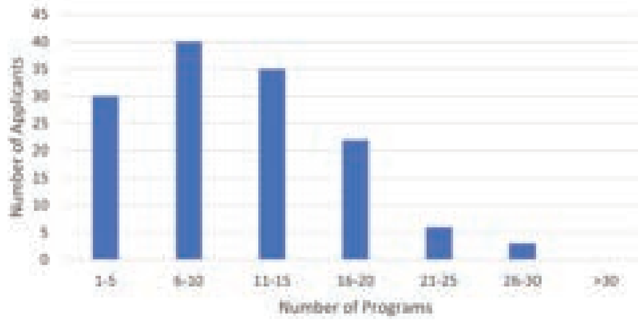

Figure 5. Number of applicants indication number of programs they ranked.

DISCUSSION

As orthopaedic surgery becomes an increasingly more competitive specialty, both applicants and residency programs are faced with challenges when it comes to the match process. In an effort to increase one's chances of matching, applicants are applying to a large number of programs. This in turn causes program directors to have to review more applications from applicants who may not truly desire to train at their program. Preference signaling, implemented for the first time in orthopaedic surgery for the 2022-2023 application cycle, has been proposed as a potential solution to this challenge.[3]

Despite the implementation of the signaling program, we found 51% of applicants surveyed still applied to 61-100 programs. This finding is similar to what has been previously reported.[1] Moreover, 32% of applicants applied to over 100 programs. In its first year, implementation of preference signaling did not appear to decrease the number of applications sent by each applicant.

The number of signals allowed varies by specialty. Orthopaedic surgery allowed applicants to signal 30 programs. We found that almost all applicants used all 30 signals. Urology and general surgery allow 5 signals.[15] Dermatology, radiology, and obstetrics and gynecology allow a different number of gold and silver signals indicating a different level of interest in programs.[15] Both otolaryngology and neurological surgery allow 25 signals.[15] We found that 50% of survey respondents felt the number of signals allowed was just right, with more applicants answering the number was "too many" rather than "too few". Orthopaedic surgery currently allows the highest number of signals and several applicants felt that this number was too high.

The preference of the selection "too many" may be a reflection of choice overload experienced by applicants. Choice overload has been demonstrated to be affected by choice complexity, preference uncertainty, and decision goals, therefore having applicants choose a smaller number of programs to signal may help them identify specific qualities of their ideal program.[16] By first identifying their optimal choice, applicants can more easily sort through options and identify a program that most closely correlates with their goals.[16] Further limiting the number of signals given to applicants may be a place for modification and improvement of preference signaling.

Preference signaling had the anticipated effect of applicants receiving more interviews at programs they signaled compared to programs they did not signal. This is consistent with previously reported results from a survey of program directors which reported preference signaling would be one of the more important factors when evaluating applicants.[13]

Many factors were found to be influential when applicants were deciding which programs to signal. Of these factors, personal interactions with a current resident or faculty member and mentor connections to a program are the only factors that programs would have known about prior to the implementation of preference signaling. Applicants chose to signal programs based on their evaluation of a program's reputation, size, and operative experience. Without preference signaling, program directors would not know that these factors were appealing or not appealing to certain applicants. In this way, preference signaling allows applicants to express specific interest in a program that might not have otherwise known an applicant was interested.

In the first year of its implementation, our survey study showed a positive overall applicant evaluation of preference signaling. Half of survey respondents thought the signaling program had a positive impact on the application process and 62% felt the signaling program increased the applicant's chances of receiving an interview offer at a signaled program. Additionally, a similar number of applicants agreed and disagreed with the statement "I would have applied to more programs if the signaling program was not in place".

This study has many limitations which are inherent to survey studies including response bias. The responders were all individuals who matched in this most recent application cycle. It is possible that unmatched applicants utilized a different number of signals and had different opinions regarding signaling implementation compared to match individuals. We also felt that sending the survey directly to applicants through personal emails would result in a higher response rate as compared to sending through medical school administrative departments. This sampling method does however introduce another level of bias as our audience only included applicants of the investigating institution. Despite its limitations, this survey study begins to discuss the impact preference signaling had on the 2023 orthopaedic surgery residency match.

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A CASE REPORT OF BRODIE'S ABSCESS OF THE CUBOID TREATED BY ANATOMIC ANTIBIOTIC-CEMENT SPACER

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ABSTRACT

Background: A case of chronic osteomyelitis with Brodie's abscess of the cuboid caused by a wooden foreign body penetrating the plantar foot. Total cuboidectomy was carried out with implantation of an anatomically molded antibiotic-impregnated cement spacer with culture-specific post-operative intravenous antibiotics. At six months of follow-up, the patient was completely asymptomatic without evidence of a recurrence of infection. Final radiographs also didn't show spacer migration or surrounding bone erosions. The spacer obviated the need for any foot fusion which preserved foot biomechanics. The patient didn't need to use any braces or insoles.

Conclusion: Osteomyelitis should always be on the differential list of lytic lesions of the tarsal bones, especially if there is a history of prior foot trauma. In this case, cuboid excision and placement of an antibiotic-impregnated cement spacer provided sustained relief of symptoms without evidence of recurrence or complications for six months.

Level of Evidence: V

Keywords: cuboid osteomyelitis, brodie's abscess, total cuboidectomy, cement spacer

INTRODUCTION

The foot is susceptible to penetrating injuries that carry a significant risk of retained foreign bodies, particularly if not adequately addressed.[1,2] The behavior of a retained foreign body may vary depending on several factors, including but not limited to the object's characteristics, level of contamination, location of the object's final seeding location, local blood supply, host immunity, and the quality and timing of treatment.[3,4] The condition has the potential to be in a quiescent state for variable period of time which adds to the variations in the clinical presentation and the complexity of the management.[2,5-7] Broadly, diagnosis requires a high index of suspicion, especially in chronic and sub-acute cases with an unclear or remote history of penetrating injury.[8] The aim of this study was to report the management of a case of cuboid osteomyelitis due to retained foreign body three years after a penetrating foot injury.

CASE REPORT

A 36-year-old male presented to our clinic with the chief complaint of a chronic lateral draining wound over the lateral aspect of his right midfoot for the last three years. He stated he was intoxicated, walking throughout the woods while hunting when he stepped on a sharp tree branch that penetrated his boot into his foot. Subsequently, he was treated with a series of operative debridement with removal of foreign bodies from his foot in an outside facility. After healing of his surgical wounds, he continued to have chronic draining sinuses over the lateral midfoot. He denied any history of recent fever, chills, or redness at the time of his presentation to our clinic. He only noticed episodic flares of pain over the cuboid with increased drainage. He was on oral cephalexin, acetaminophen, or ibuprofen as needed. He had a normal complete blood count (CBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) at time of presentation. Pre-operative radiographs showed a lytic lesion of the cuboid measuring 16.3 x 9.9 mm (Figure 1). The lesion was calculated on MRI to be 14 x 12 x 14 mm. The draining sinus originated from the cuboid. The possibility of bony sequestrum or foreign body in the cavity of the lesion was noted. (Figure 2)

Surgical Procedure

The procedure was performed under general anaethesia. The right lower limb was exsanguinated by elevation for three minutes, then a thigh tourniquet was inflated. A standard lateral approach was carried out starting from the fibular tip to the fourth metatarsal base with care to avoid injury the superficial peroneal nerve and the sural nerve branches. Using bipolar cautery, the incision was carefully deepened. The extensor digitorum brevis (EDB) was reflected from the dorsal

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aspect of the calcaneus bone, and the peroneal tendons were retracted inferiorly. The cavity was 2 mm distal to the cuboid subchondral at the calcaneocuboid joint. Debridement of the cavity with a satisfactory safe margin of at least 5 mm didn't seem to be applicable without compromising the integrity of the subchondral bone at the calcaneo-cuboid joint. The decision was made to remove the cuboid en bloc in order to obtain clear margins. The cuboid was carefully freed from the attached ligaments by sharp dissection. Using a Cushing elevator, the cuboid was mobilized and the peroneus longus was preserved. No purulence was noted around the cuboid in all aspects, and the cuboid looked structurally intact except for the sinus tract. Copious irrigation using low-pressure pulse lavage was done, and the sinus track in the skin was traced and removed. On the back table, the cuboid was transected coronally using a power saw at the top of the cavity. In the cut section, the cuboid walls were sclerotic around a cavity that contained a piece of wood, which was sent for culture. (Figure 3) The cavity bone and associated soft tissue reaction were biopsied and sent for cultures and histopathological evaluation. A package of cobalt cement was mixed with antibiotic powder (vancomycin and tobramycin). The mixture was carefully molded into the shape of the explanted cuboid and sequentially reduced in the cuboid bed for trimming the shape and size of the cement spacer, preserving normal relationships with the surrounding bone and joint surfaces, and maintaining the groove for the peroneus longus tendon on the plantar surface. (Figure 3) The final mold of the cuboid spacer was made when the foot was placed in a slightly everted position to allow for some space to accommodate normal foot pronation during a foot flat stance. The cuboid spacer was then removed to harden outside of the foot and avoid thermal burns during the peak of the exothermic reaction.

After the spacer was implanted it was stable throughout range of motion with no need for any additional fixation. Layered closure was then performed, and a standard below-knee AO splint was applied for three weeks. Histopathological examination confirmed the intra-operative findings: organic foreign body material was surrounded by granulation tissue, while the cuboid showed evidence of chronic osteomyelitis. Cultures returned positive for Ochrobactrum intermedium and Clostridium sphenoides. According to the recommendations of a musculoskeletal infectious disease specialist, metronidazole was prescribed for three weeks postoperatively. The patient was partial weight-bearing until the incision was fully healed then sutures were removed (three weeks postoperatively). Progressive weight bearing was allowed after suture removal. The patient reported significant improvement in pain and complete resolution of the sinus without any evidence of inflammation around the injury area. At six months follow-up, the patient presented with complete resolution of any pain and tenderness in the foot. He was also able to walk without any difficulties, assistive devices, or orthotics. Six-month follow-up conventional weight-bearing radiographs showed an anatomically shaped spacer with stable alignment. Foot alignment was maintained as evidenced by a symmetric lateral column length as well as unchanged forefoot and midfoot alignment. (Figure 4)

Figure 1A to 1C. Pre-operative radiographs: oval lytic lesion in the cuboid surrounded by a relatively thick and dense reactive bony sclerosis.

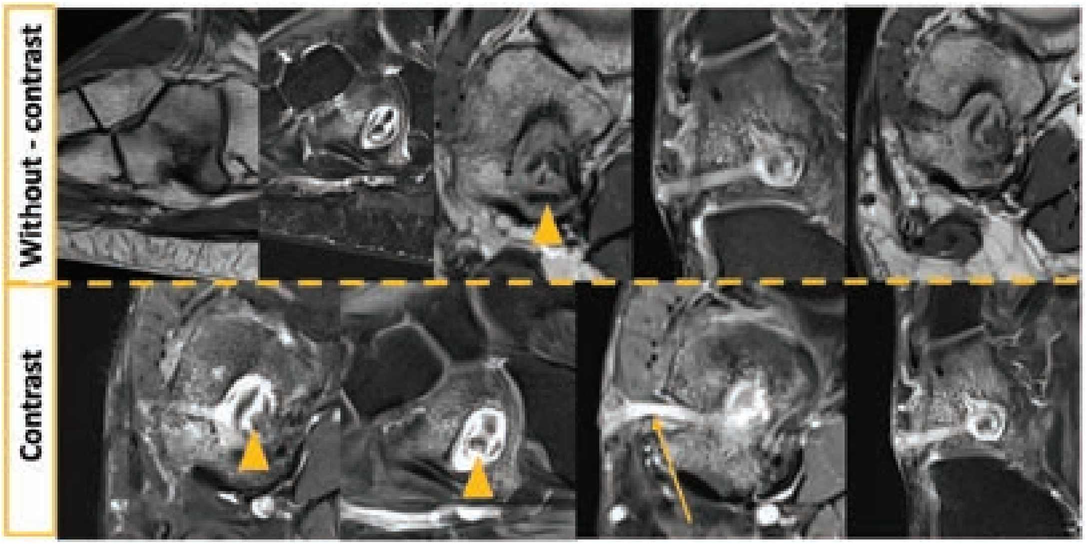

Figure 2. Pre-operative MRI imaging: The upper row shows images without contrast material, the lesion measured around 1.4 x 1.2 x 1.4 cm, it showed hypointense signal on T1 sequence and hyperintense signal on T2 with small central islands of hypodense lesions on both T1 and T2 suggesting sequestrum (arrow heads). The bottom row portrays images after contrast, there was hyperintense T2 signal with post-contrast enhancement except for the central small islands of sequestrum (arrow heads). There was a sinus track lesion extending from the central cavity to the plantar lateral skin (arrow).

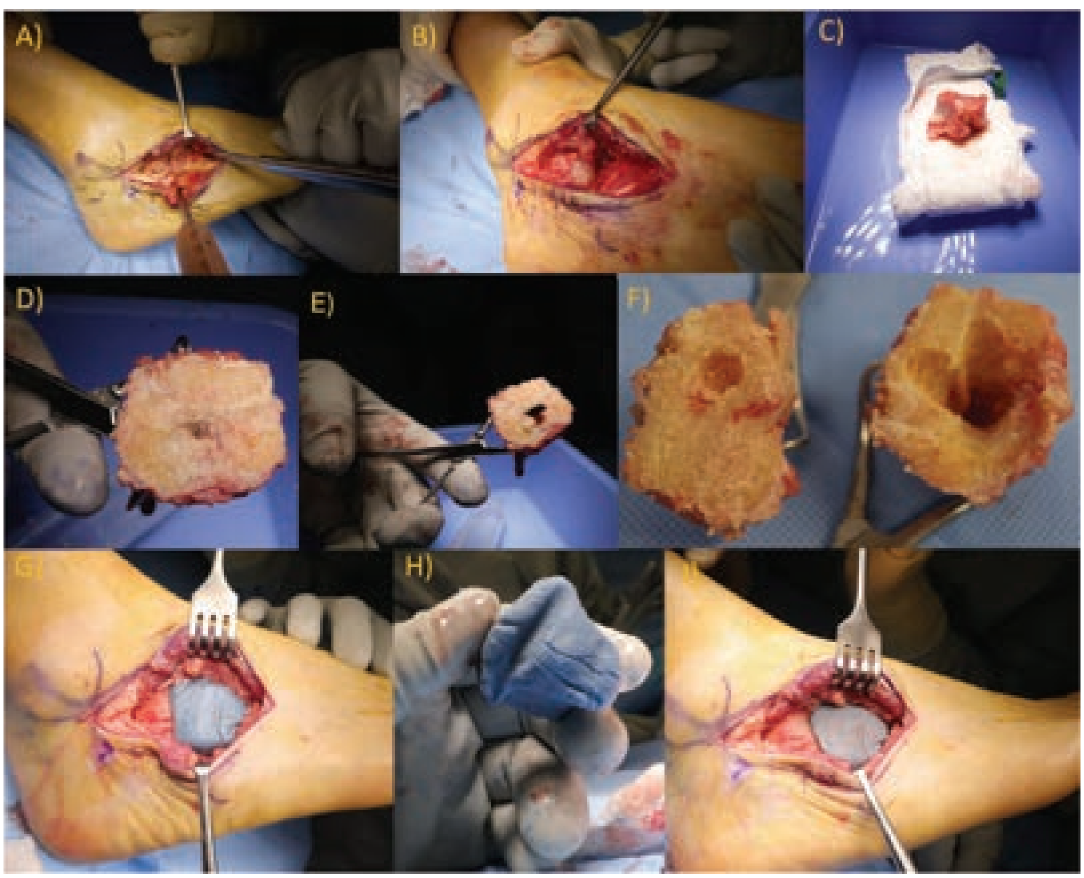

Figure 3A to 3I. (3A) Lateral approach for the hindfoot; the arrow indicates the potential aperture of the cavity. (3B, 3C) Complete en block removal of the cuboid bone. (3D to 3F) Cut-section of the cuboid showing the wooden foreign body and the surrounding sclerosed walls. (3G) Molding of the cuboid cement spacer. (3H) Cuboid cement spacer with molded groove for peroneus longus tendon. (3I) Final implantation of the cuboid spacer.

Figure 4A to 4C. Six-month follow-up weight bearing radiographs: Complete excision of the cuboid with replacement of anatomically contoured and stable cement spacer in place. Proper foot alignment of was noted in both weightbearing antero-posterior and lateral radiographs (4A and 4C, respectively).

DISCUSSION

The current study reports a novel treatment for a rare pathology of cuboid osteomyelitis caused be a foreign body following penetrating foot injury. Complete excision of the cuboid was necessary in this case to achieve full eradication of the infection in a single stage. The antibiotic- impregnated cement spacer managed to maintain foot alignment without evidence of complications such as wound healing problems, loosening, or surrounding bone resorption. There are a few reports on cuboid Brodie's abscess. To the best of our knowledge, there was only one adult case, and a few repots in the pediatric population. Tarsal bone Lytic lesions have a wide spectrum of differential diagnosis such as Brodie's abscess, osteoid osteoma, non-ossifying fibroma, giant cell tumor, eosinophilic granuloma, chondroblastoma, and unicameral bone cyst. Foreign body should be included in the differential especially if there is a history of prior penetrating foot injury.[8]

Bagatur et al. reported a Brodie's abscess in a 28-year-old woman cuboid without a prior history of trauma. The case diagnosis was delayed for approximately three months. All laboratory markers were reported within normal range; however, radiographs showed a radiolucent lesion of the cuboid, while MRI suggested a Brodie's abscess in the cuboid (2 x 1.5 cm). The patient underwent surgical debridement, which revealed a cavity filled with pus and surrounded by sclerotic bone.[9] At six-year follow-up, the authors reported no residual symptoms and normal radiographs.[9]

In the pediatric populations, Agarwal et al. reported a cuboid Brodie's abscess in a ten-year-old boy after a penetrating thorn prick injury.[1] The patient was treated with surgical debridement in addition to broad-spectrum post-operative antibiotics. A cortical window was made in the cuboid, and the cavity contents were evacuated without evidence of a foreign body. Interestingly, the culture returned negative for any microorganisms.[1] The patient was followed up only for six weeks, and he had complete resolution of symptoms at the last visit.[1] Amit et al. reported another case of Brodie's abscess in a 14-year-old child after a penetrating iron nail. The patient presented two months after the incident with pain and swelling over the cuboid. He was afebrile and had normal inflammatory markers except for ESR (36 mm/hour). Radiographs revealed the typical lucent lesion surrounded by cortical sclerosis.[2] The cultures grew Streptococcus pyogens. The patient was treated operatively with surgical debridement and post-operative antibiotics for six weeks. The patient was followed up for nine months without evidence of recurrence.[2]

Anatomic cement spacers are not novel in adult foot and ankle surgical reconstruction.[10,11] They have been used with good results in the treatment of infected ankle replacements or after a significant bone loss.[10,11] However, the spacers are usually employed as a bridging procedure for the definitive treatment. In a retrospective series of nine patients, Ferrao et al. presented the results of cement spacers as a definitive treatment after failed total ankle replacement or fusion.[12] They reported that seven patients (77.78%) retained the spacer for a 20.1 month average (range: 6–62 months).[12] Radiographic evaluation revealed that two patients had loosening and migrations of the spacer; However, interestingly, no erosion, resorption, neighboring bone loss were reported. They suggested this strategy as a valid treatment option for patients who are asymptomatic with good functionality after the spacer implantation or who are too ill to go for another reconstructive surgery.[12]

There are a few long-term reports of cement spacers after total knee or hip replacement.[13,14] Regis et al. reported a satisfactory outcome of a permanent spacer after an infected knee replacement at six year follow-up with sufficient preservation of the bone stock.[13] Durbhakula et al. reported that two patients (who were medically unfit for a second stage reconstruction) were walking with an assistive device and experiencing minimal pain at a five-year follow-up after a spacer endoprosthesis surgery for infected total hip arthroplasty.[14] Scharfenburger et al. presented a series of 16 patients who had retained cement spacers after infected total hip arthroplasty. They reported that all the patients were doing well in terms of function and pain. Ten patients were not medically fit for a second surgery, and six patients refused revision surgery since they were satisfied with the outcome of the spacer.[15]

Our rationale behind this line of surgical treatment plan was to ensure full infection eradication in one stage, in addition to maintaining the integrity of the surrounding joints as well as the lateral column length. In retrospect, we believe this strategy was the best option for the patient given the culture results, which showed an atypical organism (potentially having sub-optimal results with typical antibiotics), chronicity of the condition (approximately three years), chronic osteomyelitis of the cuboid bone on histopathologic examination, and proximity of the cyst to the calcaneocuboid joint. We elected to proceed with a cement spacer mixed with broad-spectrum antibiotics to deliver a high concentration of local antibiotics with minimal systemic side effects.[16,17] Our team reached a shared decision with the patient that the spacer could serve as a definitive management as long as he remained asymptomatic. We discussed clinical complication that could occur such as skin problems, difficulty walking, or local tenderness, or radiographic complications such as migration, spacer loosening, or resorption of the surrounding bone. We discussed if it seemed appropriated to replace the spacer in the future with a three-dimensional (3D) printed total cuboid.[18]

In conclusion, penetrating foot injuries carry a risk of sub-acute presentation of osteomyelitis in tarsal bones. In this case, excision of the cuboid was required to eradicate the infection. Preservation of hindfoot mechanics and mobility was obtained by using an anatomic cement spacer to replace the excised cuboid. This technique and the potential for future 3D printed bone implants can help to avoid motion limiting arthrodesis especially in younger patients like this.

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A CASE REPORT OF ISOLATED CERVICAL LIGAMENT RUPTURE WITH HYPER-PRONATION INJURY: SPECIFIC MRI PROTOCOL AND SURGICAL RECONSTRUCTION

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ABSTRACT

Background: The aim of this case report is to present a case of chronic cervical ligament tear and instability, which occurred by an unusual work injury with an eversion/hyper-pronation mechanism in contrast to the usual mechanism of inversion. The ligament was reconstructed using an allograft with satisfactory results up to 30 months after surgery. A new magnetic resonance imaging protocol (MRI) was developed to better evaluate the cervical ligament/graft.

Conclusion: In diagnosis of foot sprains, a specific ligament injury should always be sought. In this case, physical examination producing tenderness at the location of the cervical ligament and correlating this with an oblique intercolumn stress test that reproduced pain with apprehension and gross instability supported the diagnosis. Retrospectively applying anatomic knowledge to the earlier MRI findings of bone marrow edema at the insertion points of the cervical ligament on the talus and calcaneus was important in confirming the diagnosis. To better evaluate the cervical ligament allograft tendon reconstruction, a novel volumetric MRI sequence was developed which may prove helpful to also diagnose cervical ligament injuries in future cases. Anatomic reconstruction of the cervical ligament provided satisfactory clinical and radiographic results at 30-month follow-up.

Level of Evidence: V

Keywords: cervical ligament, hyper-pronation injury, volumetric MRI, foot sprain

INTRODUCTION

The aim of this case report is to present a case of chronic cervical ligament tear and instability, which occurred by an unusual work injury with an eversion/hyper-pronation mechanism in contrast to the usual mechanism of inversion. This was mis-diagnosed with non-specific diagnoses of "ankle sprain" and "foot sprain" and the patient was referred to our clinic 8 months after injury still requiring a walking cast boot to bear weight. Magnetic resonance imaging (MRI) seven weeks after injury showed bone edema at the footprint of cervical ligament at the calcaneus and talus. The outside radiology reading only indicated contusion of the anterior talus (Figure 1). Pre-operative MRI performed at our institution eight months after injury showed resolution of bone marrow edema as well as discontinuity and disorganization of the cervical ligament fibers (Figure 1).

CASE REPORT

Pre-operative evaluation

A 35-year-old female patient was referred to our clinic for evaluation of persistent left lateral ankle and hindfoot pain 8 months after a work-related injury. The patient described the injury mechanism that occurred as she was carrying a heavy object, and her left foot became trapped by a heavy metal object in the factory. She fell backward and to her (ipsilateral) left side causing hyper-pronation of the left foot. She stated that she felt and heard an immediate pop followed by intense searing pain in the dorsolateral left foot indicating with a finger the same location as her chronic pain upon presentation. The patient has no significant medical history. She smoked one pack of cigarettes per day. On physical examination, there was mild swelling over the lateral hindfoot. She was maximally tender over the anterior talo-calcaneal interval at the location of the cervical ligament. Cervical ligament rupture was suspected based on the location of maximal tenderness and the injury mechanism. An oblique inter-column stress (OICS) test with dorsal-plantar stress between the anterior process of the calcaneus and the talar neck/head was performed. Stress was applied along a line from dorsolateral to plantar medial while grasping the anterior calcaneus and talar head. The stress examination showed positive apprehension and sharply reproduced her stated pain. The overall excursion was approximately 8-10 mm with soft end points. She also had anterolateral soft tissue impingement at the ankle and superficial peroneal nerve tenderness with a positive Tinel's sign at the fascial exit. Both physical examination

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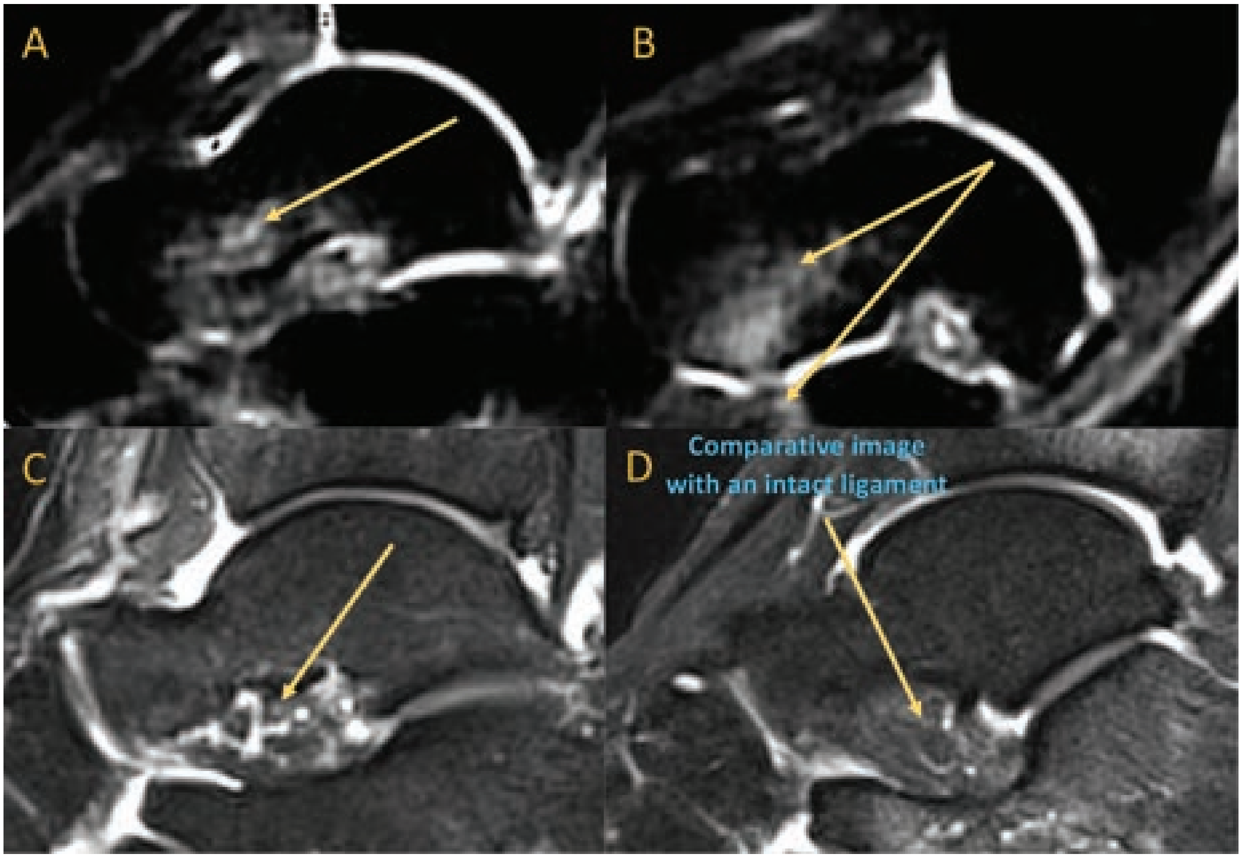

Figure 1A to 1D. (1A and 1B) Injury MRI images: Bone bruises at the cervical ligament footprint at the talus and calcaneus. (7 weeks after injury) (arrows) (1C) Pre-operative MRI: resolution of bone edema with interrupted cervical ligament fibers (8 months after injury). (arrow). (1D) Sagittal MRI of another patient to show intact cervical ligament (arrow).

findings were confirmed by ultrasound (US). This was performed by a fellowship trained Physical Medicine & Rehabilitation specialist with musculoskeletal US training and more than 10 years of experience. In addition, approximately 5 mm of first ray hypermobility was noted, which was thought to be acquired and not related to the injury. Dedicated weight bearing foot radiographs and a weight bearing computed tomography (WBCT) showed no bony avulsions. The WBCT did demonstrate that the middle facet of the subtalar joint was subluxated 40.75% and the foot and ankle offset was 1.73%. These measures have been shown to be associated with early peritalar subluxation.[4,12] The patient was counseled that she should stop smoking prior to the procedure to decrease the risks of poor healing of the reconstruction, wound complications, and infection. She did quit, passing a urine cotinine test preoperatively. She was consented for Cervical ligament reconstruction, Cotton osteotomy, ankle arthroscopy and neurolysis of the superficial peroneal nerve.

Cervical ligament reconstruction technique

Exposure and debridement of cervical ligament remnants

A lateral hindfoot incision was made centered over the anterior process of the calcaneus on a line from the tip of the fibula toward the 4th metatarsal base. Dissection was performed with an oblique approach to the anterior talo-calcaneal interval and the extensor digitorum brevis (EDB) was preserved. The neurovascular bundle to the EDB was protected distally. Plantar dissection provided for release of the inferior peroneal retinaculum, and the peroneal tendons were retracted inferiorly to expose the plantar lateral surface of the anterior process of the calcaneus. Dorsally the inferior extensor retinaculum (lateral and intermediate roots) was released from the calcaneus and retracted dorsally maintaining the EDL within the sheath dorsal to the CL footprint on the talus. The cervical ligament was found to be completely absent of any intact fibers and only loose fibrofatty tissue remaining in the interval (Figure 2). This was removed with a rongeur and the bone footprints on the lateral talar neck (inferior to the EDL sling) and calcaneus medial to the extensor digitorum brevis were debrided to cortex with cautery on low power setting and then debrided to bone.

Graft and tunnel preparation

A medial incision was made longitudinally over the talar neck between the anterior tibial tendon and posterior tibial tendon. This was deepened to the medial talar neck which was exposed between the articular margins of the ankle and talar head. A gracilis allograft was doubled around an ACL tightrope loop (Arthrex, Naples, FL) and the two ends were sutured together with a 0-fiberloop (Arthrex, Naples, FL); the diameter of the composite graft was 6 mm in diameter.

An ACL guide was then used to drill a guide wire from the medial talar neck to the lateral talus centered on the footprint of the cervical ligament and this was then reamed to 6 mm. An ACL guide was then used to place a guide wire from the plantar-lateral calcaneus to the calcaneal footprint of the CL. This was also placed at the lateral margin of the calcaneal footprint to maximize constraint of the calcaneus against external rotation (pronation). A flip cutter (Arthrex, Naples, FL) was then used to back ream 3cm from the calcaneal footprint to preserve the smaller diameter plantar lateral tunnel and cortex for button support of the ACL tightrope. Irrigation was performed.

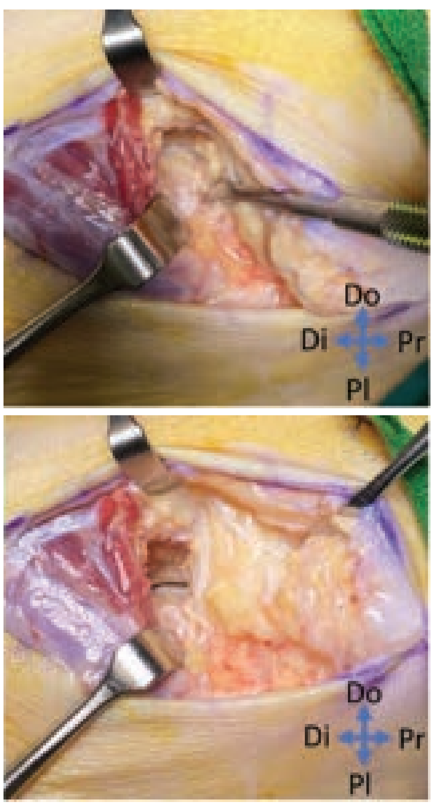

Figure 2. Initial Exposure: absent Cervical ligament with complete exposure of the anterior subtalar facet (top), bare origin on the talus after debridement of fibrofatty tissue; the lateral aspect of the anterior facet of the subtalar joint is visible beneath the cervical ligament footprint (bottom). (Do: Dorsal, Pr: Proximal, Pl: Plantar, Di: Distal).

Graft passage and fixation

The calcaneus was placed in maximal inversion and internal rotation and an intercolumn 2.0 pin was placed fixing the talus and calcaneal in this position. The ACL tightrope (Arthrex, Naples, FL) was then threaded from the talar neck tunnel to the calcaneal tunnel and the button was placed on the plantar lateral calcaneal cortex. (Figure 3) The tightrope was provisionally tightened from the lateral side drawing the graft into the calcaneal tunnel and the graft was then maximally tensioned manually from the medial side. A 6mm polyether-ether-ketone (PEEK) interference screw (Arthrex, Naples, FL) was inserted medially gaining solid fixation. (Figure 4) The tightrope was then tensioned a second time from the lateral side to maximize final tension and the intercolumn transfixion pin was removed (Figure 5).

Associated procedures

The procedure began with an anterior ankle arthroscopy with debridement of antero-lateral impingement, superficial peroneal nerve neurolysis at the fascial exit and a Cotton osteotomy, fixed with a Biosync wedge and 2.4mm dorsal X-plate (Arthrex, Naples, FL) were performed (Figure 6).

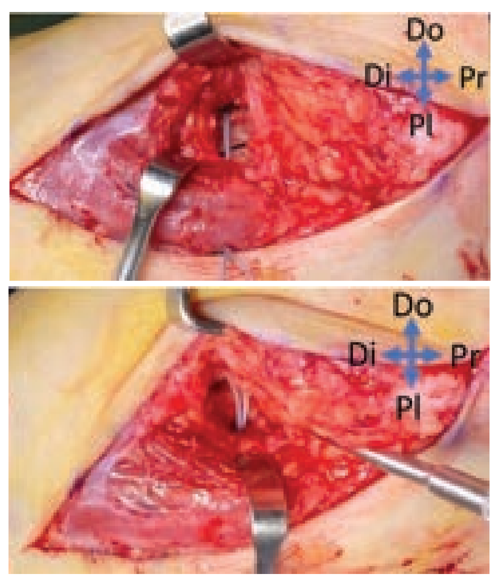

Figure 3. Suture passage through tunnels talar tunnel (top) and calcaneal tunnel (bottom). (Do: Dorsal, Pr: Proximal, Pl: Plantar, Di: Distal).

Figure 4. Fluoroscopic image shows tightrope in place and a temporary pin holding the reduction of the subtalar joint.

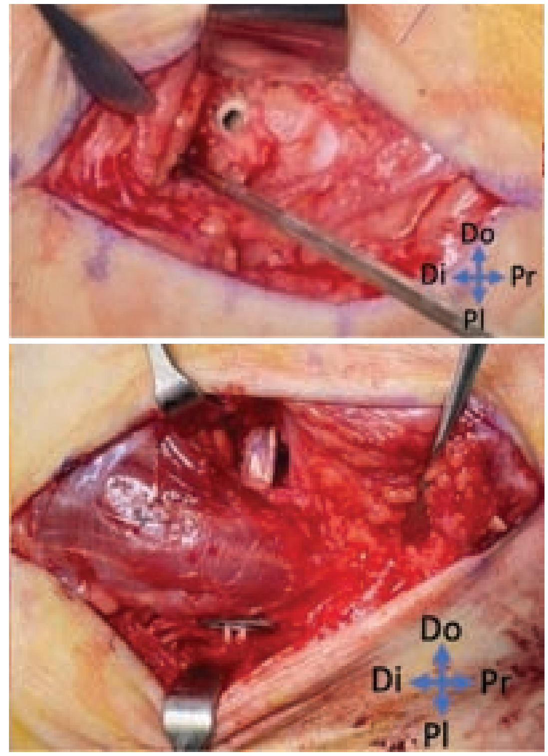

Figure 5. Medial interference screw and reduction pin (top), Lateral view of the graft with Endo button fixation (bottom). (Do: Dorsal, Pr: Proximal, Pl: Plantar, Di: Distal).

Post-operative Course

The patient was kept non-weight bearing in a cast boot for 6 weeks. Active submaximal plantarflexion and dorsiflexion was started at three weeks. No inversion or eversion was allowed prior to 6 weeks. She then started a weekly progression of weight bearing in the boot over the following 4 weeks and was started in physical therapy (PT). Throughout the first year of follow-up, the patient continued to slowly progress in physical therapy but progression in work conditioning was limited due to pain at the dorsal Cotton osteotomy plate and the plantar lateral button, which was causing peroneal tendon irritation, as confirmed by physical examination and US. On physical examination the patient had no tenderness over the cervical ligament graft interval and had stable subtalar joint motion with nearly symmetrical range of motion to the contralateral side, tending toward some limitation of inversion and eversion. Repeat oblique inter-column stress at six months (OICS) examination was stable with a hard endpoint, no apprehension and no pain. MRI obtained at six months after surgery confirmed anatomically positioned and intact cervical ligament graft with linear appearance indicating good tension. (Figure 7). At one year postoperatively, the tightrope button and dorsomedial plate for the Cotton osteotomy were both removed, and the patient's stated pain was resolved. She has a job that is classified as heavy demand. She progressed through work conditioning and was able to lift and carry 55 lbs. repeatedly without foot pain. She was back to work at 24 months postoperatively with maximal medical improvement and returned to work without restrictions. At 30 months after surgery, she sustained a new injury at work for which the CL specific MRI protocol was obtained showing an intact graft (Figure 10). Her pain was found to be related to her prior superficial peroneal nerve injury which was treated non-operatively and she was able to return to work without complains.

DISCUSSION

There is a lack of information in the literature about cervical ligament injuries in pronation injuries which most likely contributed to the eight-month delay in diagnosis. In diagnosis of foot sprain, specific ligament(s) should always be sought. In this case an MRI obtained

Figure 6. Post-operative X-rays (3 months after surgery).

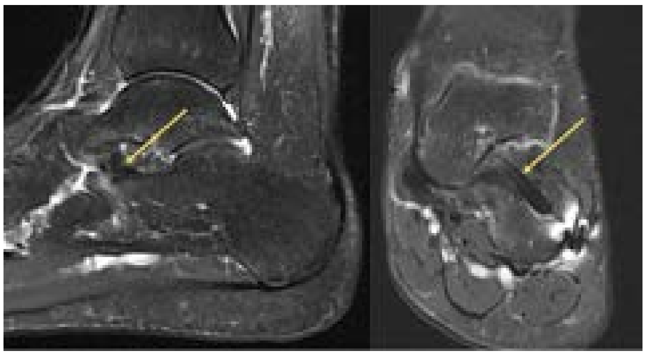

Figure 7. Follow up MRI at 6 months from surgery showing intact graft.

Figure 8A to 8B. (8A) Middle facet subluxation before surgery (40.75%) and (8B) Middle facet subluxation after surgery (22.94%).

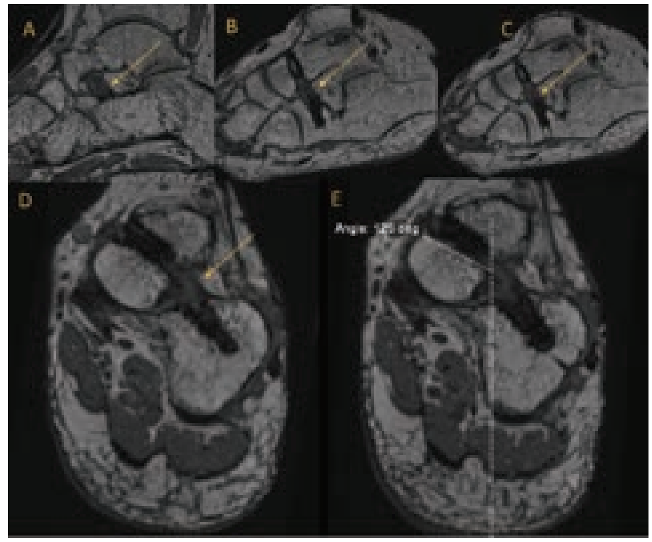

Figure 9A to 9E. Volumetric post-operative MRI images (22 months after surgery): Reconstructed coronal and sagittal images manually optimized to be parallel with the graft. The coronal slices were obtained using a 45-degree caudal tilt in the sagittal plane (9A to 9C), and the sagittal slices were obtained using a 55-degree medial tilt in the coronal plane (9D and 9E): Reconstructed sagittal image 125 degrees showed intact cervical ligament graft.

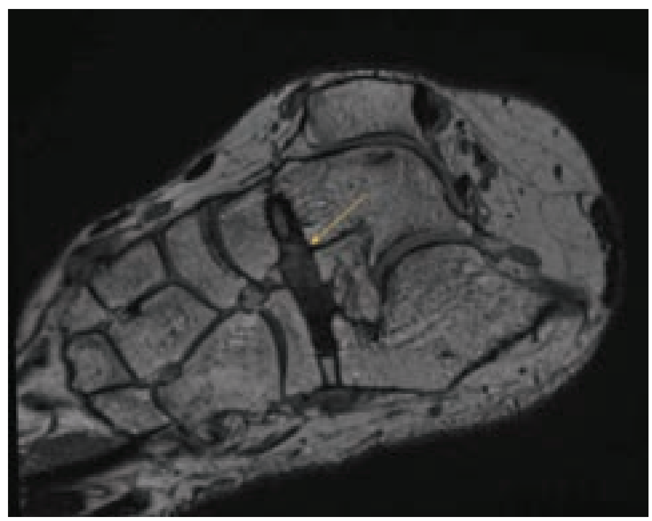

Figure 10. Volumetric Post-operative MRI images 30 months after surgery showing intact cervical ligament graft.

at seven weeks post injury demonstrated bone marrow edema at the locations of cervical ligament insertions on the talus and calcaneus, but the diagnosis of cervical ligament injury was not appreciated.

Sarrafian described the cervical ligament as the "strongest stabilizer of the subtalar joint".[10] The cervical ligament is an oblique ligament. It is located anterior to the interosseous talocalcaneal ligament (ITCL) distal to the tarsal canal.[1] It runs diagonally in the sinus tarsi; it is attached proximally to the superior and lateral aspect of the calcaneus 4.8 mm (95% CI SD ± 1.1mm) from the calcaneo-cuboid joint, and distally, to the talar neck 3.3 mm (95% CI SD ± 0.8mm) posterior to the talo-navicular joint.[1,13]

Cervical ligament injuries have been previously discussed with regard to varus instability of the subtalar joint due to inversion injury mechanisms.[3,17] Michels et al., described an algorithm for the management of subtalar instability after inversion injuries.[14] They described a physical examination to evaluate possible subtalar instability in varus or inversion. However, there was no specific maneuvers described to individually assess for cervical ligament instability.[14] An oblique inter-column stress (OICS) test of the anterior talo-calcaneal interval is not validated in the literature but does have a biomechanical basis. According to Sarrafian, under tibiotalar vertical loading with internal rotation of the talus, the calcaneus externally rotates and talar head is driven into the talo-navicular joint providing maximum stability of the foot and ankle to be able to accommodate bending stresses.[16] With external rotation of the calcaneus and internal rotation of the talus the cervical and Spring ligaments become progressively tensioned.[16] In this case the patient likely had pre-existing hypermobility of the first ray and likely had some laxity in the Spring ligament which would place the cervical ligament under greater tension with this hyper-pronation injury mechanism. Therefore the cervical ligament is vulnerable to rupture with either excessive inversion or eversion; with inversion ankle sprains being far more common than eversion ankle sprains the potential for injury of the cervical ligament has not been investigated.[8,9] In the present case, based on this understanding of the biomechanics of the cervical ligament an oblique intercolumn stress test was performed by grasping the calcaneus with one hand while stabilizing the talar head/neck with the other hand; the oblique line of stress would normally be resisted by an intact cervical ligament. Application of bi-directional stress along a line from dorsolateral to plantar medial (to tension an intact CL), demonstrated soft endpoints with apprehension, and reproduction of the patient's stated pain. These findings were taken as indications of a ruptured CL which was supported by an MRI obtained seven weeks after injury which showed bone marrow edema at the footprints of the cervical ligament. The first postoperative MRI using routine ankle imaging protocols demonstrated that the allograft tendon reconstruction remained linear and intact, however it didn't show the graft in its entirety in any plane (axial, coronal, sagittal and axial oblique). (Figure 7). The difficulty with imaging the CL on standard MRI sequences is that it is an oblique ligament relative to the standard coronal, axial and sagittal planes. In reviewing the case with one of our musculoskeletal radiologists and MRI specialist (NF), it was noted the MRI required thinner slices and modified orientation angles to show the whole length of the graft. At the final follow-up, we used new MRI imaging protocol, using a 3 Tesla Siemens MAGNETOM Skyra, to generate volumetric images and reconstructions using a slice thickness of 0.6mm with an isotropic voxel size. (Figure 9) The new protocol demonstrated the tendon graft in its entirety in several image slices. We plan to use this new imaging protocol in future cases of suspected cervical ligament injury or reconstruction.

To reconstruct the cervical ligament, we used an anatomically placed gracilis tendon allograft which was fixed between the talus and calcaneus, after reduction of the medial and lateral column dissociation. We subsequently discovered the publication by Michels et al. that described a similar technique using an autograft gracilis tendon and interreference screws for cases of chronic subtalar instability.[14]

This case also has the potential to inform our understanding for chronic conditions, such as collapsing foot deformity. In a recent biomechanical study, transection of the cervical ligament was necessary to allow the calcaneus to spontaneously reach maximal external rotation under the talus even after previous transection of medial ligaments (spring, anterior deltoid and interosseous talocalcaneal ligament).[7] This was the first study to evaluate the role of the CL as a stabilizer of the subtalar joint in the context of a collapsing foot deformity.[7,15] In a recent study, MRI identified significant higher incidence of cervical ligament insufficiency in patients with flatfoot deformity in comparison to control group (60.3% vs 10.9%). They also noted increased axial plane foot deformity with greater degree of CL insufficiency.[6,11] In the case of a more advanced collapsed feet with chronic attenuation one would suppose that the instability would not necessarily be associated with such acute pain with OIC stress as in this post-traumatic case.

This patient had a WBCT preoperatively and 12 months postoperatively. The preoperative WBCT demonstrated middle subtalar facet uncoverage with lateralization of the calcaneus consistent with peritalar subluxation pathology in a flatfoot as first described by Sangeorzan and later by de Cesar Netto.[2,5] The percent subluxation of the middle facet was measured 40.75% preoperatively and improved to 22.94% postoperatively. Additionally, the foot and ankle offset was 1.73% preoperatively and improved to -0.27% postoperatively. (Figure 8) Both the hypermobility of the first ray, and the CL rupture likely contributed to these preoperative measurements. Likewise, the Cotton osteotomy and CL reconstruction would both contribute to the improvement seen in these two measures. The relatively moderate abnormal values were due to the fact that the Spring ligament was otherwise intact by MRI and the patient denied any history of medial hindfoot pain after the injury.

This case report demonstrates an acute injury of the CL due to an uncommon mechanism. Although, we only have 30 months of follow up and no preoperative patient reported outcomes, she did objectively prove to be able to lift and carry 55 lbs. without complaints of foot pain, in a Physical Therapy supervised work conditioning program and subsequently was able to return to her high demand work. This is in sharp contrast to her initial visit eight months after injury when she was requiring a walking boot and had pain even in the boot. We hope that this study can help future patients to be diagnosed more quickly when similar injury mechanisms occur, and to aid in consideration of the surgical reconstruction with the method we have presented.

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DISPLACED PROXIMAL TIBIA FRACTURE AFTER PROXIMAL TIBIAL AUTOGRAFT HARVEST: A CASE REPORT

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ABSTRACT

Background: A 60-year-old female underwent proximal tibial autograft harvest for a Cotton osteotomy. Her postoperative course was complicated by psychogenic non-epileptic seizure (PNES) episodes leading to unintentional weightbearing. Knee radiographs at 6 weeks post-procedure demonstrated a displaced proximal tibia fracture through the autograft harvest site. Further clinical review revealed metabolic derangements consistent with secondary hyperparathyroidism. Initial non-operative treatment led to atrophic varus nonunion requiring definitive treatment with total knee arthroplasty with revision components.

Conclusion: This case describes a rare complication of proximal tibial autograft harvest and highlights the importance of preoperative metabolic workup and bone health optimization.

Level of Evidence: IV

Keywords: osteoporosis, bone health, osteomalacia, tibia fracture

INTRODUCTION

Bone grafting is commonly used in fracture fixation, arthrodesis, and reconstructive procedures to enhance healing and restore bony defects.[1] Allograft is often used as it is readily accessible and eliminates donor site complications. However, it lacks the osteogenic properties of autologous bone, which has been shown to decrease the incidence of non-union in midfoot fusions.[1,2] Cancellous autograft can be harvested from multiple sites; the proximal tibia is an appealing option as this location provides an easily accessible source, large graft volume, and less donor site morbidity than traditional iliac crest harvest.[3-6] Harvest techniques involve making a ~1 cm cortical window at Gerdy's tubercle through which cancellous bone is removed with curettes.[7,8] This is the preferred technique to preserve biomechanical stability of the proximal tibia,[9,10] and complication rates are low when combined with protected postoperative weightbearing.[3] Although the proximal tibia affords a relatively safe harvest site, complications including pain, infection, and fracture do occasionally occur.[11] Donor site fractures are rare, with a prevalence of 0.16%.[11] Smoking, immunosuppression, and malnutrition reduce healing potential[1,12] and can lead to complications including donor site fracture.[13]

Statement of Informed Consent

The patient provided verbal consent, allowing her de-identified medical history and treatment course to be published. This report does not qualify as human subject research under federal regulation 45CFR46.102 and IRB submission was not required.

CASE REPORT

A 60-year-old female presented in April 2021 with left foot pain secondary to metatarsalgia and a bunionette deformity. Her prior history included talar head/navicular excision and 2nd toe PIP fusion in 2018 (with uneventful healing), Roux-en-Y gastric bypass surgery followed by revision bypass for recurrent weight gain, post-bypass dumping syndrome, osteoporosis, and psychogenic nonepileptic seizures (PNES). After failure of non-operative therapies, she underwent bunionette excision, 5th toe interphalangeal fusion, and Cotton osteotomy with proximal tibia autograft. Preoperatively, her complete blood count, creatinine, and calcium were normal. The 25- hydroxyvitamin D (25OHD) level was 35 ng/mL (reference 20-80). She was started on 3000 units/day of ergocalciferol.

Her surgical course was uneventful. Proximal tibia autograft was harvested from an area just lateral to the tibial crest near Gerdy's tubercle. A cortical window was made and sequentially dilated up to a #4 curette (<1cm) which was used to harvest approximately 3-4cc of cancellous autograft. No other cortex was breached during the harvest. Following the harvest, she was placed into a protective splint, made non-weightbearing, and discharged home on the same day.

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Conversion to a patellar tendon bearing (PTB) short leg cast was performed 1 week later, and suture removal and cast exchange were performed 3 weeks after surgery. Six weeks post-operatively, she reported continued pain at the proximal tibia graft site. Knee radiographs demonstrated a complete fracture through the proximal tibial cortical autograft defect (Figure 1). Her postoperative 25OHD level was 41 ng/mL while on 3000 units of daily vitamin D.

She was managed conservatively with a hinged knee brace and continuation of non-weightbearing status. Radiographs and computed tomography (CT) scan 10 weeks post-operatively demonstrated varus subsidence of the fracture (Figures 2 and 3). At this time, the patient's husband reported intermittent non-compliance with weightbearing restrictions and multiple unwitnessed falls and PNES episodes in the immediate postoperative period. Additional radiographs obtained 3 to 5 months post procedure demonstrated progressive varus angulation (Figure 3). A DXA scan was obtained three months post procedure demonstrating decreased bone density (T-score-2.7 at femoral neck, -2.6 at hip, -0.2 at lumbar spine). CT was repeated 5 months post-operatively, demonstrating persistent varus alignment with minimal bony bridging at the fracture site. A SPECT/CT scan (Tc-99m and Indium-111 labeled leukocytes) showed non-union without infection in the proximal tibia. She was ultimately treated with a stemmed cemented total knee arthroplasty (TKA) at 8 months post-surgery (Figure 4). Radiographs at 16 months post-surgery demonstrated stable alignment of arthroplasty components, and clinical examination demonstrated no laxity to varus or valgus stress with range of motion from 0-120 degrees. Patient had no residual pain and had returned to all desired daily activities.

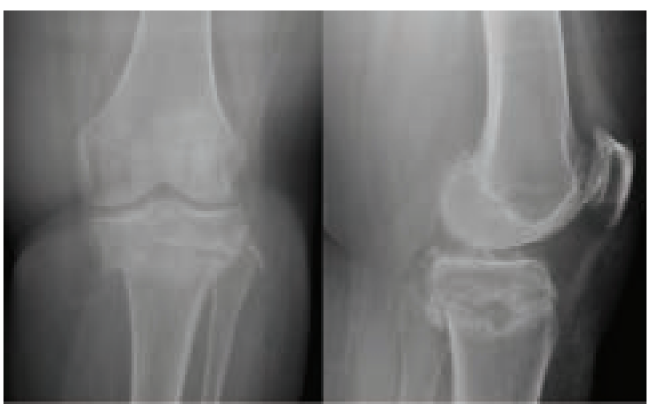

Figure 1. 6 weeks post-procedure. AP and lateral radiograph of proximal tibial donor site. Circular cortical defect from autograft harvest is visible on lateral image in addition to global bone resorption throughout the proximal tibial fracture.

Figure 2. 10 weeks post-procedure. Coronal, sagittal, and axial CT images of proximal tibial donor site with bone resorption and new bone formation.

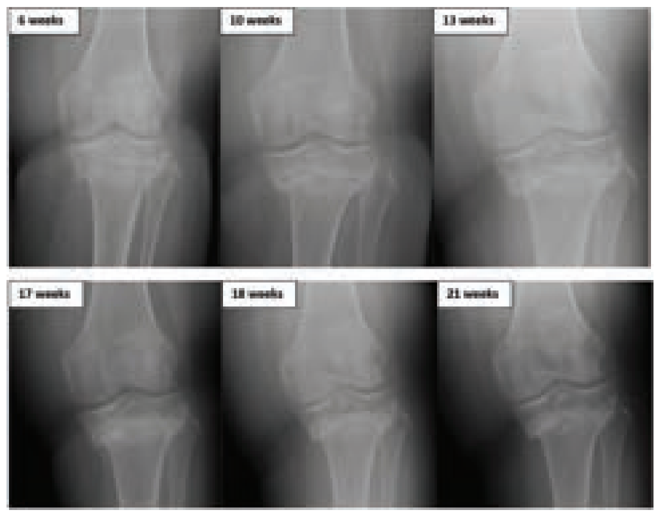

Figure 3. AP radiographs at 6 weeks, 10 weeks, 13 weeks, 17 weeks, 18 weeks, and 21 weeks post procedure demonstrating progressive varus collapse, and fracture healing.

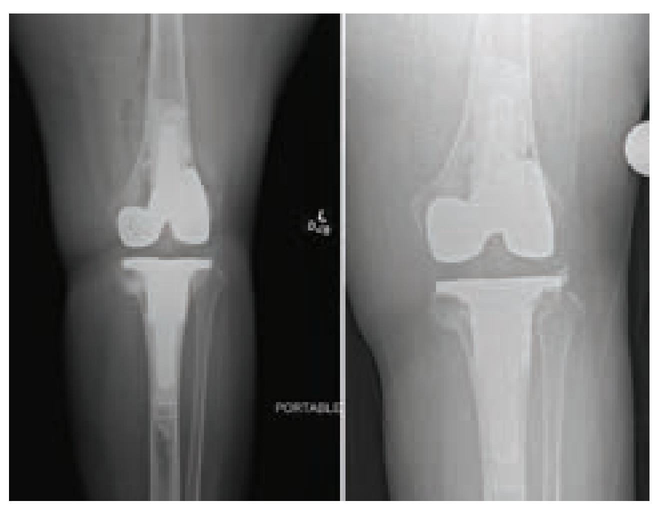

Figure 4. Total knee arthroplasty at 8-months (left) and 16-months (right) post procedure with restoration of anatomic alignment using Depuy Attune revision components with Smith and Nephew Legion cone augmentation.

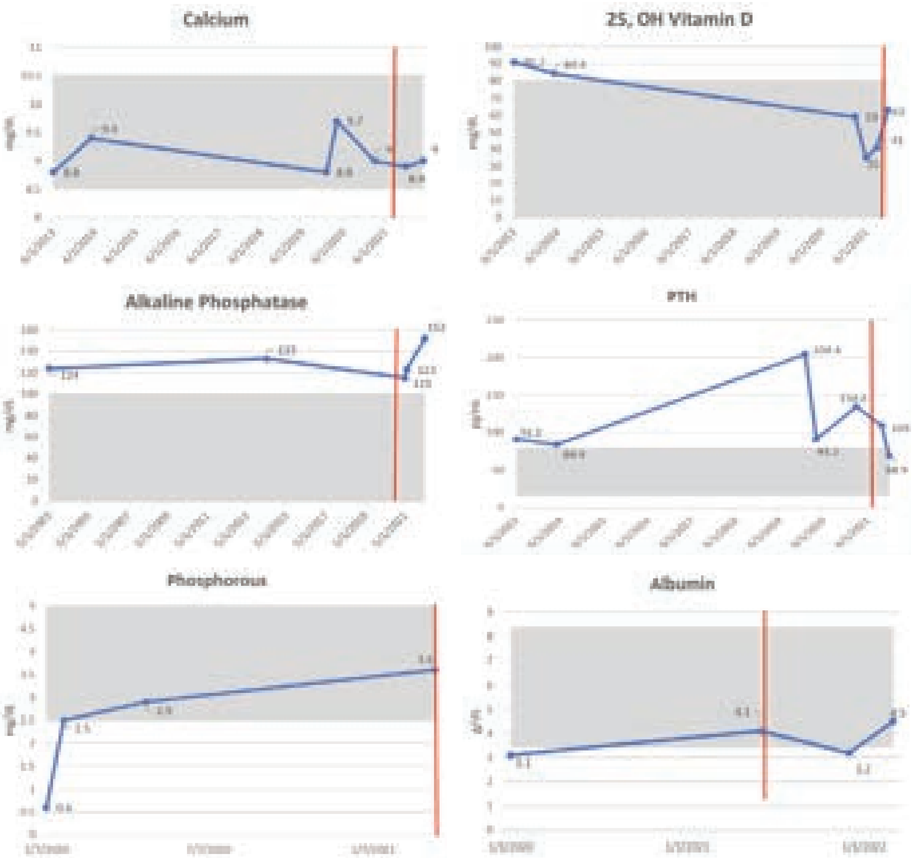

Figure 5. Laboratory values trended over time. Reference range is indicated by grey box and red line denotes the initial surgical date in July of 2021. Notable trends include a chronic elevation in parathyroid hormone (PTH) with normal to low-normal calcium and phosphorous concentrations, consistent with diagnosis of secondary hyperparathyroidism.

In retrospect, we noted that the patient had manifested a chronic elevation in her parathyroid hormone (PTH) concentration since 2013. Calcium and phosphorous concentrations were normal, though occasionally close to the lower end of the normal range (Figure 4). In the setting of gastric bypass surgery, these abnormalities were felt to represent secondary hyperparathyroidism. She was on no medications affecting calcium or bone metabolism. As mentioned previously, vitamin D supplementation was initiated preoperatively. While patients are generally encouraged to initiate 1000 mg PO calcium supplementation preoperatively, her calcium intake was not documented. The potential for malabsorption due to her prior gastric surgeries was not confirmed in the orthopaedic medical record. She was placed on 1500 mg/d of calcium carbonate in October 2021, 3 months post-operatively, and her PTH normalized within two months (Figure 5).

DISCUSSION

Proximal tibial autograft is an effective and safe source of autologous bone. O'keefe et al. reported a complication rate of 1.3% with only one instance of a proximal tibial fracture[3] among 230 patients who had undergone the procedure. While rare, some reports have described both biologic and mechanical factors that may contribute to proximal tibial donor site fracture. Michael et al. described a proximal tibia donor site fracture in the setting of osteoporosis,[14] and proximal tibial fractures were reported twice after postoperative falls.[7,15] This case is unique in that the patient's uncontrolled falls and excessive mechanical loading introduced postoperative trauma in the setting of compromised baseline bone health. This patient exhibited several metabolic risk factors for postoperative fracture including an elevated body mass index (BMI), low bone density, and inadequate calcium intake leading to chronic secondary hyperparathyroidism.[16,17]

Additionally, Roux-en-Y bariatric surgery is known to compromise enteral absorption of both calcium and vitamin D, which are essential components of bone homeostasis.[18] Without adequate supplementation, PTH secretion increases to maintain normocalcemia through increased bone resorption.[19,20] This physiologic state typically presents with elevated PTH, alkaline phosphatase, and low to low-normal calcium levels, consistent with this patient's preoperative laboratory measurements (Figure 4). Additionally, the elevated PTH promotes urinary phosphate excretion,[21] leading to hypophosphatemia.

Our patient last underwent bariatric surgery in 2000, which we hypothesize led to long-term calcium absorption disturbances contributing to secondary hyperparathyroidism and eventual osteomalacia. This process, in addition to possible concurrent postmenopausal osteoporosis, created a state of bone catabolism and poor healing potential. Of note, patients with osteomalacia can develop cystic bone lesions, or "brown tumors", through which pathologic fractures can occur.[22] Such lesions can be detected on plain radiographs, which were not obtained preoperatively at the site autograft harvest in our patient. On this background of metabolic bone compromise, the PNES-related postoperative trauma and noncompliance with weightbearing restrictions likely created a level of mechanical stress that culminated in the observed fracture.

This case highlights the importance of adequate calcium and vitamin D supplementation in patients undergoing bone autograft harvest, as these metabolites play a codependent role in bone healing and homeostasis. We have modified our former preoperative practice of only measuring the 25OHD level to a more comprehensive assessment that includes measuring serum calcium, 25OHD, and PTH. Pre-operatively, patients should also be screened for prior bariatric surgery, eating disorders, or other malabsorptive GI conditions. More specific attention to calcium consumption with Vitamin D supplementation could be standardized. We have since created a single handout with both Vitamin D and Calcium educational information that is provided to all patient's undergoing a bony operation, in addition to verbal education provided preoperatively.

A preoperative knee radiograph may have detected a Brown tumor in this patient's proximal tibia, and we have begun obtaining routine preoperative knee radiographs even when no history of knee pain or prior operations is present. With improved screening, supplementation, and preoperative bone health optimization, we hope to avoid similar complications in the future.

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RESEARCH TOWARD UNDERSTANDING THE BENEFITS AND LIMITATIONS OF ORTHOTIC USE TO IMPROVE MOBILITY AND BALANCE FOR INDIVIDUALS WITH NEUROPATHIC CONDITIONS

Bopha Chrea, MD[1]; Donald D. Anderson, PhD[1,2,3]; Koren Roach, PhD[5]; Jason Wilken, PT, PhD[4]

ABSTRACT

Background: Walking is a vital activity often compromised in individuals with neuropathic conditions. Charcot-Marie-Tooth (CMT) disease and Cerebral Palsy (CP) are two common neurodevelopmental disabilities affecting gait, predisposing to the risk of falls. With guiding scientific evidence limited, there is a critical need to better understand how surgical correction affects mobility, balance confidence, and gait compared to ankle foot orthosis (AFO) bracing. A systematic approach will enable rigorous collaborative research to advance clinical care.

Methods: Key elements of this vision include 1) prospective studies in select patient cohorts to systematically compare conservative vs. surgical management, 2) objective laboratory-based evaluation of patient mobility, balance, and gait using reliable methods, and 3) use of patient-centric outcome measures related to health and mobility.

Results: Valid and reliable standardized tests of physical mobility and balance confidence have been described in the literature. They include 1) the four-square step test, a widely used test of balance and agility that predicts fall risk, 2) the self-selected walking velocity, a measure of general mobility able to detect function change with orthosis use, and 3) the activity specific balance confidence scale, a survey instrument that assesses an individual's level of balance confidence during activity. Additionally, motion capture and ground reaction force data can be used to evaluate whole-body motion and loading, with discriminative biomechanical measures including toe clearance during the swing phase of gait, plantarflexion at 50% of swing, peak ankle plantarflexor moment, and peak ankle push-off power.

Conclusion: The tools needed to support evidence-based practice and inform clinical decision making in these challenging patient populations are all available. Research must now be conducted to better understand the potential benefits and limitations of AFO use in the context of mobility and balance during gait for individuals with neuropathic conditions, particularly relative to those offered by surgical correction.

Clinical Relevance: Following this path of research will provide comparative baseline data on mobility, balance confidence, and gait that can be used to inform an objective criterion-based approach to AFO prescription and the impact of surgical intervention.

Keywords: cerebral palsy, charcot-marie-tooth, cavovarus, AFO

INTRODUCTION

Walking is an important functional activity that is often compromised in individuals with neuropathic conditions. Charcot-Marie-Tooth (CMT) disease and cerebral palsy (CP) are two of the most common neurodevelopmental disabilities, affecting >1 million children in North America. CMT and CP are leading causes of lifelong physical disability in children,[1] often causing altered gait biomechanics (i.e. joint motion and loading) due to disruption of the central and peripheral nervous systems, which can occur any time during fetal development through early childhood.[1,2] Impaired walking or altered gait presents several additional risk factors for individuals with CMT or CP: increased falls risk and increased prevalence of osteoarthritis (OA).

Individuals with neuromuscular diseases are particularly at risk of falls due to locomotor impairment. Amongst patients with CMT, impaired walking is the most significant contributor to reduced quality of life.[3] A recent cross-sectional survey of 252 patients with CMT

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found that 86% of survey respondents reported falls or near falls.[4] The impact of falls is far reaching, in terms of injury risk and the consequences of the fear of falling. The most cited reasons for falls or near falls included muscular weakness with tripping due to foot drop or joints giving away.[4]

Altered gait and balance deficits lead to potential fall risk

CMT comprises a group of progressive inherited neuropathies that affect motor and sensory axons of the peripheral nervous system. Depending on the axons affected, motor and sensory function is progressively impaired, typically beginning in the longest axons and progressing proximally over time. Affected patients typically have progressive distal weakness, muscle atrophy and sensory loss, first in the feet and lower legs, followed by the hands.[5-7] In mild and moderate cases, individuals with CMT exhibit associated problems including cavovarus foot deformity, footdrop, and sensory changes.[8,9] These impairments result in altered gait and balance deficits.[10]

The ankle plantarflexor muscles play a critical role in supporting the body and maintaining balance during the stance phase of gait. During stance, the plantarflexor muscles support the body preventing knee buckling and forward rotation of the tibia, and during push-off the plantarflexor muscles propel the body and limb forward.[11] During swing phase, the dorsiflexor muscles lift the foot to allow clearance of the toes to prevent tripping. Ankle weakness in individuals with CMT can alter the ability to maintain balance, support the body, push the limb into swing phase, and lift the foot during swing to clear the toe, predisposing individuals with CMT to greater risk of falling.

Altered gait potentially leads to increased risk of osteoarthritis

Individuals with pediatric-onset of musculoskeletal impairments, such as CP, have a 10 times greater likelihood of musculoskeletal disease.[2] For example, up to 32% of individuals with CP have OA, which is drastically higher than the general population (14%), with individuals developing this condition in their early-to-mid 20s in contrast to the usual onset during middle-age.[2] Reported odds ratios for OA were up to 5 times higher for CP patients across all age groups, with younger age groups having higher odds ratios than older age groups compared to age-matched individuals without CP.[2] It is suspected that altered joint motion (i.e., kinematics) contributes to the development of OA, which involves the degeneration of joint tissues, and can cause pain, discomfort, and functional limitations. Previous studies on OA prevalence in individuals with CP are limited to 1) reported hip, hand, knee, and polyarticular OA;[12,13] 2) scant data regarding the influence of CP disease severity; and 3) no reported biomechanics.

Foot deformities, such as equinovalgus, equinovarus, and planovalgus, affect more than 62% of individuals with CP.[12,13] Foot deformities can cause gait abnormalities and increased loading in concentrated areas of the foot, particularly the midfoot, which likely contribute to increased rates of OA.

Treatment considerations

The lack of research on lifespan issues, such as falls and OA risk, and longitudinal studies that bridge childhood to adulthood in individuals with CP has gained attention. Specifically, adults with CP and parents of young children with CP, have requested research on CP be more focused on longitudinal studies across the age span and clinical spectrum, particularly focused on pain, fatigue, exercise, health, and wellness.[14] Not reported was the participant demographics (e.g., sex, ethnicity, background, or socioeconomic status), making it unclear how representative these opinions are of the broader community, especially members of equity-deserving groups. The perspectives of local equity-deserving communities for research endeavors focused on CP, as well as more broadly on musculoskeletal and neurodevelopmental disorders, are needed to respond with allyship and action.

Ankle foot orthoses (AFOs) are commonly used by individuals with CMT or CP, often with the intent of improving mobility, managing pain, reducing the risk of falls, and restoring a more normal gait pattern. Although AFOs are non-invasive and adjustable, they can be bulky, uncomfortable, and destabilizing for already weak individuals. Individuals with CP have high rates of foot deformity,[12,13] which often require surgical intervention. Similarly, while great strides have been made in treating cavovarus deformity in CMT, as evidenced by a recent consensus statement,[15] there remains limited information on gait and outcomes data related to balance after operative fixation. Surgical correction offers the advantages of improving limb alignment and reduced bulk while also avoiding the sometimes-arduous task of donning/doffing a brace. However, surgery carries risk, has potential complications, requires post-operative recovery, and requires re-operation if the initial goals are not achieved.

Scientific evidence needed to aid in clinical decision-making

Weight bearing CT has greatly improved our understanding of bony morphology associated with foot deformities that are not easily appreciated on plain ra-

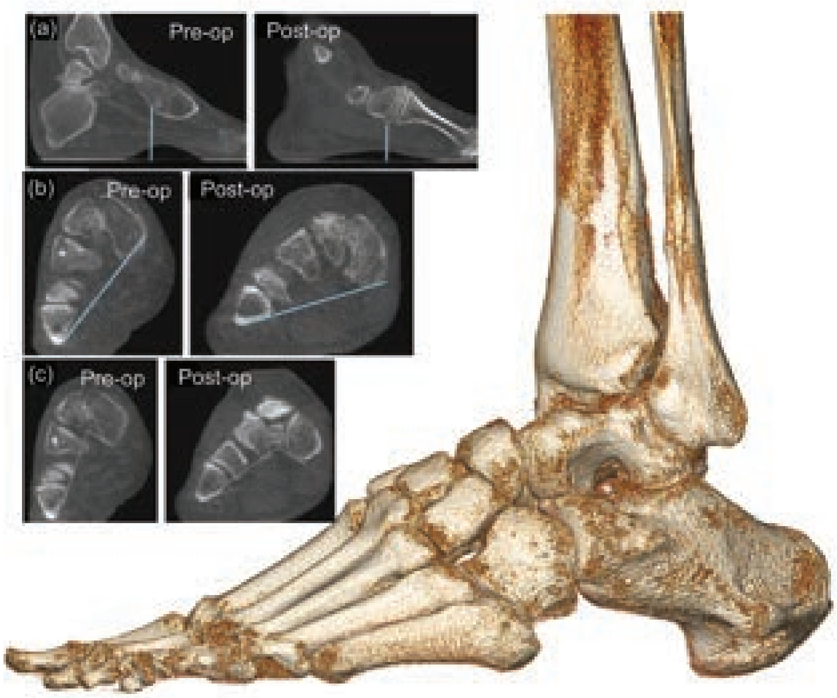

Figure 1a to 1c. WBCT volumetric rendering of the foot and ankle of a patient with CMT and cavovarus foot deformity. Morphologic measurements can be made from appropriate WBCT slices (inset images) pre- and post-op to assess the deformity and correction achieved – (1a) cuneiform-to-floor distance, (1b) forefoot arch angle, and (1c) transverse arch plantar angle.

diographs (Figure 1). AFOs are commonly prescribed to individuals with CMT and CP to support the foot and ankle and restore mobility by compensating for progressive distal limb weakness, fatiguability, foot deformity, and decreased sensation. However, AFO adherence is suspected to be marginal, and there is little evidence that AFOs help with weightbearing problems or improve foot biomechanics.

This lack of data stems partly from the use of traditional motion capture techniques that are reliant on skin markers to measure foot segment motion, which prevents measurement of individual bone movement while individuals are shod and wearing their AFO. To counteract these limitations, a recent study employed dual fluoroscopy (DF), which leverages two orthogonally-placed X-ray videos to measure 3D bone movement (e.g., Figure 2), and found alterations in the medial longitudinal arch of individuals with pes planus (i.e., flat feet).[16,17] However, DF studies have not yet investigated individuals with CMT or CP. Quantification of 3D foot biomechanics is critical to evaluate AFO efficacy and the AFO-induced changes that may prevent OA. Evidence of this sort could increase AFO adherence and decrease OA rates among patients with neurodevelopmental disorders and foot deformity.

A patient must be committed to wearing an AFO for any of its potential benefits to be realized. As alluded to above, many factors can negatively influence a patient's satisfaction with their braces such as discomfort, device appearance, limited footwear options, and the quality of clinical services provided when receiving an AFO. Additional considerations include the potential for wounds in patients with diminished sensation, and financial costs.

More data are needed to achieve optimal clinical AFO prescription. Despite small studies indicating positive effects, and widespread clinical use due to their expected benefits, there is no universal, literature-based consensus to inform decision-making for whether orthoses are indicated for a particular patient with CMT, and if so, what type of device should be prescribed.[18-21] Improved insight into the benefits and limitations of clinically provided AFOs will facilitate the development of more systematic and evidence-based refinements of AFO prescription, fitting and design.

Scientific evidence to help surgeons determine if an AFO or a surgical procedure are best for a given patient, especially in the setting of a brace-able foot, also remains limited. Recent consensus among expert orthopedic foot and ankle surgeons is "There are no evidence-based orthopedic studies to help determine optimal timing

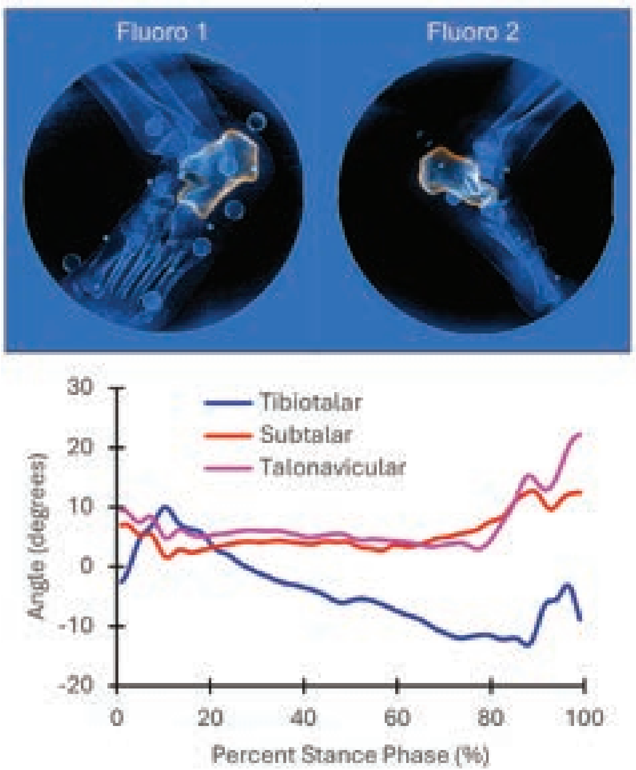

Figure 2. 3D model-based tracking of calcaneus in dual fluoroscopy images (top). Tibiotalar, subtalar, and talonavicular joint angles during stance phase of gait are shown for one female volunteer (bottom).

for surgery, and there is often contradictory advice from the patient's neurologist, physical therapist, and orthotist regarding the role of an operation."[15] There is a critical need to understand how surgical correction affects mobility, balance confidence, and gait compared to AFO bracing in the native foot (non-operatively treated). Without such information, an evidence-based approach to answering this critical question will likely remain unrealized. In addition, how surgical correction of the cavovarus foot alters gait, specifically regarding restoration of joint position, control, and balance remains unknown. Optimizing interventions to improve balance and reduce falls for individuals with CMT will require a better understanding of alterations in gait biomechanics as they relate to AFO use and surgical correction.

Approximately 20% of patients with CMT present to the orthopedic office with no motor function below the knee and no significant deformity.[15] AFOs present a reasonable first line treatment to improve gait and balance. Neuromuscular patients demonstrate varied AFO stiffness needs for optimal and efficient gait.[22] How their individual needs change after surgical correction, and what deficits may persist, is unknown. A recent study on 37 individuals with neuromuscular disease showed that while all AFO stiffness levels evaluated improved walking energy costs (15-19% decrease) and speed (20-24% increase) compared to shoes only, individually optimizing the AFO stiffness improved these parameters further.[22] This finding highlights the benefits of AFO use as well as the uncertainty in optimizing care. Understanding the resulting gait after surgical reconstruction in comparison to brace management may allow us to further refine and guide surgical decision making and provide insight into the relative costs and benefits of bracing and surgical management.

The overall objective of the proposed research approach is to characterize the benefits and limitations of AFO use and surgical correction in the context of gait, mobility, and balance in individuals with neuropathic conditions. This has the potential to be profoundly impactful to these patient populations as impaired walking is the most significant contributor to reduced quality of life in patients with neurodevelopmental disorders.[3] The comparisons embodied in this research approach represent important steps toward understanding the effects of AFO use and surgical management on balance and mobility. Further, they move us toward a longer-term goal of optimizing bracing strategies, the timing and selection of treatment options (surgical and orthotic), and post-operative management in neuromuscular patients with cavovarus foot deformity. Expected outcomes from such research are that we will have comparative baseline data on mobility, balance confidence, and gait that can then be used to inform an objective criterion-based approach to AFO prescription and the impact of surgical intervention.

METHODS

The objective of the proposed research approach is to address a knowledge gap related to mobility, balance confidence, and gait biomechanics in individuals with neurodevelopmental disorders who have, and have not, undergone surgical correction. Patients will be recruited from a variety of populations. Recruitment at dedicated research-centric clinics can draw individuals with peripheral neuropathies from across the USA and internationally. Additional recruitment strategies may be needed to reach individuals who cannot afford healthcare (e.g., indigenous populations) and are believed to be at a much higher risk for CP than the general population.

Study Populations

Studies should include, at a minimum, two groups of individuals with CP and CMT: 1) those who have undergone surgical correction; and 2) those who have not undergone surgical correction but use an AFO. The sample needs to reflect the general characteristics of individuals with neurodevelopmental conditions seeking medical care, enabling research studies that can provide preliminary data on which to base future mechanistic and intervention studies.

Inclusion Criteria: 1) Clinical diagnosis along with genetic confirmation of CMT or CP; 2) age between 12 and 75; 3) able to walk at a slow to moderate pace without an AFO, 3) able to read and write in English to provide written informed consent, provide informed consent through a translator, or surrogate provided consent; 4a) individuals in any AFO group must have an AFO prescribed for daily activities; 4b) individuals in any surgical group will also have had surgical correction of bony deformity focused on muscle balancing and hindfoot correction.

Exclusion Criteria: 1) Other causes or risk factors for peripheral neuropathy (for example diabetes, ETOH abuse); 2) uncorrected visual impairment; 3) history of musculoskeletal injury requiring surgery; 4) loss of plantar protective sensation; 5) pain >4/10 while walking (or an increase in pain during testing of >2/10); 6) for the AFO group, prior surgical correction of a foot deformity focused on muscle balancing and hindfoot correction.

Physical performance measures

Participants must be evaluated using valid and reliable tests of physical mobility, balance confidence, and gait biomechanics. Individuals in any surgical treatment group would complete all activities without an AFO, and individuals in the AFO group would complete activities with and without their clinically prescribed AFO, to determine the effect of AFOs on mobility, balance confidence, and gait biomechanics. These findings must then be compared to falls frequency, assessed by asking participants the number of times they fell in the previous 24 hours and the previous week. Participants would also report their specific circumstances most associated with a fall events. Longitudinal follow-ups would be employed to ascertain how mobility, balance confidence, and gait biomechanics change due to AFO use or following surgical correction and to determine the prevalence and time to OA onset for these individuals.

The primary performance-based mobility measure is the four-square step test (4SST), a standardized and widely used test of balance and agility that predicts fall risk in multiple patient groups.[23-25] The test of functional mobility requires rapid stepping and changes in direction, that are often limited by lower limb pathology. The measure has good to excellent reliability and validity across multiple patient populations and groups, is a key dependent measure in multiple AFO related studies and has demonstrated ability to detect changes in function in individuals with lower limb pathology and AFOs.[23-25]

Self-selected walking velocity (SSWV) is a well-accepted measure of general mobility that is useful for studying individuals of a wide range of ages, disease conditions, and injury types.[26-30] Self-selected gait speed has excellent reliability, ability to detect function change with orthosis use, and is an early indicator of reduced participation.[27-32] Participants are instructed to walk at their "normal comfortable" pace for a 10 m distance. The time traveled between the 2 m mark and 8 m mark is recorded in seconds, and two trials are completed with rest between trials.

The activity specific balance confidence scale (ABC) is a well-established survey instrument used to assess a participant's level of balance confidence during functional activities.[33] The ABC has been used to characterize deficits in confidence associated with CMT. In this patient population it has been associated with patient report of falls and functional mobility tests.[34] The ABC scale takes approximately 3 minutes to complete.

RESULTS

The following sections summarize data from experiments previously conducted over the past decade that support elements of this vision for establishing an evidence base for treatment decision-making in individuals with neuropathic conditions.

Patient acceptance of AFOs

Over 300 individuals with CMT who use an AFO were previously queried, utilizing multiple standardized questionnaires including the Orthotics and Prosthetics Users Survey (OPUS).[35] We sought to gain insight into the relative satisfaction with daily use AFOs and patient experience with the clinical fitting process. We included also the Activities Specific Balance Confidence Scale (ABC)[33] to evaluate balance confidence in individuals with CMT who use an AFO. The OPUS includes 11 device-specific questions and 10 service-related questions, with patients rating their level of agreement to statements using a six-level Likert scale. Stronger agreement indicates greater satisfaction. Participants were also given an option to elaborate on what they would change about their orthosis, and what activities their orthoses help with and limit.

A total of 314 CMT individuals completed both subscales of the OPUS.[36] Over one third of individuals who used AFOs provided negative responses to multiple questions regarding their AFOs. Among the group, 42% indicated they disliked the appearance of their AFO, 32% experienced discomfort, 35% experienced abrasions or irritations, and 36% experienced pain with AFO use (Figure 3). Aligned with these data, participants indicated poor compliance with wearing the AFO, especially if patients felt a sense of constriction, aesthetic problems, difficulty finding normal shoes that fit with bulky AFOs, or if cost was an issue.

Individuals with CMT indicated overall satisfaction with their AFO but also specific areas for improvement. The ABC data demonstrated impaired balance confidence in individuals with CMT despite the use an AFO. Further, many participants reported falling in the preceding 24 hours (14% of participants) or week (38% of participants). Despite the high rate of falls, 78% of participants indicated their AFOs improved their balance. The efficacy of AFO use in other neurological conditions has been explored with improvements in gait function, independence, confidence and energy cost.[20,37]

Gait laboratory evaluations can be done reliably and consistently across sites

Optoelectronic motion capture and ground reaction force data are routinely used to evaluate whole body motion and loading as participants walk at self-selected speed and a controlled speed based on leg length.[38,39] An array of retro-reflective markers, placed on the skin of a participant to minimize skin-bone movement, track the position and orientation of body segments using well established methods.[39] Force plates embedded in the floor capture ground reaction forces. Data from a minimum of five successful trials are analyzed using Visual-3D software package (C-motion Inc., Germantown, MD). The ability to collect reliable data within and across sites using these methods has been previously demonstrated.[35] Biomechanical dependent measures include toe clearance during the swing phase of gait, plantarflexion angle at 50% of swing, peak ankle plantar flexor moment, and peak ankle push-off power.[40,41] Time series data for ankle, knee, and hip kinematics and kinetics will be determined.

DF provides the ability to image and measure individual bone movement within the foot and ankle. While data from DF in these populations are limited, the methodology shows great promise. Participants will perform walking and sit-to-stand activities with and without their AFO, as applicable, while DF images are acquired. CT scans will be acquired of bilateral tibia through toe-tips of all participants. CT images will be segmented to create 3D models of the tibia, talus, calcaneus, navicular, and cuboid. Bone models will be overlaid on the DF images to track 3D bone movement during each activity (Figure 4). Anatomical coordinate systems are defined for each bone and applied to the DF-tracked data to calculate kinematics for the tibiotalar, subtalar, talonavicular and calcaneocuboid joints. Statistical parametric mapping[42] is employed to identify portions of the gait cycle that differ between groups and conditions.

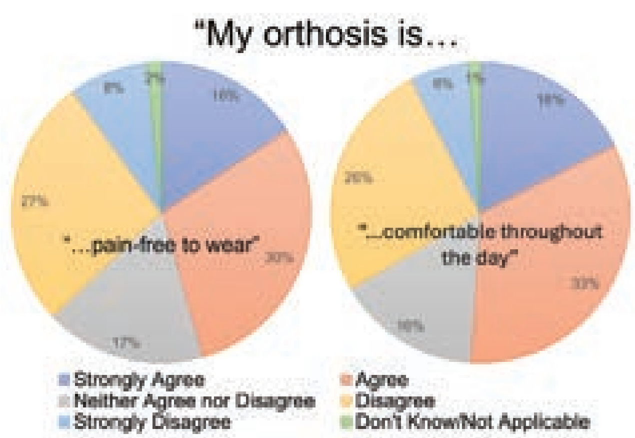

Figure 3. To gain insight into satisfaction with daily use, 329 individuals with CMT who use an AFO were queried utilizing a questionnaire that included 11 device-specific questions and 10 service-related questions. Patients rated their level of agreement to statements using a six-level Likert scale. Less than half of participants strongly or very strongly agreed that their orthosis was pain-free to wear, and only half similarly agreed that their orthosis is comfortable to wear throughout the day. These findings suggest the need to further enhance AFO related care to overcome the weakness, pain, and impaired function associated with CMT. (Expanded from Zuccarino et al. 2021).[36]

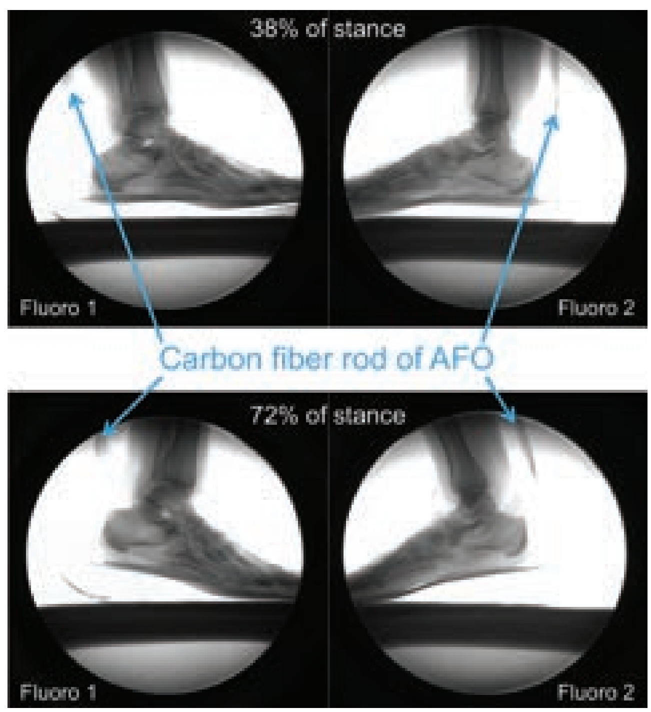

Figure 4. Biplane fluoroscopy images from a healthy control walking in a shoe and a carbon fiber ankle foot orthosis (AFO) from approximately 38% (top) and 72% (bottom) of stance. This proof-of-concept acquisition provides confidence that carbon fiber AFOs will not occlude bony geometry in biplanar fluoroscopic images.

DISCUSSION

A better understanding of the effect of surgical correction and orthosis use on mobility, balance confidence, and lower gait biomechanics in individuals with neurodevelopmental disorders (e.g., associated with CMT or CP) can inform clinical decision making, advance ongoing AFO development, and provide quantitative evidence regarding OA development in these individuals. There is variation in orthotics services, and clinicians report problems with acceptance and use of AFOs amongst people with these conditions, possibly due to a mismatch between patient needs and device provision. An improved understanding of how and when AFO use by these individuals alters gait mechanics, physical mobility, and balance confidence will provide insight into potential mechanisms by which AFO use alters stability and balance. This has the potential to improve orthotic management and guide decision making on the potential gait, balance, and reduced fall risk following surgical care of patients with inherited neuropathies. Similarly, uncertainty remains regarding the specific effects of surgical management on gait and balance in individuals with foot deformity. This includes differing perspectives regarding optimal timing and type of surgical intervention, and objective guidance to ensure optimal alignment between patient needs and the surgical procedure is lacking. Systematic study of the effects of orthotic and surgical management in individuals with peripheral neuropathy and related foot deformity, within the context of developing clinical practice guidelines, has the potential to improve pain, gait, and mobility, reduce falls, and enhance overall quality of life.

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CARPAL TUNNEL SURGERY: CAN PATIENTS READ, UNDERSTAND, AND ACT ON ONLINE EDUCATIONAL RESOURCES?

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ABSTRACT

Background: Patients often access online resources to educate themselves prior to undergoing elective surgery such as carpal tunnel release (CTR). The purpose of this study was to evaluate available online resources regarding CTR on objective measures of readability (syntax reading grade-level), understandability (ability to convey key messages in a comprehensible manner), and actionability (providing actions the reader may take).

Methods: The study conducted two independent Google searches for "Carpal Tunnel Surgery" and among the top 50 results, analyzed articles aimed at educating patients about CTR. Readability was assessed using six different indices: Flesch-Kincaid Grade Level Index, Flesch Reading Ease, Gunning Fog Index, Simple Measure of Gobbledygook (SMOG) Index, Coleman Liau Index, Automated Readability Index. The Patient Education Materials Assessment Tool evaluated understandability and actionability on a 0-100% scale. Spearman's correlation assessed relationships between these metrics and Google search ranks, with $p<0.05$ indicating statistical significance.

Results: Of the 39 websites meeting the inclusion criteria, the mean readability grade level exceeded 9, with the lowest being 9.4 ± 1.5 (SMOG index). Readability did not correlate with Google search ranking (lowest $p=0.25$). Mean understandability and actionability were $59\% \pm 15$ and $26\% \pm 24$, respectively. Only 28% of the articles used visual aids, and few provided concise summaries or clear, actionable steps. Notably, lower grade reading levels were linked to higher actionability scores ($p \leq 0.02$ in several indices), but no readability metrics significantly correlated with understandability. Google search rankings showed no significant association with either understandability or actionability scores.

Conclusion: Online educational materials for CTR score poorly in readability, understandability, and actionability. Quality metrics do not appear to affect Google search rankings. The poor quality metric scores found in our study highlight a need for hand specialists to improve online patient resources, especially in an era emphasizing shared decision-making in healthcare.

Level of Evidence: IV

Keywords: carpal tunnel release, hand surgery, patient education, readability, PEMAT

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INTRODUCTION

Carpal tunnel syndrome, or compression of the median nerve at the level of the carpal tunnel, is the most common peripheral entrapment neuropathy.[1,2] Carpal tunnel syndrome has an estimated annual incidence of 1 to 3 cases per 1,000 persons and prevalence of up to 1 to 3% in the general population.[3-6] Symptoms of carpal tunnel syndrome include night symptoms, pain and paresthesias in the median nerve distribution, and can progress to weakness with thenar muscular atrophy.[2,7] These symptoms can be debilitating and between 1997-2010, carpal tunnel syndrome was the second most common diagnosis associated with missed workdays.[8]

While carpal tunnel syndrome is noted to be a highly prevalent and a potentially debilitating disease, many treatment options exist such as observation, splinting, local corticosteroid injections, and surgical release of the transverse carpal ligament.[8] Carpal tunnel release surgery, in particular, has been shown to be highly effective in treating carpal tunnel syndrome.[9,10] Alongside the ever-growing population of the US, and the high incidence of carpal tunnel syndrome, an increasing number of carpal tunnel releases are being performed annually. Data from the United States National Survey of Ambulatory Surgery demonstrated that the number of ambulatory carpal tunnel releases performed increased by 38% from 1996 to 2006.[3] Recent analysis of Medicare & Medicaid Services data suggests that carpal tunnel surgery is the most performed outpatient hand surgery in the United States.[11]

When considering medical decisions, such as elective carpal tunnel release, patients often turn to the internet for additional resources and information.[12] In 2013, an estimated 81% of adults in the United States utilized the internet, and of those with internet access, 72% utilized the internet for health information.[13] Despite the critical role that online health texts play in a patient's understanding and decision making surrounding their care, a growing body of literature in orthopaedic, plastics, and upper extremity surgery suggests that the quality and reading level of patient education materials may be variable or questionable quality.[14-36] Additionally, given the well documented poor health literacy present among patients in the United States,[37-39] the American Medical Association (AMA) recommends that patient education materials be written at a 6th grade reading level.[40,41] Furthermore, it has been recognized that education materials should be written in a manner that is understandable and provides actionable directives to appropriately guide patients in their health care decision making.[15,19-21,28,40,42,43]

Currently, the quality of patient education materials surrounding carpal tunnel surgery is poorly understood. Previous literature has sought to grade the quality of hand and upper extremity surgery resources either through either objective or subjective measures. In terms of objective measures, "readability" statistics have been commonly used and recognized as useful measures of comprehension difficulty. These measures utilize mathematical formulas based on objective variables such as number of words per sentence or number of syllables per word to create an estimate of reading grade level which helps to quantify the complexity or difficulty which patients may face when reading a text.[14,15,23-26,29,30,44-47] An increasingly utilized and new number of studies have recognized that readability statistics are limited by their reliance on syntax, and that evaluation of the a text's ability to convey information so that it can be comprehended and acted on are also critical in the evaluation of a text's quality.[17-21] These studies have utilized the Patient Education Materials Assessment Tool (PEMAT), which seeks to provide "understandability" and "actionability" statistics. Understandability is defined as the ability of readers to "process and explain key messages," and actionability is defined as the ability of readers to "identify what they can do based on the information presented."[48]

While some data exists regarding the quality of available online hand surgery materials, no studies exist yet which seek to reproduce this data among popularly used online materials and systematically evaluate the correlation of these materials to their search rank. The purpose of this study is to utilize PEMAT and validated readability algorithms to quantify understandability, actionability, and readability of popular online carpal tunnel surgery patient education resources, as well as correlate these statistics to search engine rank.

METHODS

Identification of Materials

Our study aimed to grade patient education materials which would be commonly found or searched for by patients. Therefore, Google.com search engine was utilized to identify patient education materials. The Google search engine was selected for this study due to its substantial search engine market share of approximately 84% to 92%.[49,50] On 2/13/20, the average 12 month popularity of the following keywords was compared using Google Trends: "carpal tunnel release," "carpal tunnel procedure," and "carpal tunnel surgery."[51] The keyword "carpal tunnel surgery" was chosen as it was found to be the most popularly used search term. Two Google searches were conducted on 2/13/20 and 2/25/20. These searches were conducted independently to ensure internal validity, and executed by orthopaedic surgery residents (B.G. and T.R.G.) using their personal computers. Prior to the searches, all personal internet data was cleared including cookies, caches, and temporary Internet files as well as saved passwords and logins. Additionally, the evaluators logged out of all Google-related accounts. The results from both searches were then compiled and duplicates removed.

Of the search results, the top 50 were chosen. Studies reviewing click-through rates have suggested that about 70% of user "clicks" within common search engines reside within the top 10 search results—with some estimates suggesting that the rate at which internet users engage in websites outside of the top 10 resulted sites can be as low as <1%.[52-55] Therefore, to ensure our study covered a much broader range, the first 50 websites from each search were targeted. This number is consistent with previous PEMAT and readability statistic studies, which have varied from analyzing the first 10 to 50 websites.[56-60] After collation of these 50 websites from our two independent searches, the Google search engine ranking of each website was determined by averaging the search rank of these two searches.

From these websites, those that met any of the following criteria were excluded: content that did not address carpal tunnel syndrome or its treatment, articles from news sources, narratives based on personal experiences, materials presented solely or primarily in audiovisual format (e.g. Vimeo or YouTube videos), content intended for reference by healthcare professionals (e.g. UpToDate), research published in peer-reviewed journals, and promotional content or discussions about products or services that lacked educational elements (e.g. instructions for contacting a medical office or order forms for specific medical equipment). Materials that were primarily in audiovisual format were omitted due to the inability to conduct a readability analysis on these items. All materials which did not meet exclusion criteria were included.

Readability

In this study, six algorithms were employed to assess the readability of a material: the Flesch Reading Ease, Flesch-Kincaid Grade Level, Simple Measure of Gobbledygook (SMOG) index, Coleman-Liau Index, Gunning Fog Index, and Automated Readability Index (Appendix Table 1).[44,61-64] These algorithms have been consistently applied and proven reliable in prior studies evaluating the readability of surgical lite rature.[14,15,23-26,29,30,44-47] For the purpose of this analysis, content not directly related to patient education, such as copyright details, bibliographic references, and hyperlinks external to the primary text, was deliberately omitted from the readability assessment.

Understandability and Actionability

The evaluation of the understandability and actionability of the included materials was performed utilizing the Patient Education Materials Assessment Tool for Printable Materials (PEMAT-P).[48,65-67] This tool provides distinct scores for understandability and actionability, ranging from 0% to 100%, for each educational resource assessed. A threshold of 70% or higher being considered to have adequate understandability or actionability.[48]

Statistical Methodology

Routine descriptive statistics were utilized to summarize the results of the above assessments. The Spearman rank correlation coefficient (rS) was employed to explore the relationship between search engine ranking, readability, understandability, and actionability of the materials. All statistical computations were conducted using Stata 16 (StataCorp), with statistical significance defined as a p-value < 0.05.

Table 1. Readability Scores

Readability Statistic	Mean	Std. Dev.	Min	Max
Flesch Reading Ease	54.65	9.52	34.90	78.90
Flesch Kincaid Grade Level	9.84	2.54	1.20	14.40
Gunning Fog Index	12.69	1.94	8.60	17.10
SMOG Index	9.44	1.47	6.40	12.90
Coleman Liau Index	12.72	1.35	8.80	15.20
Automated Readability Index	10.35	2.41	4.70	15.20

RESULTS

Patient Education Material Identification and Rank

After collating and removing duplicate websites from our two independent searches, 56 distinct online materials were identified. A total of 39 websites met our predetermined inclusion criteria (Appendix Table 2). The exclusion of 17 websites was due to the following reasons: one primarily presented content which did not address carpal tunnel syndrome or its treatment, one was a narrative review, three were peer reviewed journal papers, two were intended for the promotion of services or goods only, five were intended for reference by professionals, and five were audiovisual materials. The average Google search ranking for the excluded materials was 31 ± 16 (range: 7-48). In contrast, the included materials had a slightly better average rank of 25 ± 14 (range: 1-47), however the mean rankings between included and excluded materials were not significantly different (p=0.10).

Evaluation of Readability

Readability scores are shown in Table 1 and Figure 1. Across our calculated readability scores, average reading grade level ranged from 9.4 to 12.7. The Automated Readability Index rated two websites as suitable for below 6th-grade level and the Flesch Kincaid Grade Level also rated two websites as below this level. No significant correlation was found between readability scores and search rankings (Table 5).

Evaluation of Understandability and Actionability

Understandability and actionability scores within the PEMAT scoring tool are shown in Table 2 and Table 3. The overall average scores for understandability and actionability were 26% ± 24 and 59% ± 15, respectively. No resources met the 70% threshold for adequate actionability, and only eight resources met this threshold for understandability (21%). Correlation between understandability/actionability and readability are shown in Table 4. Understandability was not correlated with any readability statistic, while actionability showed a negative association with two readability scores (Flesch Kincaid Grade Level, Automated Readability Index; p<0.05) and a positive association with Flesch Reading Ease (p<0.05). Of note, higher Flesch Reading Ease scores indicate lower reading grade level (Appendix Table 1). There was no significant correlation between understandability and actionability scores and Google search rankings (Table 5).

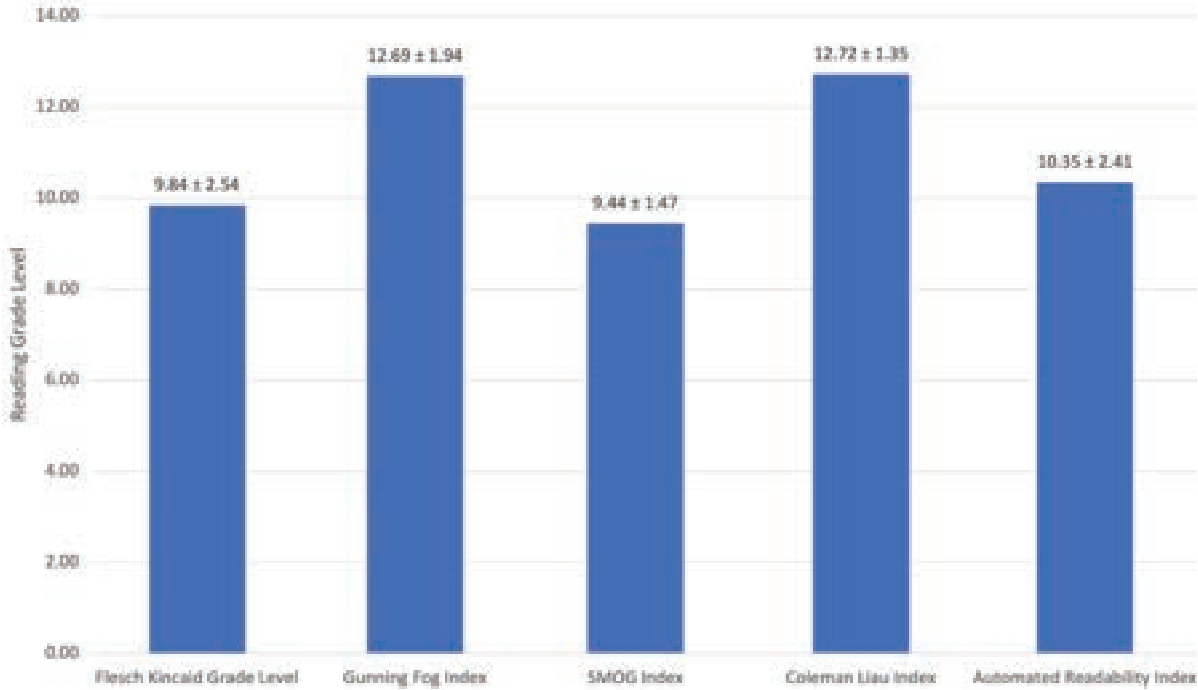

Figure 1. Reading Grade Level.

Table 2. Actionability Scores

PEMAT Item, Actionability	No. of Materials Qualified for Analysis	Percentage of Qualified Materials Fulfilling Criteria	Standard Deviation
The material clearly identifies at least one action the user can take.	39	56%	50%
The material addresses the user directly when describing actions.	39	54%	51%
The material breaks down any action into manageable, explicit steps.	39	21%	41%
The material provides a tangible tool (e.g., menu planners, checklists) whenever it could help the user take action.	39	3%	16%
The material provides simple instructions or examples of how to perform calculations. (Excluded if no calculations)	0	.	.
The material explains how to use the charts, graphs, tables, or diagrams to take actions. (Excluded if no charts, graphs, tables, or diagrams)	0	.	.
The material uses visual aids whenever they could make it easier to act on the instructions.	39	0%	0%
Overall Actionability (n=39, Min—Max: 0% – 67%)		26%	24%

Table 3. Understandability Scores

PEMAT Item, Understandability	No. of Materials Qualified for Analysis	Percentage of Qualified Materials Fulfilling Criteria	Standard Deviation
The material makes its purpose completely evident.	39	72%	46%
The material does not include information or content that distracts from its purpose.	39	51%	51%
The material uses common, everyday language.	39	54%	51%
Medical terms are used only to familiarize audience with the terms. When used, medical terms are defined.	39	51%	51%
The material uses the active voice.	39	36%	49%
Numbers appearing in the material are clear and easy to understand. (Excluded if no numbers)	0	.	.
The material does not expect the user to perform calculations.	39	82%	39%
The material breaks or "chunks" information into short sections.	0	.	.
The material's sections have informative headers. (Excluded if qualified as very short material)	0	.	.
The material presents information in a logical sequence.	39	90%	31%
The material provides a summary. (Excluded if qualified as very short material)	0	.	.
The material uses visual cues to draw attention to key points. (Videos excluded)	39	54%	51%
The material uses visual aids whenever they could make content more easily understood.	39	28%	46%
The material's visual aids reinforce rather than distract from the content. (Excluded if no visual aids)	0	.	.
The material's visual aids have clear titles or captions. (Excluded if no visual aids)	0	.	.
The material uses illustrations and photographs that are clear and uncluttered. (Excluded if no visual aids)	0	.	.
The material uses simple tables with short and clear row and column headings. (Excluded if no visual aids)	0	.	.
Overall Understandability (n=39, Min—Max: 38% to 88%)		59%	15%

Table 4. Association Understandability/Actionability and Readability Scores

	Overall Understandability		Overall Actionability	
	Spearman Rho	Significance, p-value	Spearman Rho	Significance, p-value
Flesch Reading Ease	0.23	0.17	0.39	0.02
Flesch Kincaid Grade Level	-0.20	0.25	-0.39	0.02
Gunning Fog Index	-0.18	0.28	-0.33	0.05
SMOG Index	-0.21	0.22	-0.33	0.05
Coleman Liau Index	-0.13	0.46	-0.30	0.08
Automated Readability Index	-0.21	0.22	-0.39	0.02

Table 5. Association Between Quality Scores and Google Search Rank

Quality Metric	Spearman's Rho	Significance Level, p-value
Readability		
Flesch Reading Ease	-0.15	0.37
Flesch Kincaid Grade Level	0.20	0.25
Gunning Fog Index	0.11	0.52
SMOG Index	0.18	0.30
Coleman Liau Index	0.11	0.51
Automated Readability Index	0.13	0.44
Understandability, Overall	-0.22	0.19
Actionability, Overall	-0.09	0.60

DISCUSSION

Our study utilized PEMAT and validated readability algorithms to quantify understandability, actionability, and readability of popular online patient education resources regarding carpal tunnel surgery, as well as correlate these statistics to search engine rank. Overall, CTR online education materials scored poorly with respect to readability, understandability, and actionability. This highlights the need for improvement in online patient resources. Through evaluation of thirty-nine patient education resources, we found that two readability algorithms identified two resources as below the AMA recommended 6th-grade level,[40,41] while all other algorithms found no resources were suitably below this level. PEMAT scores identified mean understandability as 59% with only eight resources (21%) meeting thresholds deemed adequately understandable. PEMAT scoring also demonstrated there were no resources which had suitable actionability, with a mean of score 26%.

Our analysis of understandability and actionability also demonstrated several items which a majority of materials did not include or execute, which could improve their quality. In terms of understandability, less than half of studies used active voice or utilized visual aids whenever possible to make content more easily understood. Additionally, no studies sought to break their material down into short sections. In terms of actionability, less than half of the studies broke down actionable tasks into explicit steps or provided tangible tools (such as checklists) to help patients identify actionable pursuits. This suggests that a majority of patient education materials could take the above outlined improvements in order to improve their quality metrics.

This study also investigated the correlation between readability, actionability, and understandability. While studies with lower reading grade levels demonstrated spearman correlation coefficients of higher understandability scores, these correlation coefficients were not statistically significant. This suggests that no correlation necessarily exists between understandability and readability. It is therefore important that when patient education material writers work to improve the syntax and vocabulary of their materials to reduce reading grade level scores, they understand that this does not necessarily mean a material is presented in a way where key messages can be comprehended by patients.

Actionability scores, meanwhile, demonstrated correlation with some readability metrics. Flesch Reading Ease, Flesch Kincaid Grade Level, and Automated Readability Index scores were all statistically significantly correlated with actionability such that higher actionability scores were correlated with lower reading grade levels. Actionability scores improve when texts present simple instructions, explicit steps, or list manageable actions. Intuitively, these characteristics would be more likely to occur in the same setting as simple sentence syntax. Therefore, there may be some natural tendency for texts which seek to improve their actionability to simultaneously improve their reading grade level.

Finally, our study also investigated the correlation between quality metrics and Google search rank. Our results found that neither readability, understandability, nor actionability were associated with Google search rank. This suggests that resources scoring highly in quality metrics do not necessarily have higher search rank and are not necessarily the most readily available to patients.

Previous studies have supported our findings. Eberlin et al. evaluated the readability of 13 of the most popular patient education resources for carpal tunnel surgery.[68] They utilized 9 different algorithms, none of which demonstrated a suitable reading level for the general population. Their overall reading grade level was 13.1 with a mean readability score range of 10.8-15.3. They also concluded that improved resources were needed to assist with patient literacy. Fang et al. evaluated patient handouts for carpal tunnel syndrome and utilized an information score (IS) for content evaluation, two readability algorithms, and PEMAT for understandability.[18] They included 56 online patient education handouts. Their average IS score was 74.6%, however 78.6% of the handouts included non-evidence-based treatment recommendations. The average PEMAT score was 70.2% and the average readability score was 7.7. Although this paper evaluated carpal tunnel syndrome while ours evaluates surgery specifically, our findings are similar. Our PEMAT scores were comparably low and reveal that further work must be done to make patient materials more understandable. Additionally, Fang et al.'s data also suggest that patient education materials are not written at a grade level that is adequate for the general population.

More broadly within the field of hand and upper extremity surgery, Wang et al. evaluated the readability of hand articles found in the patient education libraries on both the American Academy of Orthopaedic Surgeons (AAOS) and American Society for Surgery of the Hand (ASSH) websites.[69] 34 articles were found on the AAOS website with mean grade level scores of 8.5 and 8.8 through two different algorithms. Within the ASSH website, 49 articles demonstrated grade level scores of 10.4 and 10.8. Their findings demonstrated that readability of hand patient resources were poor, and should be improved even within professional society platforms.

The results of our study also fit trends found in the broader orthopaedic surgery literature. Gulbrandsen et al. evaluated the readability, understandability, and actionability of online patient materials for total knee arthroplasty.[20] 34 websites were included and the mean readability for various algorithms ranged from 11.1 to 14.7. Mean understandability utilizing PEMAT was 54.9 with mean actionability of 30.3. These quality metrics have also been investigated in the setting of ACL surgery.[19] 39 websites were included with mean readability ranging from 9.93 to 13.09. Mean understandability and actionability were also low at 59.2 and 34.4, respectively. Patient materials seem to lack readability and understandability in many specialties of orthopedics.

Despite patient materials frequently being too difficult to read and understand, online patient resources have become increasingly utilized to attempt to improve health literacy.[48,70-77] It is important to note that limited health literacy results in an increased risk for inappropriate health decisions. Multiple studies have previously shown that deficits in health literacy correlate to poor treatment adherence, increased length of stay, and higher mortality.[42,78-82] It is essential for health care providers to take steps to improve online patient education materials and in turn, assist with patient health literacy to improve patient outcomes.

Overall, our findings confirm the conclusions of many other studies which express concern over the poor the readability, understandability, and actionability of online patient materials.[48,70-77,83] Our study additionally has been the first to demonstrate that Google rank does not correlate with the writing quality of carpal tunnel surgery related materials. This should be emphasized to patients attempting to find the most appropriate information for their diagnosis and treatment. Providers, health care institutions, and medical societies should take responsibility for the lack of accessible and understandable patient education materials as these materials are crucial components to patient care and outcomes.

There are several limitations to our study that should be considered. First, the proprietary algorithm changes of Google resulted in differing search results between our two authors. However, we attempted to control for these factors by clearing all history, cookies, and cache prior to the independent Google searches. Additionally, a mean in Google rank was utilized to account for these variances. Second, our study relied on Google as the only search engine utilized. Although not all patients use Google, some estimates suggest that Google comprises up to 94% of the online search market share. While our study therefore does not encompass all patient education materials present online, it does provide a focused view on which resources are most likely the most popularly accessed. This may be of higher utility to material writers. Third, within the evaluation of the patient resources, there is grading and implicit bias in calculating the PEMAT scores. Studies regarding the development of PEMAT, however, have demonstrated that the PEMAT rubric is a reliable and validated tool for assessing understandability and actionability.[48,66,67] Furthermore, our PEMAT scores are consistent with that found in literature surrounding hand surgery.[69] Lastly, although this study suggests that that resources are of poor quality, we did not study or quantify the degree to which patients would benefit from improved resources.

CONCLUSION

Carpal tunnel surgery online education materials scored poorly with respect to readability, understandability, and actionability. There was also no association between readability, understandability, and actionability with Google search rank order. In the era of shared decision-making, future efforts should be made by hand specialists to improve the readability of online patient resources.

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APPENDIX Table 1.

Appendix Table 1. Interpretation and Calculation of Readability Statistics

Statistic	Calculation	Interpretation
Flesch Reading Ease (FRE)	206.835 - 1.015 x (words/sentences) - 84.6 x (syllables/words)	90.1-100.0 = 5th-grade material
		70.1-80.0 = 7th-grade material
		50.1-60.0 = 10th-12th grade material
		0.0-30.0 = college graduate material
Flesch-Kincaid Grade Level (FKGL)	0.39 (words/sentences) + 11.8 (syllables/words) − 15.59	Estimates grade level of material
SMOG Readability Formula (SMOG)	1.0430 x square-root(30 x words with ≥3 syllables/sentences) + 3.1291	Estimates grade level of material
Gunning Fog Index (GFI)	0.4 (words/sentences + words with ≥3 syllables/words)	Estimates grade level of material
Automated Readability Index (ARI)	4.71 (characters/words) + 0.5 (words/sentences)	Estimates grade level of material
Coleman-Liau Index (CLI)	0.0588 (Letters per 100 words) − 0.3 (sentences per 100 words) − 15.8	Estimates grade level of material

APPENDIX Table 2.

Appendix Table 2. Included Websites (n =39)

Website
https://mayfieldclinic.com/pe-carpaltunnel.htm
https://medlineplus.gov/ency/article/002976.htm
https://midwestbonejoint.com/hand/endoscopic-carpal-tunnel-release/
https://my.clevelandclinic.org/health/diseases/4005-carpal-tunnel-syndrome
https://myhealth.alberta.ca/health/AfterCareInformation/pages/conditions.aspx?HwId=ug3907
https://newsnetwork.mayoclinic.org/discussion/mayo-clinic-q-and-a-recovery-after-surgery-for-carpal-tunnel-syndrome-whats-normal-and-whats-not/
https://orthoinfo.aaos.org/en/diseases--conditions/carpal-tunnel-syndrome/
https://rothmanortho.com/specialties/treatments/carpal-tunnel-release
https://stanfordhealthcare.org/medical-conditions/bones-joints-and-muscles/carpal-tunnel-syndrome/treatments/surgery.html
https://www.barrowneuro.org/specialty/carpal-tunnel-surgery/
https://www.bnasurg.com/treatment-options/carpal-tunnel-surgery/
https://www.brighamandwomens.org/medical-resources/carpal-tunnel-surgery
https://www.cfaortho.com/endoscopic-carpal-tunnel-release-endoscopiccarpal
https://www.cooperhealth.org/services/single-port-endoscopic-carpal-tunnel-release-surgery
https://www.drugs.com/cg/carpal-tunnel-surgery.html
https://www.geisinger.org/sites/ortho/870-carpal-tunnel-surgery-central-no
https://www.healthgrades.com/right-care/carpal-tunnel-surgery/are-you-a-good-candidate-for-carpal-tunnel-release
https://www.healthline.com/health/carpal-tunnel-release
https://www.hopkinsmedicine.org/health/treatment-tests-and-therapies/carpal-tunnel-release
https://www.mercy.com/health-care-services/orthopedics-sports-medicine-spine/specialties/hand-wrist-elbow/treatments/carpal-tunnel-release-surgery
https://www.mycarpaltunnel.com/carpal-tunnel-surgery/
https://www.nghs.com/carpal-tunnel-surgery
https://www.ninds.nih.gov/Disorders/Patient-Caregiver-Education/Fact-Sheets/Carpal-Tunnel-Syndrome-Fact-Sheet
https://www.northshore.org/healthresources/encyclopedia/encyclopedia.aspx?DocumentHwid=hw212492
https://www.ogdenclinic.com/procedure/detail?name=carpal-tunnel-surgery
https://www.raleighortho.com/blog/will-i-get-better-after-carpal-tunnel-surgery/
https://www.southcoast.org/services/orthopedics/carpal-tunnel-surgery/
https://www.sports-health.com/treatment/hand-and-wrist-injury-treatment/all-about-carpal-tunnel-release-surgery
https://www.stcharleshealthcare.org/services/orthopedic-and-neurological-care/carpal-tunnel-surgery
https://www.thedailybeast.com/carpal-tunnel-can-be-treated-in-a-10-minute-surgery-heres-how-it-works
https://www.uofmhealth.org/health-library/hw212359
https://www.urmc.rochester.edu/encyclopedia/content.aspx?contenttypeid=135&contentid=29
https://www.uwhealth.org/health/topic/surgicaldetail/endoscopic-carpal-tunnel-surgery-for-carpal-tunnel-syndrome/hw212492.html
https://www.verywellhealth.com/open-surgery-or-endoscopic-carpal-tunnel-surgery-4083069
https://www.virginiamason.org/carpal-tunnel-surgery
https://www.wakemed.org/surgery-carpal-tunnel-release-what-to-expect
https://www.webmd.com/pain-management/carpal-tunnel/do-i-need-carpal-tunnel-surgery
https://regenexx.com/blog/carpal-tunnel-surgery-recovery-2/
https://www.hawaiipacifichealth.org/healthier-hawaii/be-healthy/minimally-invasive-carpal-tunnel-surgery-provides-maximum-results/

DISCORDANCE IN PUBLISHED 30-DAY READMISSION RATES FOLLOWING PRIMARY TOTAL HIP AND TOTAL KNEE ARTHROPLASTY: CENTERS FOR MEDICARE AND MEDICAID SERVICES (CMS) VERSUS THE NATIONAL SURGICAL QUALITY IMPROVEMENT PROGRAM (NSQIP)

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ABSTRACT

Background: 30-day readmission is an important quality metric evaluated following primary total joint arthroplasty (TJA) that has implications for hospital performance and reimbursement. Differences in how 30-day readmissions are defined between Centers for Medicare and Medicaid Services (CMS) and other quality improvement programs (i.e., National Surgical Quality Improvement Program [NSQIP]) may create discordance in published 30-day readmission rates. The purpose of this study was to evaluate 30-day readmission rates following primary TJA using two different temporal definitions.

Methods: Patients undergoing primary total hip and primary total knee arthroplasty at a single academic institution from 2015-2020 were identified via common procedural terminology (CPT) codes in the electronic medical record (EMR) and institutional NSQIP data. Readmissions that occurred within 30 days of surgery (consistent with definition of 30-day readmission in NSQIP) and readmissions that occurred within 30 days of hospital discharge (consistent with definition of 30-day readmission from CMS) were identified. Rates of 30-day readmission and the prevalence of readmission during immortal time were calculated.

Results: In total, 4,202 primary TJA were included. The mean hospital length of stay (LOS) was 1.79 days. 91% of patients were discharged to home. 30-day readmission rate using the CMS definition was 3.1% (130/4,202). 30-day readmission rate using the NSQIP definition was 2.7% (113/4,202). Eight readmissions captured by the CMS definition (6.1%) occurred during immortal time.

Conclusion: Differences in temporal definitions of 30-day readmission following primary TJA between CMS and NSQIP results in discordant rates of 30-day readmission.

Level of Evidence: III

Keywords: total joint, immortal time bias, NSQIP

INTRODUCTION

Thirty-day readmission is an important quality metric following primary total joint arthroplasty (TJA). Readmission rates have implications for scoring hospital performance and reimbursement.[1,2] In the United States, unadjusted 30-day readmission rates following primary total knee arthroplasty (TKA) and total hip arthroplasty (THA) are approximately 4-5%.[2,3]

Centers for Medicare and Medicaid Services (CMS) has promoted value-based care with attempts to improve care quality via the Hospital Readmission Reduction Program, Bundled Payments for Care Improvement (BPCI), and most recently, Comprehensive Care for Joint Replacement (CJR).[4] At the same time, central leadership organizations, such as the American College of Surgeons (ACS), has dedicated increased resources to capturing and maintaining data on short-term complication and readmission rates following select surgical procedures via registries like the National Surgical Quality Improvement Program (NSQIP). Recent initiatives aimed at decreasing short-term readmission rates following primary TKA and THA have proven successful, even in patients that are increasingly comorbid.[4,5]

NSQIP data has been used extensively to examine short-term outcomes following primary TKA and THA.[3-9] NSQIP data may also be used to inform policy decisions and create risk-adjustment models.[7,10] Thirty-day readmissions are captured in NSQIP, with the 30-day capture starting on postoperative day one following surgery.[11] Alternatively, CMS defines 30-day readmissions as starting from the time of patient discharge from the hospital. Thus, during the period of time from surgery to patient discharge, the patient is "immortal" to readmission.[12,13] This creates an immortal time bias which has been previously defined as "the error in estimating the association between the exposure and the outcome that results from misclassification or exclusion of time intervals."[14]

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Differences in how 30-day readmissions are defined between CMS and other quality improvement programs (i.e., NSQIP]) may create discordance in published 30-day readmission rates. The disparities in definitions have potential implications for measurement of quality measures, which may in turn affect hospital reimbursement.[12,13,15] Given projected increases in volume of primary total knee arthroplasty (TKA) over the next 10 years,[1,16] an understanding of potential discordance in published 30-day readmission rates following primary TKA and THA between CMS and NSQIP definitions will be of increasing importance.

Therefore, the primary purpose of this study was to evaluate 30-day readmission rates following primary TKA and THA using two different, commonly utilized, temporal definitions. We also identify and report demographic data to assess for national population compatibility, length of stay, and reason for readmission.

METHODS

Following institutional review board (IRB) approval, all patients undergoing primary TKA and primary THA at a single academic institution from 2015-2020 were identified via common procedural terminology (CPT) codes 27447 and 27130, respectively. Patients undergoing revision TKA or THA and patients undergoing TKA THA for an acute fracture were excluded as these patients traditionally have varying lengths of stay.

Readmission data was abstracted from the electronic medical record (EMR) and institutional NSQIP data. Readmissions that occurred within 30 days of surgery (consistent with definition of 30-day readmission in NSQIP) and readmissions that occurred within 30 days of hospital discharge (consistent with definition of 30-day readmission from CMS) were identified. Rates of 30-day readmission and the prevalence of readmission during immortal time were calculated. Other data collected included patient demographics, length of stay (LOS), readmission reason, and discharge location.

RESULTS

In total, 4,202 cases were included, including 2,345 primary THA and 2,008 primary TKA. One hundred and fifty-one patients were excluded for either fracture or revision TJA. For patients undergoing THA, average age, BMI and percentage female was 61.12 years, 31.30, and 50.84% respectively. For TKA the average age, BMI and percentage female was 63.51, 34.00, and 55.18% respectively. Table 1.

Mean hospital LOS for the cohort was 1.8 days (1.9 for THA, 1.7 for TKA). 91% of patients discharged to home. 30-day readmission rate using the CMS definition was 3.1% (130/4,202) (Table 2).

30-day readmission rate using the NSQIP definition was 2.7% (113/4,202). Eight readmissions captured by the CMS definition (6.15%) occurred during immortal time. Nine readmissions failed to be captured by NSQIP but were within the defined 30-day time frame (Table 3).

The most common reason for readmission was infection (41) (Table 4).

Table 1. Demographics

Demographics	Total Hip Arthroplasty	Total Knee Arthroplasty
Mean Age	61.1	63.5
BMI	31.3	34.0
% Women	50.8	55.2

Table 2. Discharge Location

Discharge Location	Total Hip Arthroplasty	Total Knee Arthroplasty
Home	91%	91%
Skilled Nursing Facility	8.1%	7.2%
Facility which was home	0.7%	1.6%
Rehab	0.02%	0.2%
Expired	0.05%	0.0%

Table 3. Readmission Rates

Readmission Rates	NSQIP	Electronic Health Record	"Immortal" Readmissions
Total Hip Arthroplasty	3.2% (71/2206)	3.8% (83/2206)	4.8 % (4/83)
Total Knee Arthroplasty	2.1% (42/1996)	2.5% (47/1996)	8.5% (4/47)
Combined	2.7% (113/4202)	3.1% (130/4202)	6.2% (8/130)

Table 4. Readmission Reason

Readmission Reason	Total Hip Arthroplasty	Total Knee Arthroplasty
Infection or wound issue	28 (33.7%)	13 (27.7%)
Dislocation	10 (12%)	0 (0%)
Cardiopulmonary*	16 (19%)	5 (10.6%)
Other	29 (34.9%)	29 (61.7%)

*Includes pulmonary emboli, deep vein thrombosis, chest pain, shortness of breath, syncope, pneumonia.

DISCUSSION

This study identifies differences in temporal definitions of 30-day readmission following primary TJA between CMS and NSQIP. These differences have implications for national quality measures and hospital reimbursement. Although small, these differences in readmission rates may be the difference between average and top preforming surgeons and respective hospital systems.

Immortal time bias (ITB) consistently leads to an underestimation of the rate ratio, thereby producing a misleading perception of treatment efficacy in diminishing the frequency of adverse events.[17] Immortal time bias has persisted over time and remains present across various medical specialties.[14,18,19] The significance of immortal time bias in orthopedic research is gaining interest in recent years.[20-23] In 2014, similar to our study, Lucas et al. concluded that the NSQIP database systematically undercounts 30-day post-discharge readmissions, and this bias worsens with longer lengths of stay.[12] Issues with immortal time bias in NSQIP data continue to be examined within the literature.[13]

We also identified nine readmissions not caught by the NSQIP database. These were almost always found by accessing telephone notes in the EMR where an outside provider had called in, informing us that our patient had been admitted to an outside hospital. We do not have an explanation for why these readmissions were not caught by the NSQIP database.

There are multiple limitations to the current study. This study identifies a period of immortal time within the NSQIP database. In our study, the immortal time generated by NSQIP is proportional to the length of stay. Given the short average length of stay for TJA in our study, the length of immortal time is also brief. This is a limitation of the current study, and we would expect the impact of immortal time to be larger in patients with longer hospital stays such as patients undergoing spine surgery.

CONCLUSION

Differences in temporal definitions of 30-day readmission following primary TJA between CMS and NSQIP results in discordant rates of 30-day readmission. Stakeholders should be cognizant of these differences when evaluating readmission data. The associated risk of immortal time bias is present within the NSQIP definition of 30-day readmission.

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INFLUENCE OF THE ADVANCED ONE-STEP MIXING SYSTEM UNDER NON-VACUUM ON THE MECHANICAL PROPERTIES OF ACRYLIC BONE CEMENT

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ABSTRACT

Background: The specific aim of this study was to evaluate the mechanical properties of cement prepared with the advanced one-step mixing system and whether the addition of vacuum conditions yielded an appreciable improvement in the biomechanical strength or overall quality of bone cement.

Methods: The advanced one-step mixing system was used. Twelve specimens were prepared by mixing under vacuum conditions and 12 specimens were prepared by mixing without a vacuum. Radiographs of cement specimens were analyzed to determine the porosity of the test region. Tensile testing of the specimens was performed with a loading rate of 2.54mm/min at room temperature. The ultimate tensile strength (UTS) and the tensile elastic modulus (E) were determined for each sample.

Results: The UTS of the bone cement samples mixed under vacuum conditions were not significantly different than those mixed without vacuum (vacuum: 39±6MPa; non-vacuum: 35±6MPa; p=0.637). The E of samples mixed under vacuum conditions was significantly higher than the bone cement mixed without vacuum (vacuum: 2.78±0.06GPa; non-vacuum: 2.63±0.15GPa; p=0.019). Radiographic images showed samples mixed under vacuum conditions contained fewer defects than the samples mixed without vacuum (vacuum: 3.5%±3.3% (range: 0.0%-9.0%); non-vacuum: 6.9%±1.0% (range: 4.6%-8.2%))

Conclusion: Mixing bone cement with the advanced one-step mixing system under vacuum conditions does not produce an appreciable difference in the UTS of the bone cement in a bench biomechanical testing model compared to the bone cement mixed without vacuum. It does, however, create a less porous cement mixture with a higher E compared to cement mixed without vacuum.

Level of Evidence: V

Keywords: polymethylmethacrylate (PMMA), bone cement, vacuum conditions, mechanical behavior

INTRODUCTION

Polymethylmethacrylate (PMMA) bone cement is widely used in arthroplasty procedures for the fixation of metallic prosthetic implants to living bone. PMMA bone cement is a brittle material, the presence of defects (bubbles) during mixing or curing can negatively impact its mechanical properties. Similarly, porosity has been shown to affect the fatigue life of bone cement with increased porosity leading to decreased fatigue life. It has been previously demonstrated that mixing and collecting PMMA bone cement under vacuum conditions yields a homogenous mixture without negatively affecting the viscosity or other mechanical properties of the cement.[1-3] Vacuum mixing was developed for bone cement in the early 1980s, as a technique to both reduce cement porosity and reduce the evaporation of harmful monomers in the operating room.[4-6] Hand mixing and manual collection of cement without the use of vacuum has been thought to intermix air and subsequently decrease the strength of the cement mantle around a prosthesis. However, when Messick et al.[7] used paired femoral constructs prepared with either hand-mixed or vacuum-mixed cement in a cadaver model, they concluded that the reduction in porosity achieved with vacuum mixing did not affect the porosity of the periprosthetic mantle. However, the distribution of the porosity can be affected by the mixing technique. Lindén et al.[8] evaluated mixing techniques as well and they concluded that mechanical mixing resulted in cement with decreased porosity and increased density compared to other techniques (manual, centrifuged manual,

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centrifuged mechanical). However, no studies to date have compared the mechanical properties of vacuum-mixed versus air-mixed cement within a mechanical mixing system.

The advanced one-step cement mixing and delivery system requires fewer steps to load, mix and transfer the PMMA bone cement than traditional mixing techniques. The polymerization process begins when the powder and liquid components are combined. A rotary mixing piece then connects to a power tool on a ream setting to mix the cement quickly and consistently. This aims to create a homogenous mixture and reduce variables that can negatively impact cement quality. The mixing blade helps eliminate unmixed powder, reduce defects, and bring bubbles to the surface of the mixture to reduce porosity. During cement preparation, methylmethacrylate monomer can be released into the atmosphere, exposing staff to these potentially harmful fumes. The rotary mixing piece of the advanced cement mixer contains a built-in charcoal filter to reduce the escape of these fumes. With the improvements present in this bone cement mixing system, the question arises whether mixing under vacuum conditions remains necessary. Given these advances in cement mixing systems, it is worthwhile to investigate whether vacuum mixing still carries an appreciable increase in cement quality compared to mixing in air. The specific aim of this study was to evaluate and compare the mechanical properties of bone cement samples mixed under vacuum and samples mixed under non-vacuum conditions utilizing an advanced one-step mixing system.

METHODS

This was a bench biomechanical study, and approval for this study was obtained from our institute research committee. The commercially available acrylic bone cement Simplex™ P bone cements (Stryker Howmedica Osteonics, Mahwah, NJ) with advanced one-step cement mixing and delivery system (Stryker Revolution Cement Mixing and Delivery System, Stryker, Howmedica Osteonics, Mahwah, NJ) was used (Figure 1). Two groups of specimens were compared: bone cement mixed under vacuum conditions (control) and bone cement mixed without vacuum. Universal precautions were followed in accordance with Occupational Safety and Health Administration standards, and all procedures were performed according to the manufacturer's standard protocol. Both groups of specimens were mixed using the advanced one-step mixing system with the following standard protocol: first pour bone cement powder and liquid monomer into the cartridge, then remove the loading funnel and secure the lid assembly onto the cartridge. For the vacuum mixed cement specimens, attach the vacuum tube to the lid assembly on the cartridge and apply a 508 - 559 mmHg vacuum pressure. The non-vacuum mixed cement specimens did not have the vacuum tube attached to the lid and was prepared under atmospheric pressure conditions. The mixing shaft of the lid assembly was then attached to a surgical rotary power tool set to the "ream" setting, mixing the bone cement for 90 seconds while moving the shaft up and down. This was done at standard operating room temperature (18 to 19 °C). Once the bone cement is well mixed, the vacuum tubing was removed from the lid assembly on the cartridge. The mixing blade was then released by pressing and sliding the blade release

Figure 1. Commercially available acrylic bone cement with advanced one-step cement mixing and delivery system.

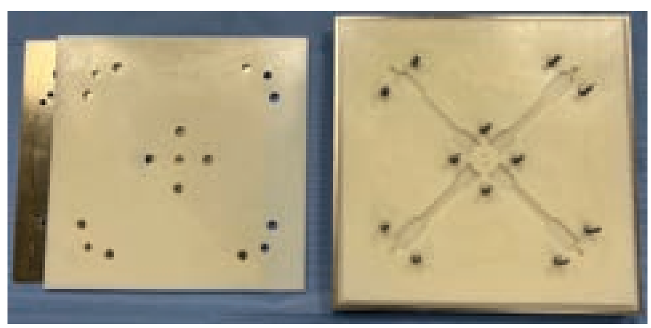

Figure 2. Bone cement tensile specimen mold.

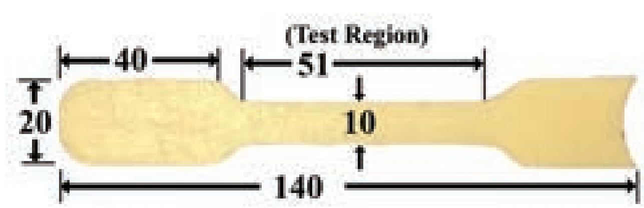

Figure 3. Tensile specimen dimension (in mm) with thickness of 3 mm.

button, and the mixing blade remained in the cartridge. The mixing shaft on the cartridge was removed from the lid assembly and attached the application nozzle. The bone cement filled cartridge was then placed into the cradle of the cement injection gun.

The experimental setup and test protocol were similar to that previously described in the literature.[9,10] A custom-designed tensile specimen mold was designed and used to create four standard tensile specimens at a time (Figure 2). The mixed cement from each group was transferred into the tensile specimen mold using a cement injection gun under "fill" setting. Care was taken not to trap air in the cement during the injection process by avoiding the layering of cement. These specimens were allowed to solidify in the mold under pressure for one hour and then removed from the mold. These specimens were allowed to fully cure for at least 24 hours before testing. Each specimen was visually inspected for any powder clots, and any flawed specimens were excluded. A total of 12 specimens from each group were tested. Figure 3 shows detailed dimensions of each cement specimen with a thickness of 3 mm.

The test regions of all the specimens (cross-sectional area) were measured by using digital caliper (General Tools & Instrument, Secaucus, NJ), and radiographic images of all the specimens were taken. The estimated porosity of each specimen was measured utilizing the radiographic images and the ImageJ software (National Institutes of Health, imagej.net).[11,12] The porosity image analysis was restricted to the test region of each specimen. The area of interest was identical for each sample, and the data was extrapolated to the area to determine percent porosity.

A servo-hydraulic materials testing system (Model 8874; Instron, Norwood, MA) with 25 kN load cell was used for load-to-failure tensile testing for both groups. Each specimen from both study groups were loaded from 0 N to complete structural failure at a stroke rate of 2.54 mm/min. Load and displacement data were collected at 100 Hz. The ultimate tensile strength (UTS) and the tensile elastic modulus (E) were then determined. This mechanical test was performed in air and at room temperature (21 °C).

Statistical Analysis

Descriptive statistics of the mean, standard deviation, and range were determined for the measured variables. Independent sample t-test method with equal variances assumed was used to compare notable effects among different parameters (UTS, E, porosity) between the two groups. All statistical testing methods used were performed using IBM SPSS Statistics software (Version 24.0; IBM Corporation, Armonk, NY). Significance was defined as $p < 0.05$.

RESULTS

The UTS of the bone cement samples mixed under vacuum conditions were not significantly different than the bone cement mixed under non-vacuum (vacuum: 39 ± 6 MPa; non-vacuum: 35 ± 6 MPa; $p = 0.637$) (Figure 4). The tensile elastic modulus (E) of the bone cement mixed under vacuum conditions was significantly higher than the bone cement mixed without vacuum (vacuum: 2.78 ± 0.06 GPa; non-vacuum: 2.63 ± 0.15 GPa; $p = 0.019$) (Figure 5).

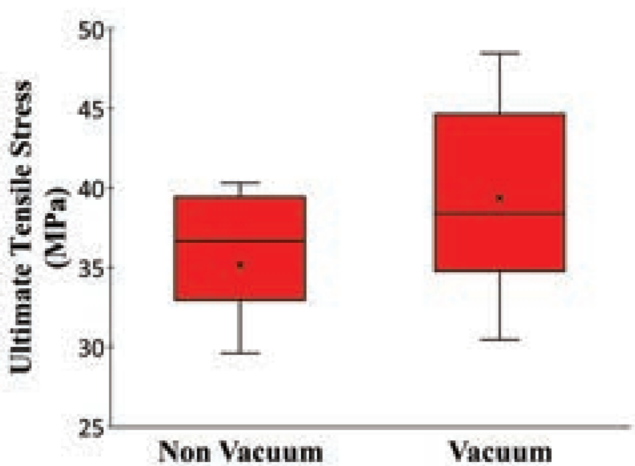

Figure 4. Ultimate tensile strength (UTS) results for each mixing technique group.

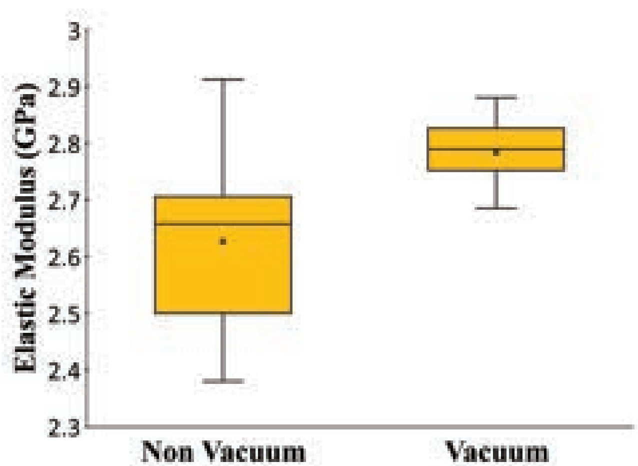

Figure 5. Tensile elastic modulus (E) results for each mixing technique group.

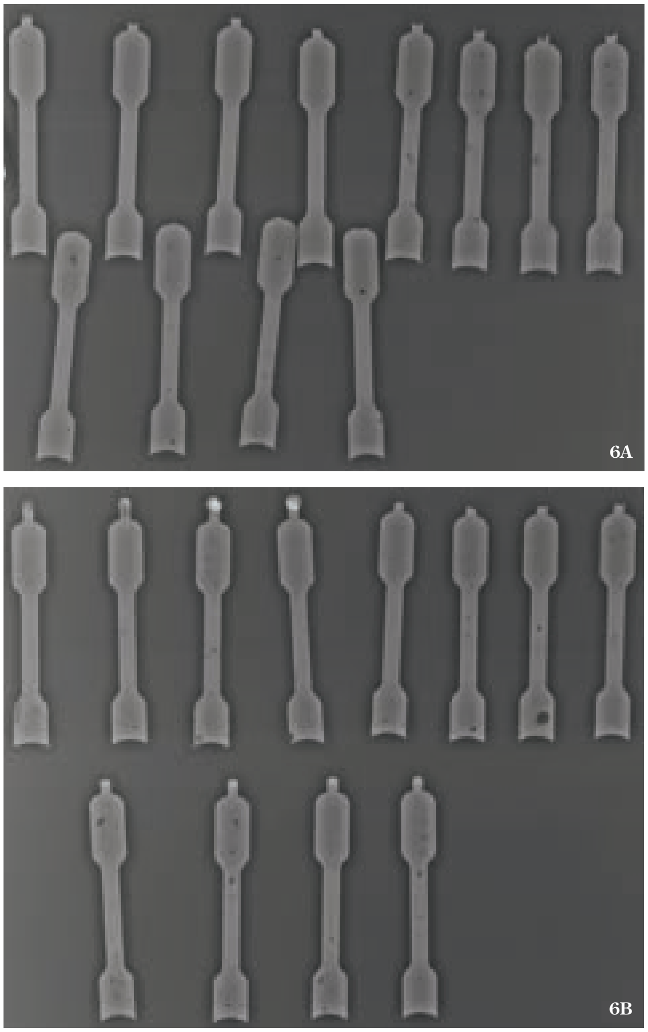

Figure 6A to 6B. Radiographic images of specimens used in this study. (6A) bone cement mixed under vacuum conditions and (6B) bone cement mixed without vacuum.

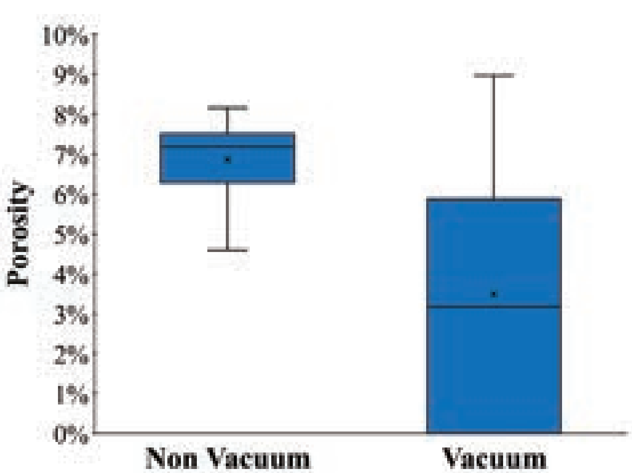

Figure 7. Porosity results for each mixing technique group.

Observing from the radiographic images for bone cement samples, it can be noted that there were fewer pores present in the samples of the cement prepared under vacuum in comparison to those under non-vacuum (Figure 6). The mean porosity image analysis showed a statistically significant difference between vacuum and non-vacuum mixed samples ($p = 0.06$). The bone cement samples mixed under vacuum conditions contained fewer defects than the samples mixed under non-vacuum (vacuum: 3.5% ± 3.3% (range: 0.0% - 9.0%); non-vacuum: 6.9% ± 1.0% (range: 4.6% - 8.2%)) (Figure 7).

DISCUSSION

The present biomechanical study is the first study to compare the mechanical properties of the bone cement samples mixed under vacuum against those mixed under atmospheric conditions utilizing an advanced one-step mixing system. The key observation is that this study found no significant difference in the UTS of the bone cement between vacuum and non-vacuum mixing using the one-step mixing system. There were, however, differences in the elastic modulus and porosity between the 2 techniques. A number of authors have concluded that manual mixing of bone cement with a traditional spatula and bowl method creates an unpredictable cement mixture with a large variation in the porosity[2,3,13] and that the addition of vacuum conditions to mixing reduces this porosity. The results of the current study were consistent with this data, showing up to a 97% reduction in porosity in the samples mixed under vacuum. However, it should be noted that the samples mixed under vacuum had a much greater variability in percent porosity compared to those mixed under non-vacuum. Vacuum mixed samples ranged from 0 to 9% porosity whereas non-vacuum mixed samples ranged from 4.6% to 8.2%. This would suggest that while vacuum mixing has the potential to create a less porous mixture, it is more difficult to consistently predict the amount of porosity that the mixture will achieve.

The results of the current study are consistent with those of Wixson et al.,[14] which demonstrated bone cement with <1% porosity did translate to significantly improved tensile and compressive strength when tested. Given that the vacuum mixed samples in the current study did not consistently achieve a porosity of <1% but rather averaged 3.5% porosity, this may explain the lack of significant difference in tensile strength during biomechanical testing. This may suggest a threshold level of porosity that must be achieved to observe significant improvements in the strength of bone cement and bears further investigation.

Macaulay et al.[15] examined cement samples mixed under vacuum, centrifugation, and traditional hand-mixing with a spatula and mixing bowl. They reported a mean porosity of 1.62 ± 1.13%, 2.84 ± 0.76%, and 2.05 ± 1.16% for vacuum mixed, centrifuged, and hand-mixed samples, respectively. While these values for vacuum-mixed porosity do fall within the range that the current study achieved. The present study found a significantly greater variability in the porosity percentage of the vacuum mixed cement. The current study, in contrast to Macaulay et al.,[15] utilized a single preparer for all cement samples, and while this should eliminate inter-preparer variability, a preparer with more experience may have a more consistent mixing technique. Further studies would be needed to assess the impact of different individuals preparing cement and whether experience or technique with cement prep can impact the mix quality with the one-step mixing system.

Reduced porosity and better material properties of the cement predispose the mantle to significantly enhance cement durability and mechanical durability.[16] Previously reported in the literature in which the elastic modulus (E) of the bone cement was measured in the range of 2.40 – 2.53 GPa.[9,17] Kurtz et al.,[18] who used ASTM F2118-01a with 65 mm long tensile specimens, found the tensile E to be 2.44 ± 0.19 GPa for Simplex™ P bone cement. This study demonstrated that utilizing the one-step mixing system provided a 4% – 16% average increase in the tensile E compared to the data from previous studies in the literature.[9,17,18] We suspect that the discrepancy is caused by the better and consistent mixing of the cement utilizing the power tool. This can also be noted in the UTS data (Figure3), where the vacuum mixed bone cement, utilizing the one-step mixing system were slightly higher than previously reported (current study: 39 ± 6 MPa; Struemph et al.:[9] 39 ± 5 MPa; Davies et al.:[17] 36 ± 10 MPa; Kurtz et al.:[18] 32 ± 1 MPa).

Theoretically, vacuum mixing with the one-step mixing system leading to decreased porosity of a cement mixture and a reduction in large defects should translate to improved resistance to cement fracture or failure. When Messick et al.[7] examined vacuum mixed versus hand-mixed cement in paired femoral THA stem constructs, they did not find significant differences in the porosity or the UTS between vacuum mixed or hand-mixed cement mantles. However, the distribution of the porosity can be affected by the mixing technique. They reported overall percent porosity of 5.7% and 6.0% for vacuum and hand-mixed samples, respectively. The 5.7% noted for their vacuum mixed samples is notably higher than the 3.5% porosity noted in the present study results. The traditional mechanical mixing system uses a mixing bowl with a rotational axis paddle or blade to mix the PMMA cement. Cement is then transferred to the injection cartridge, and the cartridge placed into a cement gun. The process of mixing and transferring the bone cement from the bowl to the cartridge could potentially trap air within the cement and create defects. The one-step cement mixing system, however, has fewer steps to load, mix and transfer the PMMA bone cement compared to traditional mixing techniques, and limits the potential for the creation of defects (bubbles). Wang et al.[3] and Mau et al.[19] evaluated several commercially available vacuum mixing systems on the reduction of porosity compared to mixing at atmospheric pressure. They concluded that vacuum mixing is effective in reducing cement porosity but not all systems tested were effective in reducing the number and size of large voids.

This study has certain limitations to recognize. First, this study only performed a single load-to-failure tensile test. Previous data would suggest that four-point bending, compression, and fatigue failure of cement under cyclic loading may be more clinically relevant tests to model the way total joint prostheses fail. Second, this study only examined one type of bone cement and may not be broadly generalizable to the multiple types of bone cement used clinically. Third, the authors recognize that the porosity of the bone cement was determined by using two-dimensional radiographic images to represent a three-dimensional structure. A three-dimensional measurement technique, such as utilizing micro computed tomography, could provide a more reliable and precise evaluation of the number, size, and distribution of pores of the bone cement.[20]

CONCLUSION

In conclusion, mixing bone cement with the advanced one-step mixing system under vacuum conditions does not produce an appreciable difference in the UTS of the bone cement in a bench biomechanical testing model. It does, however, create a less porous cement mixture with a higher modulus of elasticity compared to cement mixed without vacuum.

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PREDICTING SEPTIC ARTHRITIS IN THE SETTING OF CRYSTALLINE ARTHROPATHY IN THE NATIVE JOINT USING LABORATORY DATA

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ABSTRACT

Background: Septic arthritis is an orthopedic emergency. Diagnosis is difficult in patients with concomitant crystalline arthropathy (gout or pseudogout). The symptomatology of crystal arthritis mimics septic arthritis, clouding clinical diagnosis. Arthrocentesis and synovial fluid analysis are the standard diagnostic tests for both pathologies. Crystals on microscopy are diagnostic of crystal arthritis, however their presence does not rule out septic arthritis. Septic arthritis is diagnosed by positive microbiology culture. Though septic arthritis is associated with elevated synovial total nucleated count (TNC), TNC elevations can also occur with gout. The literature suggests that a TNC count of > 50,000 cells in a crystal-positive joint should raise suspicion for concurrent septic arthritis, however data is limited. Further diagnostic indicators are needed to help clinicians promptly identify crystal positive septic arthritis as the treatments and prognoses are different.

Methods: Patients were retrospectively identified who had arthrocentesis of a native joint positive for monosodium urate (MSU) and/or (CPPD) crystals. Laboratory data was collected including synovial fluid cultures, total nucleated cell count (TNC), percent polymorphic neutrophils (%PMN), and crystal analysis; and serum CRP, ESR, and white blood cell count (WBC). Statistical analysis performed using Spearman correlation, Univariate-Fischer's exact and Wilcoxon tests, and multivariate analysis.

Results: 442 joints identified with positive CPPD and/or MSU crystals, 31% female, 69% male. Of 442 aspirates, 58 had positive cultures. Patients were more likely to have positive cultures if synovial TNC > 50,000 (odds ratio 7.7), CRP > 10 mg/dL (OR 3.2), PMN > 90% (OR 2.17), and if the patient was female (OR 1.9), all were statistically significant with $p < 0.05$. There were 55 patients who underwent irrigation and debridement based on clinical suspicion or a positive gram stain, 37 of these ultimately had a positive culture (67%), the remaining 18 had negative cultures.

Conclusion: Results are consistent with the literature, a TNC > 50,000 warrants a high suspicion for concurrent septic arthritis and should prompt providers to critically evaluate other patient laboratory data. Results further suggests that a patient with positive crystals, synovial TNC > 50,000 cells, PMN > 90%, and serum CRP > 10mg/dL is at high risk for having a concurrent septic arthritis and may warrant urgent irrigation and debridement and antibiotic therapy. This data serves as a supporting to develop an infection risk calculator for crystal positive septic arthritis.

Level of Evidence: III

Keywords: gout, septic arthritis, crystalline arthropathy

INTRODUCTION

A red, hot, and painful joint is a relatively common reason for a patient to seek medical care. While there can be many reasons for an inflamed joint, the diagnosis of a septic joint is an orthopedic urgency. The incidence of septic arthritis is low,[1] however complications can be devastating including irreversible cartilage destruction[2] and increased risk for mortality.[1,3] Therefore, prompt diagnosis and management are crucial to prevent long-term sequelae.[3] The diagnosis of septic arthritis itself can be challenging and diagnosis is made only more difficult in patients with concomitant crystal arthritis.[3] The symptomatology of crystal arthritis mimics septic arthritis, clouding clinical diagnosis. Arthrocentesis and synovial fluid analysis are utilized as standard diagnostic test for both pathologies.[3,4] Crystals on microscopy are diagnostic of crystalline arthropathy, however their presence is not sufficient to rule out septic arthritis.[3,5] Though septic arthritis is associated with elevated synovial white blood cell count (WBC),[1,2,6] WBC elevations can also occur with gout.[3,5] Other diagnostic indicators

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like blood inflammatory markers such as C reactive protein (CRP) and erythrocyte sedimentation rate (ESR) are helpful, they have low specificity for distinguishing between the two.[1,6-9]

While concurrent septic arthritis and crystalline arthritis is rare,[9-14] accurate diagnosis of septic arthritis is critical to maintain joint integrity. The aim of this study is an attempt to identify key diagnostic laboratory values that aid in identifying patients with concurrent septic arthritis and crystalline arthropathy. We hope to identify any lab values that are predictive of concurrent disease.

METHODS

We performed a single institution retrospective review of patients who underwent aspiration of a joint between 2016-2019. Patients with crystalline arthropathy, defined as a joint arthrocentesis positive for either monosodium urate (MSU) or calcium pyrophosphate crystals were included. Exclusion criteria included patients less than 18 years old, patients with insufficient laboratory data, and aspirations involving joint replacements. Key demographic data were collected from each chart including age, gender, race, and ethnicity. Synovial laboratory data included synovial fluid cultures, total nucleated cell count (TNC), percent polymorphic neutrophils (%PMN), and crystal analysis. Serum laboratory values were also collected for each patient including ESR, CRP, and WBC. Finally, operative intervention with irrigation and debridement, either via open arthrotomy or arthroscopically, was recorded. Statistical analysis performed using Spearman correlation, Univariate-Fischer's exact and Wilcoxon tests, and multivariate analysis.

RESULTS

442 patients were identified with crystalline arthropathy between 2016-2019. The majority of the patients were male (n=307, 69%) and white (84%). The median age at presentation was 67 with a range of 20 to 97 years old.

The knee was the most involved joint (n=206, 50.6%) followed by the ankle (n=61, 14.9%), and the wrist (n=50, 12.3%). Other commonly involved joints included the elbow (n=33, 8.1%), the shoulder (n=31, 7.6%), and the hip (n=12, 2.9%). Right-sided joints were more commonly involved than left sided. See table 1 for demographics.

The median serum WBC count in our cohort was 10.8k/mm^3 with a range of 8.3-37.5. The majority of patients presented with a CRP >5mg/dl (n=235) with a median CRP of 11.1 (range 5.2-19.9). Similarly, the majority of patients presented with an elevated ESR >30 (n=247) with a median ESR of 60mm/hr (range 32-140). With respect to synovial laboratory results, the median synovial TNC in our cohort was 27,337/mm^3. Sixty-eight patients (16.1%) had a synovial TNC greater than 50,000. The median percent PMN in our patient samples was 91%. Forty-two percent of patients (n=179) presented with synovial %PMN >90%.

In this cohort of 442 patients with crystalline arthropathy, synovial cultures were positive for bacterial growth in 58 patients (14.6%). There were a total of fifty-five patients (13.9%) taken to the operating room for irrigation and debridement of the involved joint. Of the 55 patients taken to the operating room, 37 (67.3%) of those had positive cultures, while 18 patients remained culture-negative.

Female patients were significantly more likely to have a positive synovial culture in the setting of concomitant crystalline arthropathy (p=0.03). Compared to their male counterparts, female patients were 1.9 times more likely to have a positive culture (95% CI 1.09-3.41). There was no statistically significant association between elevated ESR (ESR>30) with positive cultures (p=0.64). Similarly, there was no significant association with elevated WBC (WBC >10), though it did trend toward significance (p=0.051). CRP greater than 5mg/dl was associated with positive synovial cultures (p=0.017). Patients who presented with CRP >5 were 2.67 times more likely to have positive cultures (95% CI 1.17-6.10). Furthermore, patients who presented with CRP >10 were found to be 3.2 times more likely to develop positive cultures than their counterparts who presented with CRP <10 (95% CI 1.69-6.07). When comparing synovial fluid results, crystalline arthropathy patients with a TNC >50,000 were significantly more likely to develop positive cultures (p<0.0001) with a 7.7 increased likelihood of positive synovial culture (95% CI 4.06-14.62). Elevated %PMN greater than 90% was also statistically associated with positive synovial cultures (p=0.018) with an odds ratio of 2.17 (95% CI 1.13-4.27). Finally, patients who were taken to the operating room for irrigation and debridement were 31 times more likely to have positive cultures compared to those who were managed nonoperatively (95% CI 15.23-63.67). (Table 2)

DISCUSSION

Septic arthritis of a native joint is one of few orthopedic urgencies to prevent cartilage destruction that can result in significant morbidity and even mortality.[7,15] The diagnosis of septic arthritis, however, can be challenging as multiple pathologies can present as a red, hot, swollen joint.[16,17] While synovial culture remains the "gold standard" for diagnosis, it can take up to 2 weeks for results.[9] Other serum and synovial tests are helpful to guide decision-making, however, these clinical and laboratory findings are not definitive. High-grade fever has been reported in only 58% of patients[15] and Gram stain is positive in only 50-70% of non-gonococcal septic

Table 1. Demographic Results

Demographics	
Sex	N (%)
Male	307 (69.5)
Female	135 (30.5)
Race	
African American	26 (5.9)
Hispanic/Latino	25 (5.7)
White	370 (83.7)
Native Hawaiian/Pacific Islander	9 (2.0)
Multiracial	4 (1.0)
Unknown, Declined	3 (1.0)
Joints	
AC	1 (0.2)
Hand (DIP, MCP, PIP, CMC)	7 (1.6)
Hip	13 (2.9)
MTP	5 (1.1)
Ankle	61 (13.8)
Elbow	33 (13.6)
Knee	206 (46.6)
Missing	36 (8.1)

Table 2. Univariate Analysis

	Negative culture	Positive culture	P-value	Odds ratio (CI)
TNC				
≤50k	262	17		
>50k	68	34	<0.001	7.7 (4.1-14.6)
PMN				
<90%	151	14		
≥90%	179	36	0.018	2.2 (1.1-4.2)
ESR				
<30	67	14		
≥30	247	44	0.635	
WBC				
<10	150	18		
≥10	185	40	0.051	
CRP				
<10	162	14		
≥10	159	44	0.0004	3.2 (1.7-6.1)
Sex				
Male	244	33		
Female	96	25	0.023	1.9 (1.1-3.4)
Washout				
No	318	21		
Yes	18	37	0.001	31 (15.2-63.7)

arthritis.[18,19] Serum white blood cell count and serum ESR have been found to have only fair sensitivity for septic joint with sensitivities ranging from 0.5 to 0.75.[7] These diagnostic challenges can be further exacerbated when synovial fluid analysis of a red, hot, swollen joint is also positive for MSU or CPPD crystals.

The aim of this study was to delineate, if possible, serum and synovial laboratory findings that could help clinicians discern isolated crystalline arthropathy from concomitant septic arthritis. In this series of 442 patients with crystalline arthropathy, 58 patients developed positive bacterial cultures. Elevated CRP was the only serum laboratory value we found that was associated with an increased risk of septic arthritis. From a synovial fluid analysis standpoint, both elevated synovial TNC and %PMN were associated with an increased risk of concurrent septic arthritis. In our study, patients with a synovial TNC >50,000 were 7.7 times more likely to develop positive synovial cultures.

A recent 2020 study looking at the sensitivity of synovial cell count for diagnosing septic arthritis in the setting of 358 cases of crystalline arthropathy found only a positive predictive value of 6% for a TNC threshold of 50,000.[17] In this series, only 3 joints (0.6%) had concomitant crystalline and septic arthritis and all three had a TNC ≥85,000. Twelve out of fifteen patients with crystalline arthropathy and a TNC >50,000 were taken to the operating room for a potentially unnecessary procedure. Therefore, given the 100% sensitivity of a TNC ≥85,000, the authors conclude that utilizing a TNC threshold of ≥85,000 may be reasonable for diagnosing concomitant septic and crystalline arthritis, given the low rate of the concomitant conditions.

In our study, however, we found that 13.7% of patients with crystalline arthropathy presented with concomitant septic arthritis, as defined by positive synovial cultures. Though the literature on concomitant septic and crystalline arthritis is relatively limited, several studies have suggested a higher rate of concomitant septic and crystalline arthritis than reported in the study by Luo et al. A recent study by Hong et al. found a 21.3% rate of co-existing septic and crystalline arthritis[20] while a 2019 study investigating open versus arthroscopic management of septic native knee arthritis reported a 19.9% rate of concomitant crystalline arthritis.[9,21]

Based on the results of our study and above literature, we feel that clinicians should maintain a high index of suspicion for septic arthritis in patients who present with elevated TNC >50,000 in the setting of crystalline arthropathy, especially if coupled with other key laboratory values such as %PMN >90 and elevated CRP >10. While none of these lab values are definitive for diagnosing concomitant crystalline and septic arthritis, we encourage clinicians to utilize these markers to assist with systematic diagnosis of this challenging clinical scenario.

There are several important limitations of this study that should be addressed. First, this study was conducted via retrospective chart review at a single institution. Our dataset was limited by incomplete laboratory collection on some individual patients during their work-up. Importantly, this study defined septic arthritis as the presence of positive synovial culture, or Newman Grade A. We did not utilize Newman Grade B (positive associated sample culture) or Newman Grade C (patients with intraoperative pus, turbid fluid, or histological evidence of septic arthritis) criterion.[22] Thus, our study could underestimate the true rate of concomitant septic arthritis and crystalline arthritis in this cohort.

CONCLUSION

Native septic arthritis is an orthopedic urgency and diagnosis can be challenging in patients with concomitant crystalline arthropathy. Based on the results of our study, we feel that clinicians should maintain a high index of suspicion for septic arthritis in patients who present with elevated TNC >50,000 in the setting of crystalline arthropathy, especially if coupled with other key laboratory values such as %PMN >90 and elevated CRP >10.

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TOTAL HIP ARTHROPLASTY AFTER PERI-ACETABULAR OSTEOTOMY RESULTS IN SIGNIFICANT IMPROVEMENT IN HIP FUNCTION WITH LOW REVISION RATES AT MID-TERM FOLLOW-UP

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ABSTRACT

Background: Bernese periacetabular osteotomy (PAO) improves symptoms and delays degenerative changes in patients with acetabular dysplasia. Yet, eventual total hip arthroplasty (THA) is needed in many of these patients. The impact of PAO on subsequent THA outcomes is not well defined.

The purpose of this study is to define: 1) clinical outcomes, 2) post-operative complications and 3) implant survivorship for patients undergoing THA after prior ipsilateral PAO.

Methods: A retrospective review was conducted at three institutions to identify individuals undergoing THA after ipsilateral PAO surgery with minimum 1 year follow up. Patient reported outcome measures (PROMs) were collected preoperatively and at final follow-up. Surgical details, radiographic and clinical outcomes, and major complications according to the modified Dindo-Clavien classification system were identified through review of the medical record. Regression analysis and student's t-test were used to compare pre- and post-operative outcome scores. Kaplan-Meier analysis was performed to estimate reoperation-free survivorship.

Results: A total of 113 THA in 112 patients were identified with initial review. 103 hips had a minimum of 1-year follow-up and an average follow of 5 ± 4 years (range, 1 to 20). 10 hips (9%) were lost to follow-up leaving 103 (91%) hips available for review with a minimum of 1-year follow-up (mean = 5 years). Mean interval from PAO to THA was 7.7 years (range, 2-15). The average post-operative mHHS improved 37 points (50 to 87, $P < 0.001$) when compared to pre-operative scores. Eight patients (7.1%) experienced a major grades III-V) surgical complication. These included 2 cases of instability, 2 cases of acetabular loosening, and one case each of periprosthetic fracture, wound dehiscence, periprosthetic infection, acetabular loosening and pneumonia. Failures occurred early at average 3.2 years and survivorship analysis for all-cause revision demonstrated 96% survivorship at both 5 and 10 years.

Conclusion: THA after PAO achieves significant clinical improvement and satisfactory survivorship (96%) at mid-term follow-up, with a major complication rate of 7.1%.

Level of Evidence: III

Keywords: total hip arthroplasty, periacetabular osteotomy, survivorship, mid-term follow-up, young adult

INTRODUCTION

Acetabular dysplasia of the hip results in premature degenerative changes through labral injury and chondral shear,[1] thereby pre-disposing individuals with dysplasia to hip pain and end-stage osteoarthritis. Bernese periacetabular osteotomy (PAO) in this patient population can not only provide symptomatic relief and restore function[2] through re-orientation of the acetabulum, but also serves to alter the natural history of the hip by preventing degenerative changes from occurring.[3] Moreover, the benefits of this procedure can be realized with minimal surgical morbidity,[2] particularly once a surgeon progresses through their respective "learning curve".[4] As such, the relative utilization of the PAO has expanded beyond isolated dysplasia in the young adult hip to include numerous other conditions: symptomatic borderline dysplasia,[5] dysplasia in the setting of mild degenerative changes,[6] deformity as a sequalae of Legg-Calve-Perthes,[7] and dysplasia in the setting of spastic cerebral palsy.[8]

Despite the relative success of PAO in both improving symptoms and reducing degenerative changes, approximately 26-40% of individuals will undergo THA

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at 20 years[9] after PAO. Given the excellent results of THA – even in younger[10] and more active patients[11] – concerns may exist that PAO may demonstrate a deleterious effect on subsequent THA. These concerns may be well-founded, as individuals with prior open (i.e., open reduction internal fixation of an acetabulum fracture[12] and hip hemi-arthroplasty[13]) or arthroscopic[14] procedures about the hip demonstrate higher rates of complication, when compared to patients undergoing primary total hip arthroplasty without previous procedures. Unique to the PAO population, retained hardware, disruption of surgical planes, abnormal femoral morphology, and loss of landmarks for acetabular cup placement may all contribute to increased technical difficulty or adverse outcomes at time of THA. Given a subset of patients (i.e., slightly older patients or patients with early degenerative changes) may be reasonable candidates for either PAO or THA, understanding the impact of PAO on THA is essential for both patient counseling and surgical indications.

Currently, the understanding of surgical impact of THA after PAO is limited to smaller (<40 patients), single-center, or single-surgeon studies,[15,16,17] which yield conflicting data regarding clinical outcomes and surgical complications. As such, this three-institution, retrospective study was designed to answer two major questions. 1) What are the clinical outcomes and complications of THA after previous PAO surgery? 2) What is the mid-term survivorship of THA after previous PAO surgery? The hypotheses of this study are that patients undergoing THA after PAO will demonstrate a significant improvement in hip function with an acceptable surgical complication risk and excellent long-term survivorship.

METHODS

This study retrospective review was performed at three centers and cases were performed between the years 1994 and 2020. All procedures were performed by high-volume surgeons with fellowship training in adult reconstruction. Implant selection, surgical approach, and post-operative rehabilitation were conducted at the discretion of the treating surgeon. Individuals were eligible for inclusion in this study if the underwent THA after previous Bernese PAO. Patients with previous non Bernese PAO were excluded or those where the type of osteotomy was unknown. Institutional review board approval was obtained.

Demographic data including patient sex, age, self-identified race, and body mass index (BMI) were all obtained through chart review. Operating time was defined as the interval from incision to wound closure, to obviate the impact of induction of anesthesia, patient positioning, and post-operative processes. The modified Harris Hip Score (mHHS) was collected pre-operatively and post-operatively at a minimum of one year. The most recent available follow-up scores were used for the purpose of this analysis. Major peri-operative complications were recorded according to the Clavien-Dindo Classification adapted by Sink et al.,[18] including grades III, IV, and V.

Radiological parameters which were recorded included cup abduction angle (as measured on the AP radiograph) and cup anteversion[19] (as measured on the cross-table lateral radiograph). The Lewinnek safe zone[20] was utilized to assess acceptable acetabular component positioning defined by cup abduction angle from 30 to 50 degrees and cup anteversion angle from 5 to 25 degrees. Implant material, fixation method, and geometry data was also recorded.

Regression analysis and student's t-test were used to compare pre- and post-operative outcome scores. Kaplan-Meier analysis was performed to estimate reoperation-free survivorship. Statistical significance was defined as a $p<0.05$.

RESULTS

A total of 113 hips in 112 patients were identified with initial review. 103 hips were had a minimum of 1-year follow-up and an average follow of 5 ± 4 years (range, 1 to 20). Ten hips (9%) were lost to follow-up leaving 103 hips for analysis. All 103 hips had complete outcomes data and 84% had complete radiographic data. Most patients were female (n= 92, 81%). The mean BMI was 27.9 (SD 5.7). The average time from PAO to THA was 7.7 years (range 2-15). Average age at the time of THA was 40 years (range, 16-67). Surgical details, implants and acetabular component position are displayed in Table 1.

Average mHHS score improvement was 37 points (50 to 87, $p < 0.001$). Eight (7.1%) major complications occurred in the post-operative period: 1 re-admission for pneumonia at 1 week post op, 1 late peri-prosthetic femoral fracture at 2 years treated with revision, 1 wound dehiscence at 1 months requiring operative intervention, 1 peri-prosthetic infection at 1 month treated with DAIR, 2 instance of aseptic acetabular loosening treated with revision at 3.2 and 17.7 years, 1 revision for instability at one year post op and 2 hip dislocations in one patient (treated with closed reduction). Most failures occurred early at average 3.2 years and survivorship analysis for all-cause revision demonstrates 96% survivorship at 5 and 10 years (Table 2).

Table 1. Operative Duration, Estimated Blood Loss, Approach, and Implant Selection for Patient Undergoing Total Hip Arthroplasty After Prior Peri-Acetabular Osteotomy

Operative Details	
Operative time (min)	66 (SD 16)
Estimated blood loss (ml)	285 (109)
Approach – n (%)	
Posterior	86 (76%)
Anterior	20 (17.7%)
Anterolateral	7 (6.2%)
Implants	
Fixation type	
Cup	100% cementless
Femur	96% cementless
Femoral stem geometry – n (%)	
Wedge Taper	81 (76%)
Conical	4 (3.7%)
Cylindrical	22 (21%)
Headball – n (%)	
Ceramic	81 (78%)
Cobalt Chrome	22 (21%)
Acetabular Liner –n (%)	
Polyethylene	100 (92%)
Ceramic	6 (5.5%)
Dual Mobility	3 (2.7%)
Radiographic cup position – degrees (SD)	
Abduction	40.8 (5)
Anteversion	28 (8.5)

Table 2. Complication Rates and Survivorship for Patients Undergoing Total Hip Arthroplasty After Peri-Acetabular Osteotomy

SURGICAL OUTCOMES		SD
Average follow-up (years)	5 (range 1-20)	4.0
MHHS improvement	37 points	18
Pre Op	50	15.7
Final follow up	87	14.3
Major complications – n (%)	8 (7.1%)	
Readmission for pneumonia	1 (0.88%)	
Periprosthetic femoral fracture	1 (0.88%)	
Wound dehiscence (requiring surgery)	1 (0.88%)	
Periprosthetic infection (?surgery)	1 (0.88%)	
Acetabular loosening	2 (1.77%)	
Revision for instability	1 (0.88%)	
Hip dislocation	1 (0.88%)	
Survivorship		
5 years	96%	
10 years	96%	
15 years	96%	

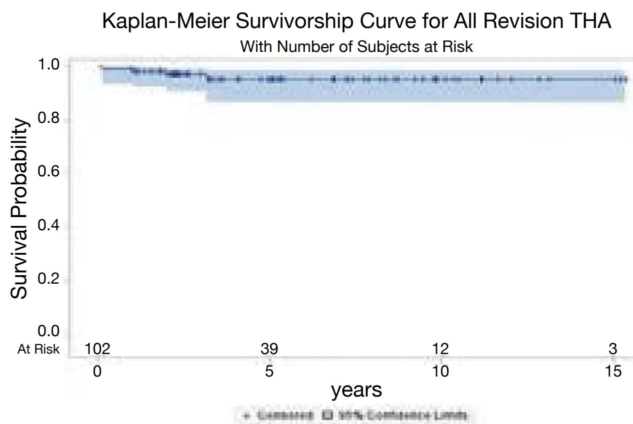

Figure 1. Kaplan-Meier survivorship curve for revision arthroplasty in patients undergoing total hip arthroplasty after prior peri-acetabular osteotomy.

DISCUSSION

Peri-acetabular osteotomy demonstrates a significant improvement in hip pain and function in patients with symptomatic hip dysplasia, but a significant portion of patients may ultimately undergo subsequent THA. As such, the outcomes of THA after PAO are vital to define, particularly for patients who may also be reasonable candidates for alternative procedures (i.e., isolated hip arthroscopy or arthroplasty). In this series of 113 hips with an average of 5-year follow-up, THA after PAO demonstrated excellent 5- and 10-year survivorship (96%) with significant improvement in hip-specific outcome scores. THA did not result in unexpectedly high blood loss, surgical duration, or rate of major complication. As such, prior PAO does not appear to compromise outcomes of subsequent THA in high-volume adult reconstruction surgeons.

Limitations of this study include the expertise bias which may be present, given all surgeons performing THA in this cohort work a tertiary care center and possess an interest in the management of hip dysplasia. However, these data do suggest favorable outcomes for THA after PAO, when performed by high-volume surgeons at tertiary care centers. Moreover, this study does not possess a control cohort for comparison, thus results can only detail the outcomes of arthroplasty in this select population rather than describe relative changes in complication profiles compared to other populations. Finally, patients presented in this cohort received treatment over nearly three decades, during which the orthopaedic communities understanding of hip preservation and arthroplasty has significant evolved.

This study represents the largest cohort – to our knowledge – of patients undergoing THA following prior ipsilateral PAO and represents a significant addition to the relatively small (363 hips from 11 studies) body of literature available defining outcomes in this unique population.[17] In this cohort, the identified re-operation rate of 4%, lower than prior systematic reviews indicating a cumulative re-operation rate of 7.7% in patients undergoing total hip arthroplasty after any pelvic osteotomy for dysplasia.[17] Although not designed to directly compare survivorship or complication rates of our cohort to other populations, larger registry data indicates cumulative revision rates of 2-5% at 5 years in patients undergoing THA.[21] As such, prior PAO does not appear to significantly elevate an individual's risk for subsequent revision compared to the general population or patients undergoing THA in the setting of developmental dysplasia.[22]

Moreover, this data is in direct contrast to the marked increase in revision arthroplasty and complications (>10% at 2 years) in patients with prior isolated hip arthroscopy[23] or for patients undergoing total hip arthroplasty for patients with prior operative fixation of acetabular fractures.[24] The observed increase in revision THA after primary THA in setting of previous hip arthroscopy is unclear and deserves additional investigation. Given the increased interest in concurrent hip arthroscopy with PAO,[25] future consideration may be given to how intra-articular procedures combined with PAO may impact infection rate in patients undergoing subsequent THA. Acetabular fracture injury and fixation can result in distorted pelvic anatomy, retained hardware, heterotopic ossification, and associated neuromuscular compromise. These factors may very well impact THA outcomes after previous acetabular fracture treatment. In contrast, PAO acetabular fixation screws are commonly removed after healing and if retained usually do not require removal at the subsequent THA. As such, surgeons performing THA in this cohort may not have to contend with intra-operative removal of implants (i.e., periarticular fixation that interferes with cup placements) that may prolong operative duration and theoretically increase the risk of infection. Given the clear relationship between both hospital and surgeon surgical volumes and improved outcomes,[26] these results should be considered within the context of high volume surgeons at high volume centers.

Given alterations in acetabular anatomy after PAO, concerns exist that alterations in landmarks for cup placement may compromise acetabular cup position. Select prior publications have suggested that prior PAO may place individuals at risk for excessive abduction or retroversion of the acetabular component.[17] In this cohort, however, approximately 70% of acetabular components were placed within conventionally defined parameters and outliers were primarily related to increased acetabular anteversion. These outliers may be a consequence of numerous surgical factors: a significant percentage of hips performed from a posterior approach (where increase acetabular anteversion may be intentional), controversy regarding the ideal cup anteversion, degree of acetabular anteversion performed at time of index PAO or knowledge of pre-existing literature[27] detailing risk of acetabular retroversion in this patient population. Given only a single patient required a revision for instability, component position and instability do not appear to adversely affect outcomes of these hips. Additionally, in this study there were no acetabular grafts or augments in this relatively large cohort of dysplastic patients. This suggests that previous PAO does enhance acetabular bone stock for future THA and may alleviate the need for augmenting acetabular support. We would echo sentiments regarding the value of pre-operative planning and diligent intraoperative technique,[27] appropriate component placement can be reliably achieved in patient with prior PAO. Moreover, the increased availability of intra-operative robotics or navigation may assist surgeons in reliably positioning the acetabular component during THA in the setting of prior PAO.

CONCLUSION

THA after PAO achieves significant clinical improvement and satisfactory survivorship (96%) at mid-term follow-up, with a major complication of 7.1%.

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UTILITY OF DEBRIDEMENT, ANTIBIOTICS, AND IMPLANT RETENTION FOR ACUTE PERIPROSTHETIC JOINT INFECTION IN REVISION TOTAL KNEE ARTHROPLASTY

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ABSTRACT

Background: Periprosthetic joint infection (PJI) in revision arthroplasty presents as a challenging complication that is difficult to manage. Debridement, antibiotics, and implant retention (DAIR) is a recognized treatment option, although few studies have investigated success rates in addition to eventual amputation rates for failed cases.

Methods: A retrospective review of 365 DAIR cases was performed at a single institution from 2008-2020. Patient records were thoroughly reviewed for inclusion and exclusion criteria by multiple members of the research team, discovering 45 cases met criteria for the study cohort. Demographic information, medical history, culture data, and surgical history, were recorded. DAIR's overall survivorship was evaluated with a Kaplan-Meier (KM) survival curve. Additional KM curves were constructed to compare acute postoperative versus acute hematogenous infections as well as DAIR survivorship relative to infecting organism.

Results: DAIR's success rate in revision TKA was 77% at 0.5 years, 56% at 2 years and 46% at 5 years. No significant difference was noted in survivorship when comparing acute postoperative and acute hematogenous cases at 5 years (29 vs 51%, P=0.64). No significance differences in survivorship were noted according to infecting organism (P =0.30). Median follow up duration was significantly lower in the failed DAIR cohort with a median time of 0.5 years in comparison to 1.7 years for the successful DAIR group (P =0.012). There were 20 DAIR cases that failed, 10 of which resulted in eventual amputation.

Conclusion: DAIR's success rate for managing acute PJI in revision arthroplasty cases was 46% at 5 years. Of the 20 failed DAIR cases, 10 resulted in eventual amputation. DAIRs utility in managing these complicated PJI cases in the setting of revision arthroplasty is concerning with low success rates and high rates of amputation in failed cases.

Level of Evidence: III

Keywords: TKA, infection, debridement

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INTRODUCTION

Periprosthetic joint infection (PJI) is a devastating complication of total knee arthroplasty (TKA). The current literature suggests the incidence for PJI ranges from 1-2% of primary arthroplasty cases.[1] Two-stage revision has long been considered the gold standard for PJI management in primary TKA, however rates of infection free survival only range near 80%, therefore leaving a subset of patients with infected revision arthroplasty.[2-4] Revision procedures completed for aseptic cases can be complicated by PJI in up to 10% of cases.[5,6] PJI following revision arthroplasty for non-infectious causes is devastating in patients who already have a complex clinical picture. Additionally, acute PJI in patients with a history of two-stage resection arthroplasty for previous infection present as an operative challenge with no clear guidelines in management. Treatment options include irrigation and debridement, antibiotics, and implant retention (DAIR), two-stage revision, knee arthrodesis as well as amputation. Of these methods DAIR is the only method that retains the previous knee implant, focusing on preserving knee function and reducing morbidity. DAIR success rates have been variable ranging from 39-85% with a majority of the studies focusing on PJI in primary TKAs.[7-11]

Outcomes of infected revision arthroplasty management are limited with few published studies investigating the utility of DAIR.[12-14] Additionally, these studies did not investigate the outcome of failed DAIR cases.

The primary aim of this study was to evaluate the success of DAIR for acute postoperative and acute hematogenous PJI following revision arthroplasty. A secondary aim was to analyze the rate of eventual amputation in these patients who have a failed DAIR when attempting to manage infected revision arthroplasty. We hypothesized DAIR would have a worse rate of success when used to treat PJI in revision TKA with comparison to previously reported success rates in primary TKA cases given the findings of prior studies.[12-15] It was also hypothesized that approximately 10% of infected revision arthroplasty cases treated with DAIR would result in amputation, similar to a previously reported incidence.[16]

METHODS

A retrospective analysis was performed of all patient cases that underwent irrigation and debridement with poly exchange at a single tertiary facility using the current procedural terminology (CPT) code 27486 (figure 1). Cases ranged over the time course of January 1, 2008 – December 31, 2020. A total of 365 cases were identified. Further investigation was performed for eligibility. Patient cases met inclusion criteria if there was a diagnosed PJI, chronic antibiotic suppression was utilized, the patient was >18 years old, and they had a history of revision TKA in place at the time of the DAIR procedure. MSIS criteria along with the 2008 and 2018 Parvizi et al. definitions were utilized to diagnose PJI.[10,17-19] Patients were excluded if they had a superficial surgical site infection that did not involve the knee joint, irrigation and debridement was utilized for aseptic wash out of the knee, or they had a history of oncologic conditions. A total of 45 cases met criteria for the study cohort. The indication for revision arthroplasty was a two-stage reimplantation for prior PJI in 19 of the cases.

Survivorship of DAIR was evaluated in patients with a history of revision TKA at the time of the diagnosed acute PJI. Failure of DAIR was defined as a subsequent procedure performed to treat PJI following the single, index DAIR.

Demographic information such as age, sex, body mass index (BMI) tobacco use, along with medical and surgical history were obtained. Cases were further classified as acute postoperative if PJI was suspected within 4 weeks of the revision procedure or acute hematogenous if the PJI occurred beyond 4 weeks postoperatively yet was acute in nature.[20] Infecting organism was also collected from patient records by utilizing culture data.

Infection Treatment

Postsurgical infection management at our institution was consistent with previously reported methods for PJI treatment.[10] The antibiotic regimen was managed in conjunction with our institution's infectious disease team. Standard antibiotic management consisted of a 6-week course of intravenous antibiotics which were directed by culture results and weekly or biweekly lab work. Our institution utilized dual therapy oral rifampin for the first 6 weeks of treatment if staphylococcus species were confirmed.[21] Following intravenous antibiotics, an extended course of oral antibiotics were prescribed for 3-, 6-, or 12-month durations. The timeline of oral antibiotic suppression was a variable discussed between infectious disease and orthopaedic staff. Additional guidance was obtained by infectious lab work: white blood cell count (WBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) as well as clinical presentation.

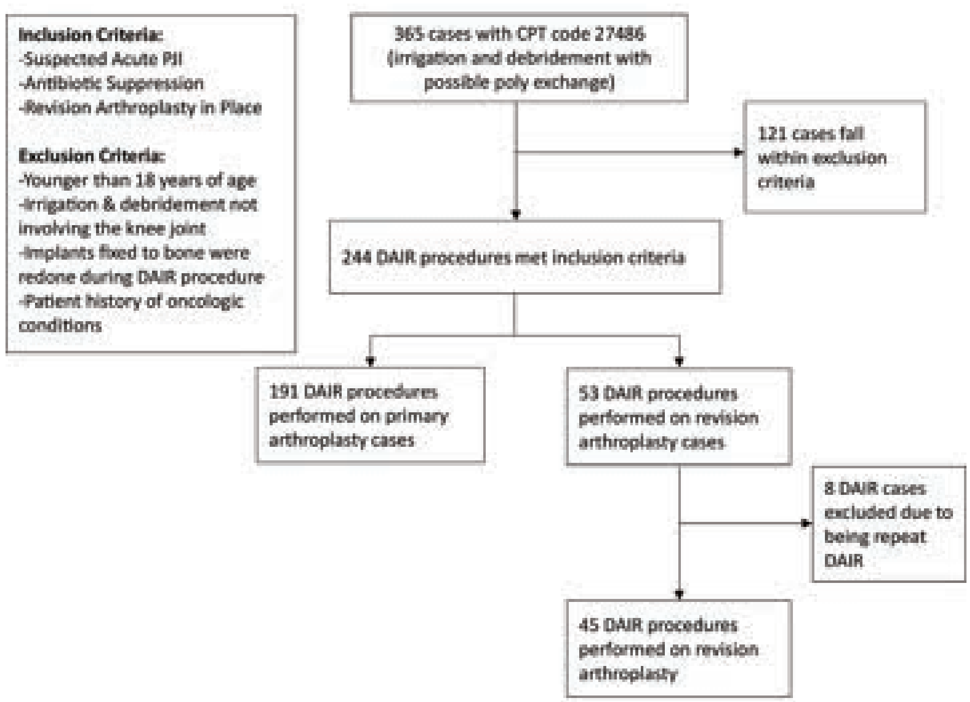

Figure 1. Flow chart demonstrating the distribution of DAIR cases.

Data analysis

Kaplan-Meier survivorship curves were constructed for surgical treatment of PJI, for acute postoperative versus acute hematogenous, and by infecting organism. Survivorship curves were compared using the log-rank test. Characteristics were compared between participants with successful vs failed surgeries using the Chi-square test for categorical variables and independent t-test or Wilcoxon Rank Sum test for continuous variables that were or were not normally distributed, respectively. In subgroup analyses, patients with failed surgeries who did or did not undergo subsequent amputation surgeries were compared using similar analytic techniques. Analyses were completed using SAS statistical software version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

DAIR's success rate in revision TKA was 77% at 0.5 years, 56% at 2 years and 46% at 5 years (figure 2). No significant difference was noted in survivorship when comparing acute postoperative and acute hematogenous cases (29 vs 51%, P =0.64) (figure 3). Staphylococcus aureus was the most commonly isolated organism, appearing in 17 cases. Eleven cases were culture negative followed by 'Other gram positive' species totaling 8 cases. 'Other staph' organisms were noted in 7 cases and 0 cases were positive with gram negative organisms (figure 3). No significant differences were noted when comparing survivorship by infecting organism (P =0.30) (figure 4). Demographic data of the 43 patients, totaling 45 cases, comparing successful versus failed DAIR is listed in table 1. The mean age of patients with successful DAIR was 68.1 years in comparison to 61 years in those who had a failed DAIR (P =0.028). The median follow-up duration was significantly lower in the failed DAIR cohort with a median time of 0.5 years in comparison to 1.7 years for the successful DAIR group (P =0.012).

There were 20 DAIR cases that failed, 10 of which resulted in eventual amputation. There was no significant differences in age, BMI, sex, diabetes, smoking status, or follow up duration when comparing patients that underwent eventual amputation versus no amputation (table 2). However, comparisons were limited by sample sizes.

DISCUSSION

Management of subsequent acute PJI in knees with a history of revision arthroplasty is difficult. DAIR is a recognized treatment option for these infections although a majority of the literature regarding DAIR has been focusing on primary arthroplasty cases.[10,13,14,22,23] The main purpose of this study was to better define the utility of DAIR by defining its success rate for PJI treatment in knees having previously undergone revision arthroplasty. A secondary aim was to investigate outcomes in failed DAIR cases. Survivorship at 5-years was estimated to be 46% with no significant difference in acute postoperative versus acute hematogenous cases. Infecting organism did not have a significant relationship with DAIR success. A total of 20 failed DAIR cases were accounted for in our cohort with 10 resulting in eventual amputation, equating a 50% amputation rate.

A recently published study at our institution evaluated outcomes of DAIR in primary TKAs and concluded a success rate of 79% at 5 years.[10] The present study was conducted with a similar methodology and analysis, demonstrating the significantly lower success rate of

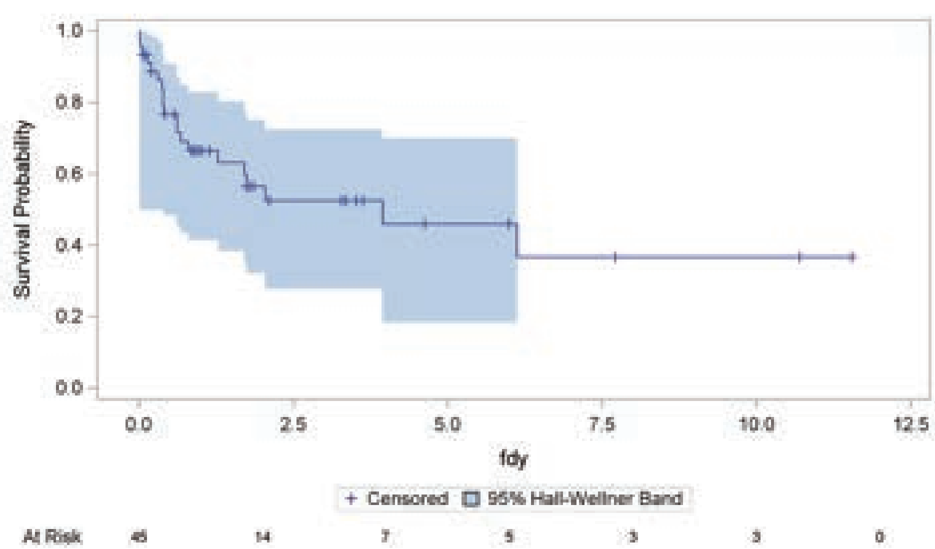

Figure 2. Kaplan-Meier curve demonstrating survival analysis of all 45 DAIR cases meeting inclusion criteria and exclusion criteria.

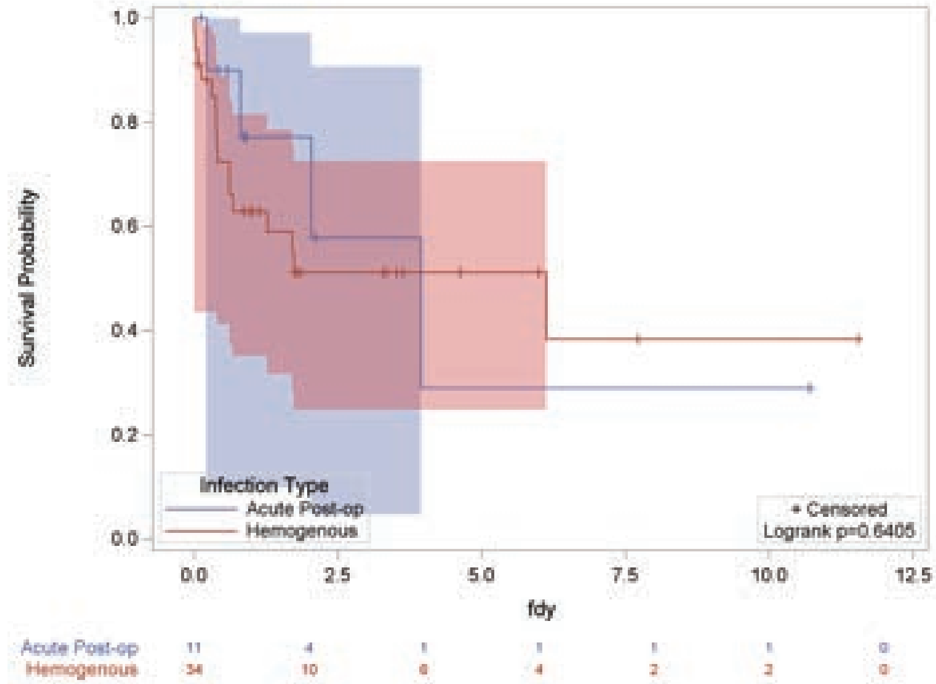

Figure 3. Kaplan-Meier curve graph comparing success of acute postoperative and acute hematogenous cases treated with DAIR.

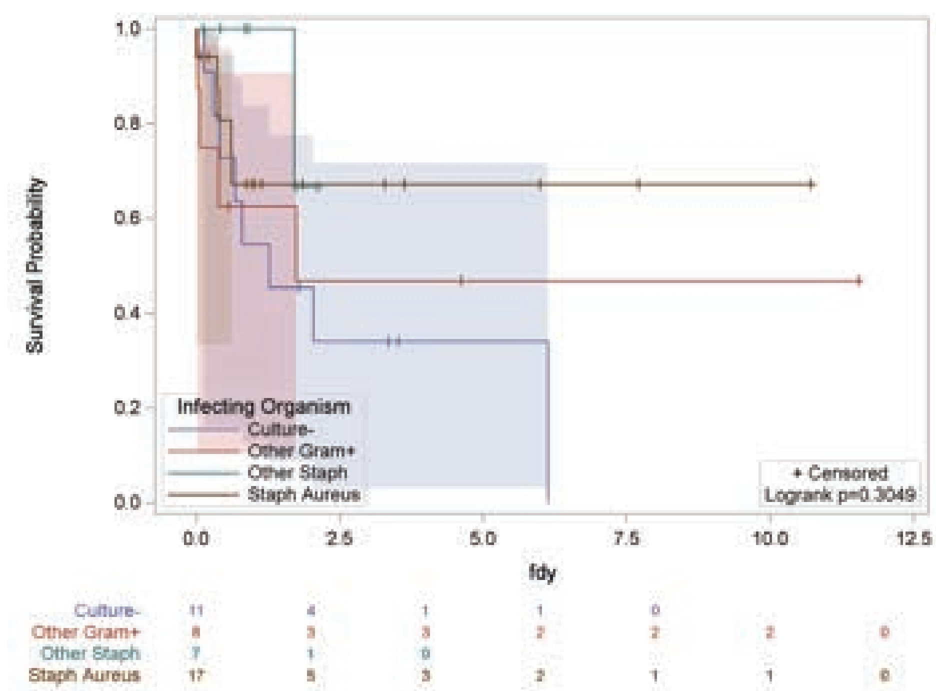

Figure 4. Kaplan-Meier curve graph comparing success of DAIR cases dependent on infecting organism type.

Table 1. Demographics of Successful and Failed DAIR in Revision Knee Arthroplasty Patients

Variable	No Fail (n=23)	Failed (n=20)	P-value
Age*	68.1± 12.3*	61.0 ± 7.8*	0.028
BMI*	34.8 ± 7.1*	35.3 ± 9.4*	0.84
Sex (n, % female)	7 (30%)	7 (35%)	0.75
Diabetes (n, % yes)	11 (48%)	6 (30%)	0.23
Smoker (n, % yes)	1/22 (5%)	3/19 (16%)	0.32
Follow-up Duration (years)**	1.7 [0.9-3.5]**	0.5 [0.3-1.5]**	0.012

Key: BMI = body mass index, *= mean ± standard deviation, ** median (interquartile range).

Table 2. Demographics of Patients Who Underwent Eventual Amputation in Comparison to Those Who Did Not Have Amputation

Variable	Amputation (n=10)	No Amputation (n=33)	P-value
Age*	60.1±8	66.2 ±11.4	0.12
BMI*	36.3±11	34.6 ± 7.2	0.66
Sex (n, % female)	6 (60%)	23 (70%)	0.70
Diabetes (n, % yes)	5 (50%)	12 (36%)	0.48
Smoker (n, % yes)	2 (20%)	2/31 (6%)	0.25
Follow-up Duration (years)**	0.4 [0.2-2.0]	1.0 [0.6-2.1]	0.22

Key: BMI = body mass index, *= mean ± standard deviation, ** median (interquartile range).

46% at 5 years. A single center retrospective review by Veerman et al. investigated outcomes of DAIR after revision arthroplasty in both knee and hip arthroplasty, they found a total success rate of 68% after 2 years.[14] Faschingbauer et al. investigated DAIR's utility in acutely failing two-stage revisions finding a 63% success with no significance in causal organism, similar to our study.[13] However, Faschingbauer did note BMI to be significantly higher in their successful DAIR group (31.5 versus 25.5 kg/m^2, P =0.026), contrasting our investigation.[13]

Successful treatment of PJI extends beyond infection eradication, as functional outcomes should not be ignored. Lower cost, morbidity, and mortality continue to be an attraction for surgeons as they consider DAIRs utility. The current study however demonstrates high morbidity if DAIR procedures fail with a high amputation rate of 50%. A systematic review by Maden et al. is one of the few studies investigating survivorship along with self-reported clinical outcomes. Successful DAIR was summarized to have lower complication rates in comparison to further revision, arthrodesis, and amputation when managing failed two-stage revision arthroplasties.[23] DAIR success was similar to our present study, defined as 57% at a 2-year minimum follow up.[23]

Several limitations are present in this study. The data was collected via retrospective chart review at a single tertiary care facility, predisposing the findings to selection bias. Additionally, when conducting a thorough chart review, patient records commonly only contained history of the present DAIR procedure. This limited the availability of medical and surgical history on file in our electronic medical record (EMR). This is a common obstacle at our institution given we receive complex orthoapedic referrals from across the region. Procedure variability is a final limitation. The 45 DAIR cases included in this study were performed by 13 surgeons over a 13-year period. Although standard protocols were followed, variations in surgical technique and antibiotic regimens are present and should not be over-looked.

In conclusion, management of infected revision arthroplasty cases with DAIR has a high failure rate and poor outcomes with a concerning potential for amputation. Our present study demonstrated a DAIR success rate of 46% at 5 years when treating acute PJI in revision arthroplasty cases. Amputation was the final outcome for 50% of failed DAIR cases when performed in a revision arthroplasty. Patients presenting with acute postoperative (<4 weeks) or acute hematogenous (<4 weeks) infections may be viewed similarly when considering DAIR as there was no difference in PJI eradication. Organism should be considered in the management of acute PJI, although our results did not demonstrate infecting organism to have an impact on DAIR success. Further studies are needed to address alternative interventions and functional outcomes for these patients.

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IS PERIOPERATIVE RADIOTHERAPY EFFECTIVE IN PREVENTING LOCAL RECURRENCE IN MYXOFIBROSARCOMA?

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ABSTRACT

Background: Myxofibrosarcoma (MFS) is a rare type of soft tissue sarcoma that is locally aggressive and has a high risk of recurrence. The effectiveness of perioperative radiotherapy (RT) in preventing local recurrence (LR) of MFS remains uncertain. This retrospective study aimed to evaluate the impact of perioperative radiotherapy on local recurrence in patients with MFS.

Methods: A total of 75 patients diagnosed with MFS and treated at a single institution were included in the study. Patient data, including demographics, tumor characteristics, and treatment variables, were collected from electronic medical records. The primary endpoint was the occurrence of local recurrence.

Results: Among the patients, 25/75 (33.3%) received radiation therapy, while 50/75 (66.7%) did not. Local recurrence in the radiated group was 28% (7/25) compared to 36% (18/50) in the non-irradiated group (p = 0.20). The LR rate trended higher in patients who received RT postoperatively (adjuvant) (6/12, 50%) than preoperatively (neoadjuvant) (1/13, 7.6%) (p = 0.124). Of the 54 patients with negative margins, the local recurrence rate was lower in the radiated group (1/12, 8.33) than the non-irradiated group (9/36, 25%) (p = 0.034). A subgroup analysis based on tumor grade did not reveal any significant differences in recurrence rates between the radiated and non-irradiated groups. Furthermore, there was no significant difference in recurrence rates between the irradiated and non-irradiated groups at the one-year (p = 0.32), two-year (p = 0.24), and five-year (p = 0.32) follow-up marks.

Conclusion: Although radiotherapy demonstrated a trend toward reduction in recurrence rates in patients with MFS in this study, the observed difference did not reach statistical significance. Neoadjuvant radiation appears to be more effective than adjuvant radiation. However, there was a significant reduction in recurrence in patients with negative margins who received radiation demonstrating that effective surgical resection continues to be the most important intervention in patients with myxofibrosarcoma.

Level of Evidence: III

Keywords: myxofibrosarcoma, local recurrence, perioperative radiotherapy, survival

INTRODUCTION

Myxofibrosarcoma (MFS) is a rare sarcoma and accounts for approximately 5% of all soft tissue sarcoma diagnoses. It is a subtype of soft tissue sarcoma that is more common in adults, especially the elderly. It typically affects the extremities, such as the arms and legs, and is characterized by a diffusely infiltrative pattern radiographically.[1] MFS is considered a locally aggressive tumor. This characteristic makes it more challenging to treat and increases the risk of recurrence as it is technically challenging to obtain negative margins due to the infiltrative nature of the tumor. The recurrence rates of MFS are reported to range from 16% to 57%, which is relatively high compared to other types of sarcomas.[2-6] Moreover, a significant proportion of MFS patients experience multiple recurrences, with rates ranging from 25% to 52%. The median time to local recurrence is approximately 8 to 27 months, but in some cases, it can occur up to 8 years after initial treatment.[2]

The standard treatment of MFS includes a complete surgical resection, and in some cases, radiation therapy may be used as an adjuvant therapy to reduce the risk of local recurrence. Randomized trials in various types of sarcomas have shown that radiation therapy can improve local control in the treatment of soft tissue sarcomas.[7,8] However, there are no randomized studies specific to MFS. Retrospective studies have been conducted, but these studies are small and may not have had enough statistical power to demonstrate a significant difference in outcomes.[2,4]

The purpose of this study was to determine if perioperative radiotherapy is effective in preventing local recurrence of MFS and to determine if perioperative radiotherapy is effective in delaying recurrence of MFS.

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METHODS

Study design and setting

This study was conducted involving a retrospective chart review of consecutive patients at a single institution. The study was approved by an institutional review board (IRB). We accessed and analyzed the electronic medical records (EMR) of patients who had undergone complete myxofibrosarcoma resection for cure.

Participants

Patient Eligibility: The study included patients' histological diagnosis of primary myxofibrosarcoma who were presented for definitive tumor resection from September 1, 2010 and December 8, 2022 with at least one post-surgical follow-up. Recurrent tumors (tumors that had previously been treated with an attempt at curative excision and/or radiation) were excluded, but incomplete excisions with positive margins that were referred for a formal tumor bed re-excision were included. The study encompassed pelvic and extremity tumors of all sizes and depths. Patient and treatment variables were collected from the EMR of the hospital where the study was conducted. Each sarcoma patient's case was reviewed by a multidisciplinary tumor board consisting of specialists in orthopedic oncology, surgical oncology, medical oncology, radiation oncology, musculoskeletal radiology, and bone and soft tissue pathology. The general indications for administering perioperative RT in soft tissue sarcoma were tumors that were intermediate or high grade (2-3/3), greater than 5 cm in size, located deep to the fascia, and inadequate margins. Sarcoma presents in a highly heterogeneous fashion, and there are exceptions to the general guidelines mentioned above (e.g., the anticipation of wide margins, wound healing delays, patient preference).

Variables, outcome measures and data sources

In this study patient data, including demographics, recurrence, survival, and tumor characteristics (such as type, margins, size, and grade), were collected from the EMR. Information regarding radiation treatment, including timing and dosage, was also documented in the EMR if administered to the patients. The final surgical margins were determined by a specialized bone and soft tissue institutional pathologist in a synoptic report.

The postoperative follow-up in accordance with the National Comprehensive Cancer Network (NCCN) Soft Tissue Sarcoma (STS) surveillance guidelines was followed as part of the institutional protocol. The primary endpoint of interest in this study was the presence of the details surrounding local recurrence (LR), which always had histologic confirmation. Routine use of MRI for local surveillance was not employed, and LR cases primarily

Table 1. Patient and Tumor Characteristics

		Total Number	RT	No RT
AGE	>65	51	19	32
	<65	24	6	18
Sex	male	52	16	26
	female	33	9	24
Grade	high	30	15	15
	intermediate	22	7	15
	low	23	3	20
Margin	Negative	54	14	40
	Positive	21	11	10
Depth	deep	38	17	21
	superficial	37	8	29
Size	<5cm	29	7	22
	>5cm	46	18	28
Metastasis	yes	12	7	5
	no		18	45
LR	yes	25	7	18
	no	49	18	31
1yr LR	yes		1	8
	no		23	40
	death		1	2
2yr LR	yes		3	15
	no		18	35
	death		4	3
5yr LR	yes		5	17
	no		15	30
	death		5	3
Status	dead		11	10
	alive		14	40

were reported by the patients themselves or noted during physical examinations. In cases where concerns for LR were present, confirmatory MRI and tissue sampling were performed.

Participants who did not experience local recurrence were censored at the time of their most recent clinical evaluation, calculated from the date of surgery. Participants who died during the study period were censored at their date of death. The time to local recurrence was defined as the duration between the surgery and the time of recurrence, considering the presence of a competing risk of mortality for the time-based analysis.

Analyses

Patient demographics comparing local recurrences in the entire cohort and in patients without radiation were analyzed with chi-squared or Fisher's exact test for categorical variables and Wilcoxon sum rank test for continuous variables, as appropriate. Kaplan-Meier curve was calculated for patients' survival time to recurrence as 1, 2 and 5 years. Cumulative incidence function was calculated using proc lifetest considering death as competing risk towards the recurrence.

RESULTS

A total of 75 patients met the inclusion criteria. The median follow-up period for these patients was 2.6 years (range 0.03 to 12.3 years). The median age of the patients was 72 years (range 30 to 80 years). The tumors were categorized based on grade as low-grade, intermediate-grade, high-grade in 30 (40%), 22 (29.33%) and 23 (30.67%) of cases, respectively. Additionally, the tumors were categorized based on size as less than or equal to 5 cm in 29 (38.67%) and greater than 5 cm in 46 (61.33%) (Table 1).

Among the 75 patients in the study, a total of 50 (66.67%) patients did not receive radiation therapy (RT). Among the 25 radiated patients, 12 patients received neoadjuvant RT and 13 were treated postoperatively. In Table 2, in the RT group, 7 (28%) experienced recurrences while the non-RT group 18 (36%) patients had a recurrence (Figure 1) (p=0.20). 6/12 (50%) developed recurrence in adjuvant group while 1/13 (7.6%) of patient developed recurrence in neoadjuvant group (Figure 2).

During the first year of follow-up, one patient in the irradiated group had a recurrence. In the non-irradiated group, eight patients experienced recurrence. At the two-year mark, 3/24 (12.5%) patients remaining in the irradiated group experienced a recurrence, cumulatively. In the non-irradiated group, 12/42 (28.5%) patients experienced recurrence. At the five-year follow-up, 5/21 (23.8%) in the irradiated group had a recurrence. In the non-irradiated group, 17/30 (56.6%) patients experienced recurrence. Despite this trend, there was no statistically significant difference in the occurrence of local recurrence between the two groups at the one-year mark (p = 0.32), two-year follow-up (p = 0.24) and five-year mark (p = 0.32) (Table 3).

In this study, three different tumor grades were analyzed: high grade, intermediate grade, and low grade.

High Grade Group

There was a total of 30 patients with high-grade tumors. Among these patients, 15 received radiation therapy (RT), while the other 15 did not. In the RT group, 5/15 (33.34%) patients developed recurrence. In the non-RT group, 7/15 (46.6%) patients developed recurrence. There was no significant difference in recurrence between the RT and non-RT groups in the high-grade group. The high-grade group showed no significant difference in recurrence between the RT and non-RT groups at 1 year (p=0.47), 2 years (p=0.60) and 5 years (p=0.57) follow up (Table 3).

Intermediate Grade Group

There was a total of 22 patients with intermediate-grade tumors. Among these patients, 7 received RT, while 15 did not. In the RT group, 1/7 (6.67%) patients developed recurrence, while 6 did not. In the non-RT group, 7/15 (46.6%) patients developed recurrence (p=0.19).

The intermediate-grade group showed no significant difference in recurrence between the RT and non-RT groups at 1 year, 2 years and 5 years (p-values of 0.61, 0.54 and 0.19, respectively) follow up (Table 3).

Low Grade Group

There was a total of 23 patients with low-grade tumors. Among these patients, 3 received RT, while 20 did not. In the RT group, 1/3 (33.33%) patients developed recurrence while 4/16 (25%) patients developed recurrence in non-RT group (p = 0.59).

Margins

Of 75 patients, 54 (72%) had negative margins. Among the 54 patients with negative margins, 14 received radiation treatment and 40 did not. In the radiation group, 1/12 (8.33%) patients experienced recurrence while 2 expired compared to 9/36 (25%) in patients without RT and 4 expired at 5 years (p=0.0345).

Overall, the study included 21 patients (28%) with positive margins, 5/11 (45.45%) patients had recurrences in irradiated group, while in the non-radiation group, 6/10 (60%) patients had recurrences (p = 0.66).

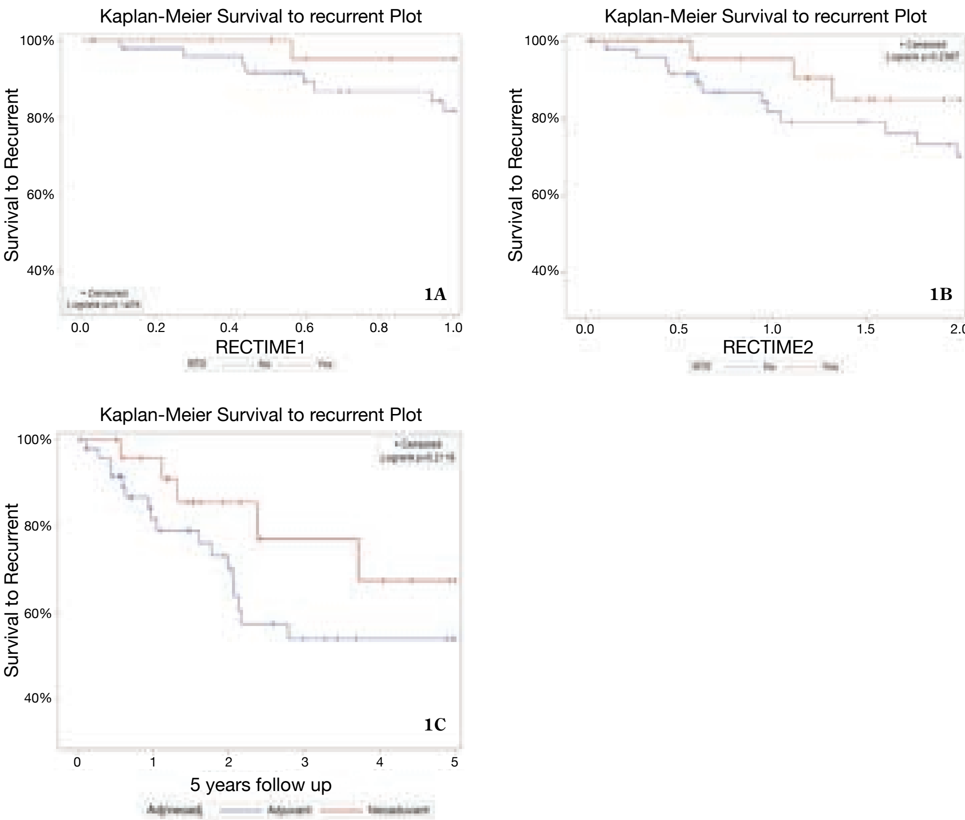

Figure 1A to 1C. Kaplan-Meier Survival to recurrent Plot. Comparison of local control rates in the entire cohort with and without radiation within 1 year (1A), 2 years (1B) and 5 years (1C).

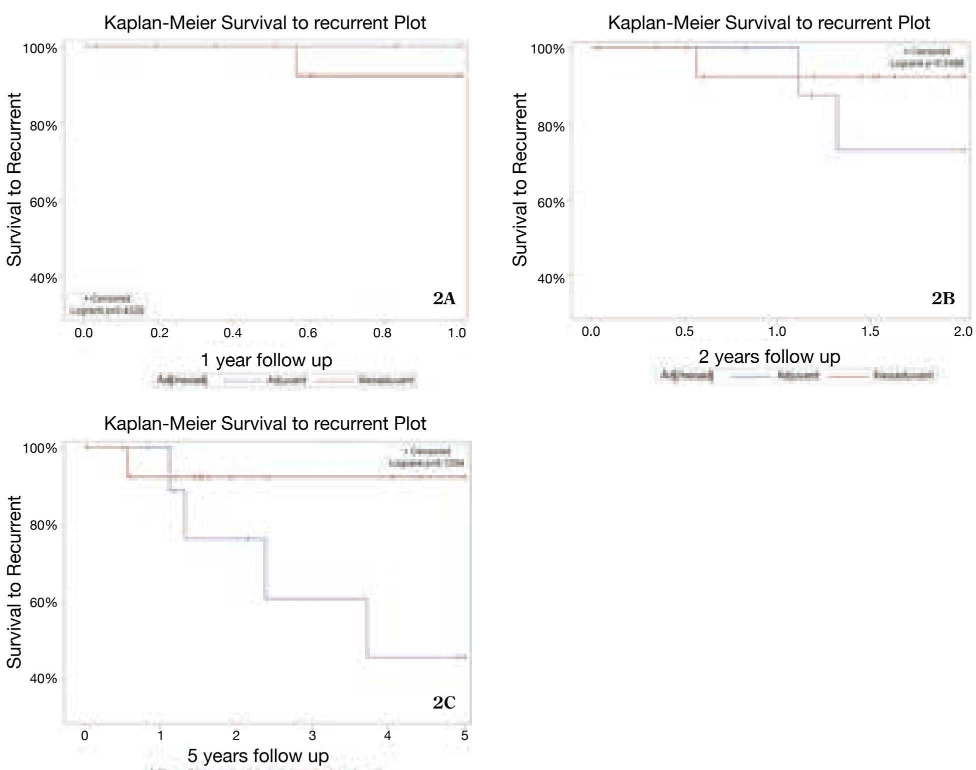

Figure 2A to 2C. Kaplan-Meier Survival to recurrent Plot. Comparison of local recurrence rates in adjuvant radiation and neoadjuvant RT within 1 year (2A), 2 years (2B) and 5 years (2C).

Table 2. Univariate Analysis for the Association Between Variables of Interests with Local Recurrences Among Cohort

		RT	NO RT	P value
Grade				
High Grade	LR	5	7	0.4561
	No LR	10	8	
Intermediate grade	LR	1	7	0.1932
	No LR	6	8	
Low grade	LR	1	4	0.193
	No LR	2	16	
Size				
<5cm	LR	1	8	0.3816
	No LR	6	14	
>5cm	LR	6	10	0.8686
	No LR	12	18	
Depth				
Superficial	LR	3	8	0.672
	No LR	5	21	
Deep	LR	4	10	0.1258
	No LR	13	11	
Margins				
Positive	LR	5	6	0.6699
	No LR	6	4	
Negative	LR	2	12	0.4561
	No LR	12	18	

Tumor size

In this study 29 patients (38.6%) had sizes less than 5 cm. Among the 29 patients with size less than 5 cm, 7 received radiation treatment and 22 did not. In the radiation group, 1/7 (14.2%) patients experienced recurrence, while in the non-radiation group, 8/22 (36.36%) patients developed recurrence. Among the 46 patients with size more than 5 cm, 18 received radiation treatment, and 28 did not. In the radiation group, 6/18 (33.33%) patients developed recurrences, while in the non-radiation group, 10/28 (35.71%) patients had recurrences (p = 0.66).

Recurrence-Free Survival Analysis

A Kaplan-Meier survival plot was utilized to examine the association between survival probability and recurrence time within the study population. The graph revealed no statistically significant difference in survival between the observed groups at 1, 2, and 5 years, as indicated by log-rank p-values of 0.14, 0.23, and 0.21, respectively. Censored observations, represented by the '+' symbol, accounted for incomplete information concerning individuals who had not experienced recurrence or reached the end of the follow-up period. These findings suggest that there is no substantial discrepancy in survival regarding recurrence time within the study population (Figure 1).

DISCUSSION

Soft tissue sarcomas (STS) require surgical removal for optimal oncologic and functional outcomes. Surgery as a standalone approach can be considered, aiming to achieve wide margins, while preserving critical structures such as bones, nerves, or vessels.[9] Randomized studies comparing surgery alone to surgery combined with adjuvant RT showed improved LR rates with RT for STS in general (but not for MFS specifically). For high-grade sarcomas, the addition of external beam RT (EBRT) resulted in a statistically significant improvement in LC compared to surgery alone. The same trend was observed for low-grade sarcomas, although statistical significance was not reached.[7,10] In our study we analyzed the role of radiation therapy in myxofibrosarcoma specifically. We found a high rate of local recurrence for the entire cohort (25/75, 33.34%) as well as for subgroups of patients treated with no radiation (18/50, 36%), postoperative radiation (6/12, 50%), and preoperative radiation (1/13, 7.6%). Several additional findings warrant further discussion.

Despite the advancements made in treatment radiotherapy techniques, the current methods still yield local recurrence rates nearing 20%, with a significant portion of these recurrences happening within the treatment area. There are two possible explanations for this finding. First, MFS is known to be an infiltrative tumor and often occurs suprafascially in the subcutaneous fat which acts as a poor oncologic barrier. Therefore, it is technically difficult to visualize the margins intraoperatively and pathology reports also likely undercall the rate of true positive margins by missing subtle areas of microscopic extension. Second, the tumors biologically may demonstrate a tendency toward inherent radio resistance.[7,11] The local recurrence rate in our study is 28% which is higher than local recurrence in other sarcoma subtypes, consistent with prior reports.[1,12,13] The presence of inherent radio resistance could be a contributing factor to the overall local recurrence rates observed. This resistance might limit the effectiveness of radiotherapy in preventing local recurrences in myxofibrosarcoma. Unfortunately, but consistent with this theory, we did not find that the addition of postoperative radiotherapy to microscopic positive margins was able to substantially mitigate the risk of LR (5/11 [45%] in the RT group compared to 6/10 [60%] without RT [p=0.66]). In other words, postoperative RT was not able to rescue an inadequate excision.

Table 3. Bivariate Analysis for the Association Between Variables of Interests with Local Recurrences at 1 year, 2 years and 5 years

		1 year				2 years				5 years			
		LR	No LR	Death	P value	LR	No LR	Death	P value	LR	No LR	Death	P value
High grade	RT	1	13	1	0.477	3	9	3	0.605	4	7	4	0.527
	No RT	4	10	0		6	7	2		7	6	2	
Intermediate grade	RT	0	7	0	0.6818	0	6	1	0.564	0	6	1	0.198
	No RT	2	12	1		3	11	0		6	8	1	
Low grade	RT	0	3	0	1	0	3	0	1	1	2	0	0.539
	No RT	2	18	0		3	17	0		4	16	0	
<5cm	RT	0	7	0	1	0	7	O	0.546	0	7	0	0.142
	No RT	2	20	0		4	18	0		8	14	0	
>5cm	RT	1	16	1	0.408	3	11	4	0.480	5	8	5	0.393
	No RT	6	20	2		8	17	3		9	16	3	
Superficial	RT	0	7	1	1	0	6	2	0.369	1	5	2	0.452
	No RT	3	24	2		5	21	3		8	18	3	
Deep	RT	1	16	0	0.196	3	12	2	0.239	4	10	3	0.108
	No RT	5	16	0		7	14	0		9	12	0	
Positive	RT	0	11	0	0.090	2	8	1	0.659	6	4	1	0.669
	No RT	3	7	0		4	5	1		6	3	1	
Negative	RT	1	12	1	1	1	10	3	0.154	1	9	4	0.034
	No Rt	5	33	2		8	30	2		11	27	2	

RT: Radiotherapy, LR: Local Recurrence.

The predictive role of surgical margins in other soft tissue sarcomas has also been established in multiple studies.[14,15] Positive margins were found to be a significant predictor of LR in myxofibrosarcoma. Individuals with close/positive margins have higher risk of experiencing LR compared to those without such margins.[16,17] Nevertheless, the utilization of postoperative radiotherapy in this cohort did not demonstrate enhanced tumor control and failed to yield a notable decrease in recurrence rates for patients with positive margins compared to those with negative margins. This indicates that postoperative radiation therapy may lack efficacy in reducing recurrence, particularly in cases where positive margins are detected. Although not definitively proven by this small, single-center, retrospective study, our findings do suggest that close or positive margins generally should not be accepted and additional excisions should be done until the margins are widely free of tumor. If widely negative margins are not achieved, the high likelihood of local recurrence must be expected and accepted by the patient and treating team. In some cases, obtaining a wide margin may require more invasive procedures such as skin grafts, rotational flaps, free tissue transfer, or even amputation. These complex cases should be reviewed by a multidisciplinary tumor board and employ shared decision-making with the patients.

The prognosis for deep sarcomas located in the fascia is generally worse compared to subcutaneous sarcomas. High-grade sarcomas have a higher rate of local recurrence compared to low-grade sarcomas.[18] For high-grade sarcomas, the addition of EBRT resulted in a statistically significant improvement in LR compared to surgery alone.[7] We found a trend toward improved local control in patients treated with preoperative radiation therapy; this did not result in a statistically significant reduction in recurrence rates for patients with high-grade or deep tumors due to the small cohort size.

Tumor-specific factors play a more significant role in determining overall and disease-free survival compared to patient-specific factors. These factors include tumor grade, nodal status, tumor size, the number of organs resected, and margin status. Furthermore, nonsurgical treatments like chemotherapy and radiation therapy do not seem to be associated with improved survival.[19] In this study addition of radiation therapy make no statistically significant difference in survival between the irradiated and non-irradiate groups at 1, 2, and 5 years.

Limitations: The study has several limitations that should be taken into account when interpreting its results and applying them to broader clinical practice. Firstly, the study design is retrospective, which introduces inherent biases in treatment decisions and limitations in data collection and analysis. Additionally, the study was conducted at a single institution, which limits the generalizability of the findings to other settings. Moreover, the sample size of 75 patients is relatively small, potentially limiting the statistical power of the study and its ability to detect significant differences between groups. Another limitation is the lack of standardized treatment protocols, as the decision to administer radiation therapy was based on individual factors and the judgment of a multidisciplinary tumor board. This variability in treatment protocols could impact the interpretation of the study.

CONCLUSION

The study aimed to determine if perioperative radiotherapy effectively prevents local recurrence and delays recurrence in primary and recurrent myxofibrosarcoma (MFS). The statistical analysis found no significant difference in recurrence rates between patients who received radiation therapy and those who did not. We found a trend toward lower LR rates when preoperative radiation was given at different follow-up periods (1 year, 2 years, and 5 years) and across different tumor grades. Although radiotherapy demonstrated a reduction in recurrence rates in patients with MFS in this study, the observed difference did not reach statistical significance. The recurrence rates were lower in the irradiated, compared to the non-irradiated, group at 5 years in patients with negative margins. Local control rates may be improved by assertive use of preoperative radiation in cases where margins are anticipated to be inadequate. The results highlight the need for further research, including prospective studies with larger sample sizes and longer follow-up periods, to establish more robust evidence regarding the efficacy of perioperative radiotherapy for treating myxofibrosarcoma.

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OUTCOMES OF SIMULTANEOUS LENGTHENING AND ACL RECONSTRUCTION IN FIBULAR HEMIMELIA: A RETROSPECTIVE CASE SERIES

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ABSTRACT

Background: Fibular hemimelia is the most common congenital long bone deficiency. It is often associated with femoral and tibial deficiencies which result in a clinically evident leg length discrepancy. The primary soft tissue concern is ACL/PCL deficiency. If treatment includes bony lengthening, joint stability is imperative to avoid complications. In this study, we detail a novel technique for long bone lengthening and ACL reconstruction in a single, cohesive surgery. This consolidates the need for multiple procedures and offers improved limb length symmetry and knee stability for this patient population. Clinical outcomes of pediatric patients with hemimelia who underwent either femoral or tibial lengthening with PRECICE® nail and concomitant ACL reconstruction are presented.

Methods: After IRB approval, we identified five patients with complex fibular hemimelia who underwent ACL reconstruction and concomitant lengthening with at least two years of follow-up. Two patients (40%) presented with congenital short femur, and three (60%) with congenital short tibia. In each case, ACL reconstruction and either femoral or tibial guided growth via PRECICE® nail were performed. Operative techniques involving both soft tissue and bony methodology are described in detail.

Results: All patients had objective improvement in knee stability as assessed both intra and post operatively, as well as successful intermedullary lengthening without complications related to joint stability. Three patients had minor complications unrelated to joint stability that did not interfere with overall result.

Conclusion: Fibular hemimelia associated with hypoplasia of bony and soft tissue structures can be successfully addressed with concomitant ligamentous reconstruction at the time of implantation of lengthening devices. This addresses knee instability and reduces both number of operative procedures and potential complications related to joint instability while pursuing bony lengthening.

Level of Evidence: V

Keywords: fibular hemimelia, ACL reconstruction, pediatrics, case series, PRECICE

INTRODUCTION

Fibular hemimelia, also known as postaxial hypoplasia of the lower extremity (PHLE) is the most common congenital long bone deficiency, with a variable incidence reported between 5.7-20 cases per 1 million live births.[1] Fibular hemimelia is commonly associated with bony malformations such as hypoplasia or dysplasia of the ipsilateral femur, tibia and/or foot. The primary soft tissue concern is ACL/PCL deficiency with an incidence of 95% in patients with hemimelia.

On presentation, the key clinical problem in these individuals is a leg length discrepancy. When greater than 2 cm, this can be addressed with bone lengthening procedures utilizing external fixation or intramedullary lengthening nails, often in combination with ipsilateral or contralateral epiphysiodesis.[2] More recently, externally controlled, motorized internal lengthening devices, such as the PRECICE® nail (Globus Medical, Audubon, PA), have been recognized as reliable and safe to achieve accurate long bone lengthening.[2,3] Lengthening procedures may be complicated by instability of the knee, with joint stability being a key factor in avoiding joint subluxation during lengthening. However, due to the variability in presentation of these patients, the necessity and feasibility of ACL reconstruction has been debated.[4,5]

In this study, we detail a novel technique for long bone lengthening and ACL reconstruction in a single, cohesive surgery. This technique consolidates multiple procedures, and offers improved limb length symmetry and knee stability. Clinical outcomes of pediatric patients with hemimelia who underwent either femoral or tibial lengthening with PRECICE® nail and concomitant ACL reconstruction are presented.

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METHODS

Following IRB approval, a query of our patients who had congenital fibular hemimelia was performed. Inclusion criteria consisted of patients presenting with congenital short femur or tibia and ACL deficiency with clinical evidence of knee instability. Patients who did not show knee instability on clinical exam were excluded.

Surgical Technique

Pre-operative examination is performed to confirm knee instability characterized by increased grade Lachman and pivot-shift compared to the unaffected extremity. Pain control is done on an individual basis through either epidural anesthesia or the appropriate peripheral nerve blocks. Patients are prepped and draped in standard sterile fashion according to hospital protocols.

Arthroscopically assisted ACL reconstruction is performed prior to insertion of the PRECICE® nail. Three standard arthroscopic portals are established, and systematic diagnostic arthroscopy is performed. ACL deficiency is confirmed intraoperatively, and graft choice is based on skeletal maturity. Skeletally immature patients with at least two years of growth remaining are reconstructed with iliotibial (IT) band physeal sparing technique, while a quadriceps tendon-patella bone graft is utilized for skeletally mature patients.

As in the technique described by Kocher et al. for physeal sparing reconstruction with IT band graft, an incision is made over the lateral aspect of the distal femur, extending proximally 3-4 cm from just proximal to Gerdy's tubercle.[6] Dissection is taken down to the IT band which is incised longitudinally to obtain a 2 cm wide graft. The graft is transected proximally to achieve a length of approximately 20 cm and the distal attachment is spared. The graft is then tubularized via whip-stitch and shuttled over the top of the lateral femoral condyle, through the femoral notch. The graft is then tensioned with the knee in neutral rotation and flexed to 90°, and then sutured to the lateral femur. The tibial insertion is secured with an anchor and oversewn to anterior tibial periosteum prior to antegrade nail placement or after retrograde nail placement to avoid violation of the graft with reaming.

In the case of quadriceps tendon autograft, the graft is harvested with a bone plug from the mid-portion of the proximal pole of the patella.[7] The tendinous portion of the graft is tubularized via whip-stitch with high tensile non-absorbable suture. The graft is secured via transphyseal tunnels if the patient is skeletally mature. If the patient is skeletally immature, the graft is secured via epiphyseal tunnel confirmed on fluoroscopy of the distal femur and physeal sparing tibial anchor, and is oversewn as described above.

Prior to completing the final tibial fixation of the ACL reconstruction, attention is turned to the guided growth aspect of the procedure. In cases of congenital short femur, a radiolucent ruler is utilized to plan the nail length and diameter, as well as the level of the osteotomy approximately 9 cm distal to the tip of the greater trochanter. A 2-3 cm longitudinal incision is made over the lateral aspect of the proximal femur, centered at the level of the osteotomy. The IT band is split, and several vent holes are made using a 3.5 mm drill bit perpendicular to the femoral cortex at the level of the planned osteotomy. An incision is then made proximal to the greater trochanter and a smooth guide pin is placed in the greater trochanter start point. A cutting entry reamer is advanced to the level of the lesser trochanter before a guidewire is pushed down the femoral shaft. Flexible reamers are utilized to prepare the medullary canal for the appropriately sized implant. The PRECICE® nail is then advanced to the level of the osteotomy. K-wire pins are partially driven into the femoral cortex proximal and distal to the osteotomy site to facilitate rotational control. The osteotomy is then completed, and the nail is advanced to the distal end of the femur. Interlocking screws are placed. The IT band is identified distally through the previously made incision and transected completely by a single transverse cut. The PRECICE® nail is then tested for function by distracting the femur 1 mm.

In cases of congenital short tibia, a radiolucent ruler is utilized to plan the nail length and diameter, as well as the level of the osteotomy approximately 7-10 cm below the level of the joint line. An incision is made just lateral to the tibial crest, and dissection is carried down to the periosteum. The tibia is then vented perpendicular to the cortex at the level of the planned osteotomy. Proximally, the lateral arthroscopy portal is lengthened distally to expose the proximal tibia. A guide pin is placed into the proximal tibia, just anterior and medial to the lateral tibial spine. The physis is visualized under fluoroscopy and the entry reamer is used to access the tibial medullary canal 1 cm below the level of the physis. A guide wire is then advanced, and the tibia is reamed with flexible reamers to the appropriate size. With the tibia prepared, attention is directed to performing the fibular osteotomy. First, the syndesmosis is fixed utilizing a 3.5 mm screw spanning from the fibula into the tibia 2-3 cm proximal to the distal tibial physis. Another incision is made at the level of the junction of the middle and distal thirds of the fibula and dissection is carried down to periosteum. An oscillating saw is then utilized to cut the fibula obliquely in a proximal posterior to distal anterior direction. Attention is then directed back to completing the tibial osteotomy. The PRECICE® nail is advanced to the level of the osteotomy. The osteotomy is completed, and the nail is advanced distally to 2-3 cm proximal to the level of the syndesmosis fixation screw. Rotation of the proximal and distal tibial fragments are aligned, and interlocking screws are placed. The PRECICE® nail is then tested for function by distracting the tibia 1 mm.

With the guided growth portion of the procedure now complete, attention is directed back to completing the ACL reconstruction. For IT band grafts, a rasp is used to remove sharp bony transitions and build a trough in the ACL footprint extending to the proximal anterior tibial cortex. The IT band graft is then passed under the intermeniscal ligament. With the knee flexed 30°, the graft is tensioned and sutured into the periosteum of the proximal anterior tibial cortex. For added reinforcement, a PushLock® suture anchor (Arthrex, Naples, FL) is placed into the tibia distal to where the graft is sutured into the proximal tibia.

In cases of quadriceps tendon autograft, the graft is tensioned and secured to the proximal tibia. Arthroscopic evaluation of the ACL is performed, confirming no evidence of impingement or limitations in range of motion. All surgical wounds are then irrigated and closed with monofilament and dressed with Steri-Strips® and standard sterile dressings. Finally, a hinged knee brace locked in extension is applied to help prevent posterior subluxation of the tibia.

Table 1. Patient Demographics

Participant ID	1	2	3	4	5	Average
Age at Time of Surgery (years)	11.9	11.7	8.9	10.4	9.8	10.5
Age at Time of Diagnosis (years)	0.4	2	3.4	0.7	0.4	1.4
Side of Hemimelia	Left	Left	Left	Left	Right	
Congenitally Short Bone	Tibia	Tibia	Femur	Femur	Tibia	
Associated Anomolies	Polydactly	N/A	N/A	N/A	Polydactly	
Plays Running/ Jumping/ Cutting Sports	No	Yes	Yes	Yes	Yes	
Epiphysiodesis/Hemiepiphysiodesis	Yes, Left	Yes, Left	Yes, Left	Yes, Left	No	

RESULTS

A total of five patients with fibular hemimelia undergoing ACL reconstruction and concomitant lengthening were identified. Of these patients, there were two (40%) with congenital short femur and three (60%) with congenital short tibia (Table 1). In all cases, ACL reconstructions and either femoral or tibial guided growth via antegrade PRECICE® nail were performed. Four patients were male (80%) and one was female (20%). The average age at the time of surgery was 10.5 years old (range 8.9-11.9). The average pre-operative femoral length discrepancy was 1.56 cm (range -0.9-3.3 cm) and the average pre-operative tibial length discrepancy was 2.66 cm (range 0.1-6.9 cm). The total pre-operative leg length discrepancy averaged 4.22 cm (range 2.1-8.0 cm). Femoral guided growth resulted in an average lengthening of 6.95 cm (range 5.9-8.0 cm) and tibial guided growth resulted in lengthening of 5 cm in each case. At an average follow up of 3.7 years (range 2.6-5.6 years), residual leg length discrepancy following guided growth averaged 2.56 cm (range 1.3-4.2 cm) (Table 2) (Figures 1, 2, 3).

In total, two of the five PRECICE® nails were removed from within the intramedullary canal with an average hardware implantation duration of 2.46 years. Complications of guided growth occurred in three of the five cases, as two patients required repeat osteotomy of the fibula for early consolidation and one patient developed arthrofibrosis.

DISCUSSION

Clinically significant leg length discrepancy is commonly characterized as an inequality of greater than or equal to 2 cm.[8] Each of our patients presented cases of hemimelia with a significant leg length discrepancy. On average, affected limbs were lengthened via motorized intramedullary nail by 5.78 cm. This resulted in a mean reduction in overall leg length discrepancy of 1.66 cm, from pre-operative time to the time of the last post-operative visit. Two of the five patients had residual leg length discrepancy of >3cm (4.2 and 3.1 cm) due to expansile limitations of the initial nail that could accommodate the small canal. However, the residual discrepancies have not been clinically significant to the patients and have not warranted a second lengthening. A residual leg length discrepancy is not uncommon following an initial limb lengthening, and may be approached through a contralateral epiphysiodesis if growth remaining exists, a second lengthening of the shorter extremity, or conservative measures such as a shoe/heel lift.[9]

Table 2. Complications

	Patient ID	1	2	3	4	5	Average
Bone Lengthened		Tibia	Tibia	Femur	Femur	Tibia	
Pre-operative Total LLD (cm)	Femur	1.1	1.5	2.8	3.3	-0.9	1.56
	Tibia	6.9	1.3	0.1	2	3	2.66
Total Initial LLD (cm)		8	2.8	2.9	5.3	2.1	4.22
Post-operative Total LLD (cm)	Femur	2	2.6	0	0	0.1	0.94
	Tibia	2.2	-1.3	1.9	3.1	2.2	1.62
Amount Lengthened (cm)	Femur			5.9	8		6.95
	Tibia	5	5			5	5
Total Residual LLD (cm)		4.2	1.3	1.9	3.1	2.3	2.56
ACL Reconstruction		Yes	Yes	Yes	Yes	Yes	
Time From Diagnosis to Surgery (years)		11.5	9.7	5.5	9.7	9.4	9.16
Length of Follow-up (years)		1.1	1.5	4.1	2.7	1.7	2.22
Duration of Hardware Implantation (years)		1.4	2.7	3.1	1.2	3.9	2.46
Complications		Early Fibular Consolidation	N/A	N/A	Knee Arthrofibrosis	Early Fibular Consolidation	

Figure 1A to 1C. 9 year 3 month old male with right tibial hemimelia. (1A) Anterioposterior (AP) standing radiograph of lower extremities showing a 4.7-centimeter leg length discrepancy with a predicted leg length discrepancy at maturity to be approximately 7.5 centimeters. (1B and 1C) AP and lateral radiographs of the right tibia/fibula prior to surgery.

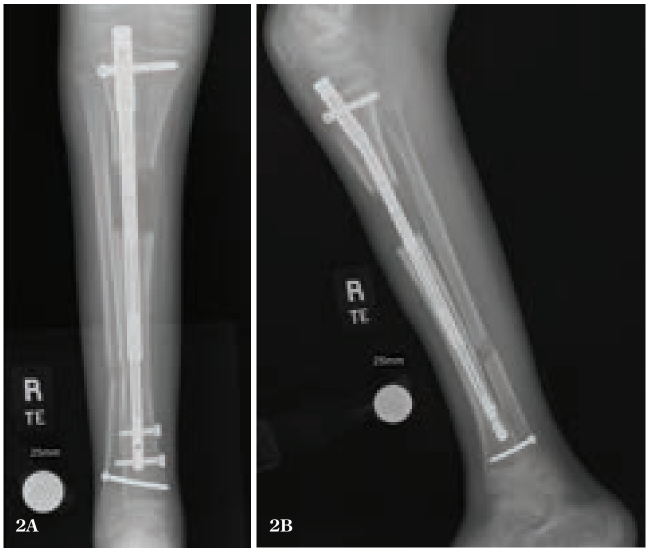

Figure 2A to 2B. 9 year 11 month old male following right tibial lengthening. (2A and 2B) AP and lateral radiographs following ACL reconstruction, PRECICE® nail implantation and lengthening.

Figure 3. 10 year 10 month old male following right tibial lengthening and consolidation. AP standing radiograph of lower extremities shows residual leg length discrepancy of 0.2 centimeters with a projected leg length discrepancy of 2.6 centimeters.

Obstacles to achieving adequate limb lengthening are common in fibular hemimelia and include early osteotomy consolidation, knee flexion deformities, joint stiffness, periprosthetic fracture, mechanical axis deviation and patellar subluxation.[3] Two of our five subjects developed early consolidation of their fibular osteotomy, requiring a return to surgery for repeat osteotomy in order to continue with lengthening. One patient developed significant knee pain and stiffness, prompting a one-week pause in lengthening. This led to resolution of associated pain, facilitated less painful lengthening following the break, and was not complicated by early consolidation. However, this same patient developed arthrofibrosis of the knee, requiring an additional surgery for manipulation under anesthesia, which was successful in improving joint range of motion long-term.

Complete release of the anterior compartment fascia was performed in all cases of tibial intramedullary nailing to address the increased risk for compartment syndrome in this population. Two subjects underwent routine explant of the PRECICE® nail following completion of lengthening and consolidation. Although hardware removal of the intramedullary nail is planned for the remaining three subjects, no magnet related complications have been noted to date.[10]

Current surgical interventions for fibular hemimelia are centered around correction of leg length discrepancies with incongruent consideration given to addressing knee instability given the prevalence and potential sequela of ACL deficient knees in this pediatric population.[11,12] The most accepted ideology for not performing ACL reconstruction in cases of hemimelia is that the natural history of a congenitally deficient knee is not equivalent to a knee with a traumatically ruptured ACL.[5,13] Anatomical variances in knee stabilizers as well as conscious and subconscious activity modification are thought to contribute primarily to the joint stability perceived by patients.[14,15] However, individuals who present with both subjective knee instability and objective instability per clinical exams have been shown to benefit from reconstruction.[14,16] All participants in this study presented with complaints of subjective knee instability and were found to have at least a grade 2 pivot shift and grade 2A Lachman's test clinically. ACL reconstruction by the method described above conferred objective improvement in knee stability, as assessed intra-operatively during the time of reconstruction. Patients who underwent ACL reconstruction during the time of guided growth also did well clinically, with all athlete participants returning to cutting, running, and jumping sports without reported limitations or subjective instability on follow-up.

CONCLUSION

Fibular hemimelia is a rare disease process associated with variable hypoplasia or dysplasia of ipsilateral lower extremity structures. Intramedullary magnetic motorized devices prove a safe and effective method for addressing leg length discrepancy. For patients with associated subjective and objective knee instability, our technique for concomitant ACL reconstruction during the time of guided growth surgery has shown to be a feasible and effective method to restore functional knee stability, while addressing significant leg length discrepancies.

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UTILITY OF RECOVERY ROOM VS POST-OPERATIVE DAY 1 RADIOGRAPHS FOLLOWING SHOULDER ARTHROPLASTY

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ABSTRACT

Background: Postoperative radiographs may be performed on different timelines after shoulder arthroplasty. Radiographs obtained in the post-operative recovery unit (PACU) are often of poorer quality. The purpose of the current study was to explore and compare the quality of PACU radiographs and radiographs performed in the radiology suite on post-operative Day 1 (POD1), as well as determine their impact on changes in post-operative management.

Methods: Our series included 50 consecutive anatomic total shoulder arthroplasties (TSA) for which post-operative radiographs were obtained in the PACU and 50 consecutive TSA for which post-operative radiographs were obtained in the radiology suite on POD 1. TSA radiographs were blinded and reviewed by 3 authors and graded on their quality using criteria described using previously published methods. The weighted kappa was used to describe the intra-rater agreement and inter-rater agreement between two raters.

Results: There was no difference in age, sex, BMI, and comorbidities between cohorts. Intra-observer reliability was moderate to substantial with weighted kappa values of 0.65±0.07 (p<0.001), 0.58±0.09 (p<0.001), and 0.67±0.07 (p<0.001). Inter-observer reliability was moderate to substantial with weighted kappa values of 0.605±0.07 (p<0.001), 0.66±0.07 (p<0.001), and 0.65±0.08 (p<0.001). When assessing quality of radiographs, 30% of radiographs obtained in PACU were deemed quality while 57% of radiographs obtained in the radiology suite were deemed quality (p<0.001).

Conclusion: Post-operative radiographs in the PACU do not alter patient management and are often inadequate to serve as baseline radiographs. Conversely, radiographs obtained in the radiology suite are of higher quality and can serve as a superior baseline radiograph.

Level of Evidence: IV

Keywords: total shoulder arthroplasty, radiographs, post-anesthesia care unit (PACU), quality

INTRODUCTION

Radiographs in the immediate post-operative period after shoulder arthroplasty serve several purposes. They are used to judge component positioning and to evaluate for possible complication including periprosthetic fracture or dislocation.[1-4] Post-operative radiographs can also be shown to patients for educational purposes, potentially increasing patient satisfaction and compliance with post-operative protocols. As such, post-operative radiographs are ubiquitous in shoulder arthroplasty practice.

Many surgeons perform radiographs in the recovery room or post-anesthesia care unit (PACU). Images from the PACU offer immediate feedback regarding operative complications and implant placement. They can aid in that patient's care and inform the surgeon on operative technique, which has the potential to improve future surgical decision-making. These PACU radiographs, though, are often underpenetrated and can be difficult to interpret, particularly for films that are taken with some degree of technical error.[5] This is likely due to the inherent nature of the PACU with drowsy patients making positioning difficult, portable radiography machines having decreased resolution, among other difficulties.

Literature in total hip arthroplasty has repeatedly shown PACU radiographs to be inferior in quality to radiographs performed in a radiology suite.[6-8] This has also been evaluated in total knee arthroplasty, where PACU radiographs are found to be difficult to interpret, often underpenetrated, obscured by bulky dressings, and not of high enough quality to serve as baseline radiographs.[9] Namdari et al. evaluated the quality of PACU radiographs in shoulder arthroplasty and concluded that these radiographs are both costly and of poor quality. In addition, they found in their series that no treatment changes were made based on PACU radiographs.[3]

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Some surgeons only obtain post-operative radiographs in the formal radiology suite. In this scenario, alert patients and radiology technicians can optimize positioning, increase resolution of the study, and obtain higher quality radiographs to serve as post-operative evaluation and baseline films for future comparison. The purpose of the current study was to explore and compare the quality of PACU radiographs and the immediate post-operative radiographs performed in the radiology suite, as well as determine their impact on potential changes in post-operative management.

METHODS

This study was approved by the Institution's IRB (IRB# #202106409). We retrospectively reviewed 392 consecutive shoulder arthroplasties performed between January 2020 and July 2021. Patients were identified using current procedural terminology (CPT) 23472 for total shoulder arthroplasty. All reverse shoulder arthroplasty cases, 234 in total, were excluded. Thus 158 anatomic total shoulder arthroplasty cases were included for final analysis. There are two shoulder & elbow fellowship-trained physicians at our institution. One surgeon obtains post-operative radiographs (AP, Grashey, Scapular Y) in the PACU and again at two weeks, 6 weeks, 3 months, 6 months, and yearly (AP, Grashey, Axillary Lateral) post-operatively, while the other surgeon obtains post-operative radiographs (AP, Grashey, Axillary Lateral) in the radiology suite on post-operative day (POD) 1 that are meant to serve as baseline and does not repeat radiographs until one year post-operatively.

Our series included 50 consecutive anatomic total shoulder arthroplasties (TSA) for which post-operative radiographs were obtained in the PACU and 50 consecutive TSA for which post-operative radiographs were obtained in the radiology suite on POD 1 prior to discharge, that were selected from the total sample.

Single view, true AP TSA radiographs were blinded and reviewed by 3 authors (JVN, BMP, TDH) and graded on their quality. For patients that had radiographs obtained in the PACU, two week post-operative radiographs were also reviewed and graded. Quality was based on prior description by Alolabi et al. who defined radiographic criteria including: less than 2mm overlap of the humeral head at the level of the osteotomy surface, greater tuberosity and calcar in profile with minimal overlap of the prosthesis and lateral or medial bone (Figure 1).[2,10] Criteria and quality examples were provided during the review process. Radiographs were reviewed independently. A second review was completed approximately one month following the first review. Reviewers were asked to score "yes" or "no" if the radiograph met the pre-determined quality criteria.

TSA radiographs were also reviewed for evidence of fracture or dislocation and final radiology reads were also reviewed for fracture or dislocation. The weighted kappa was used to describe the intra-rater agreement and inter-rater agreement between two raters. The inter-rater agreement for all three raters was completed using the SAS MAGREE macro. Between group comparisons in age was evaluated using independent t-tests while BMI and comorbid conditions were compared between groups using Wilcoxon Rank Sum tests. Radiographic quality was scored as "Yes" or "No" and results were compared with chi-squared test. All analyses were completed using SAS statistical software version 9.4 (SAS Institute, Inc., Cary NC).

RESULTS

There was no statistical difference in age, sex, BMI, and number of comorbidities between all groups (Table I). No patients were discharged same day. Intra-observer reliability was moderate to substantial with weighted kappa values of 0.65±0.07 (95% CI 0.51-0.80, $p<0.001$), 0.58±0.09 (95% CI 0.41-0.75, $p<0.001$), and 0.67±0.07 (95% CI 0.53-0.82), $p<0.001$). Inter-observer reliability was moderate to substantial with weighted kappa values of 0.605±0.07 (95% CI 0.46-0.75, $p<0.001$), 0.66±0.07 (95% CI 0.52-0.81, $p<0.001$), and 0.65±0.08 (95% CI 0.50-0.80, $p<0.001$).

When assessing quality of radiographs, 30% of radiographs obtained in the PACU were deemed to be of adequate quality while 57% of radiographs obtained in the radiology suite were deemed to be of adequate quality, which was statistically significant ($p<0.001$). Of the 50 patients who received two week post-operative radiographs, 60% were deemed to be sufficient to serve as baseline radiographs which was significantly improved from PACU radiographs ($p<0.001$) but not radiology suite radiographs ($p=0.64$).

When reviewing final radiology reports, two patients' final radiology read reported possible fracture on PACU films. On review of these radiographs the possible fracture was determined by the reviewers to be the lesser tuberosity osteotomy site (Figure 2). There were no changes in patient's post-operative courses including weightbearing status, therapy protocol, or return trip to the operating room based on imaging findings.

The cost of PACU and POD1 radiographs were compared. Professional billing (radiologist read) and hospital billing costs were equal for PACU radiographs and for radiographs taken in the radiology suite (POD1 and 2-week postoperative). Nevertheless, since there are no special rates for outpatient radiographs, all radiographs taken are billable, thus patients that receive radiographs at PACU and then again at 2-weeks following surgery have a two-fold increased billable cost.

Table I. Patient Characteristics

	PACU				POD 1				
Variable	Min	Max	Mean	SD	Min	Max	Mean	SD	p-value
Age	47	80	65.4	7.6	48	93	66.6	8.8	0.4518
Sex (n, % female)	26 (52%)				28 (56%)				0.6882
BMI	19.7	52.8	31.6	7.6	21.2	52.1	31.9	6.5	0.6516
Comorbidities[1]	1	29	8.9	5.6	0	30	8.4	5.4	0.7115

[1]Comorbidities: obesity, hyperlipidemia, Diabetes Mellitus, acute blood loss.

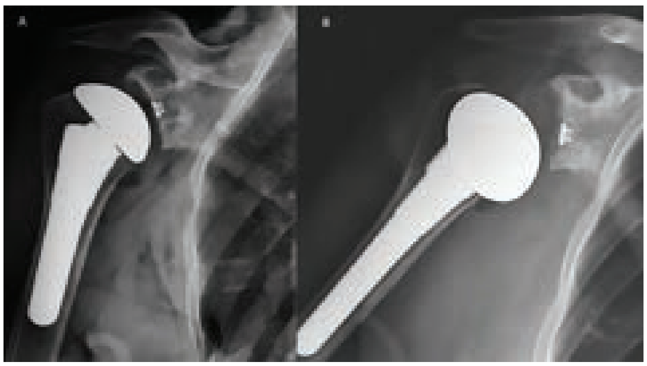

Figure 1A-1B. (A) True AP high quality radiograph. (B) low quality radiograph.

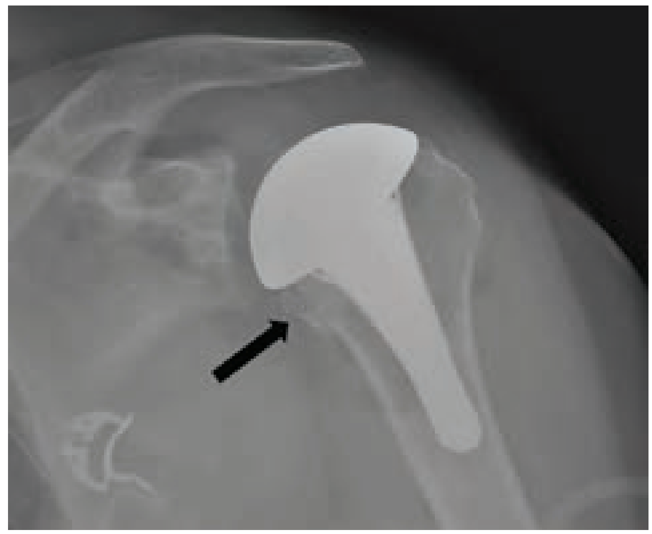

Figure 2. X-Ray showing the minimally displaced lesser tuberosity osteotomy site.

DISCUSSION

Historically, many institutions have routinely obtained immediate post-operative portable radiographs in the PACU following arthroplasty procedures. Based on published literature, these studies are often of poor quality and potentially should not serve as baseline radiographs. Surgeons at our institution vary in their preferences for postoperative radiographs. This conveniently allows for the comparison of these radiographs in a largely homogenous patient population. The results obtained in our study show that immediate post-operative radiographs are often of poorer quality than those obtained in the radiology suite on POD 1. This study also showed that there was no difference in patient management based on when radiographs were obtained.

There are multiple studies in the total hip arthroplasty (THA) and total knee arthroplasty (TKA) literature that question the cost-effectiveness and quality of immediate post-operative radiographs. Glaser completed a two part study in which 200 patients had immediate post-operative radiographs with a total cost of $36,000, and only 36% were determined to have sufficient quality to act as baseline radiographs.[11] In their second part, 550 patients prospectively received first post-operative radiographs at two weeks. They determined that there was no change in management based on immediate post-operative radiographs.

Ndu reported on 632 consecutive PACU radiographs following THA. 17% of their series was determined to be inadequate to detect technical issues and only 2 (0.3%) impacted inpatient management.[6] They concluded that routine inpatient radiographs should be obtained in the radiology suite. Novack reviewed 195 readmissions within 90 days of uncomplicated TKA to evaluate if there was evidence of abnormality that may have prevented readmission.[12] There was no evidence of fracture or other abnormality that could have predicted readmission. They determined that the cost associated with identifying a single fracture in 2,415 patients was $1,072,260. Hassan reviewed 624 consecutive TKA over a 34-month period and concluded that early post-operative radiographs did not change routine post-operative management.[13]

There is a paucity of literature regarding immediate post-operative imaging following shoulder arthroplasty. Namdari did report on shoulder arthroplasty patients who received a single view (88% true AP) in the PACU compared to a second group of patients who obtained a full series after discharge. They concluded that routine

PACU radiographs may result in poor-quality images and elimination of these radiographs may reduce cost without changing clinical care.[3] Their series however did not evaluate the utility and quality of post-operative x-rays completed prior to discharge in the radiology suite.

Some advantages of PACU radiographs are that they offer immediate feedback not only on possible complications, but also on operative techniques. Some surgeons find advantageous to analyze the postoperative radiograph the same day of the surgery, in order to potentially improve future surgical techniques or decisions, and for teaching purposes as well. Despite of this, PACU radiographs tend to be of low quality and they usually do not serve as high quality baseline images for follow up. On the contrary, there are multiple advantages to obtaining radiographs in the radiology suite on POD 1. Radiographs were found to be of higher quality when compared to portable PACU films. Obtaining baseline radiographs prior to discharge can also streamline post-operative clinic visit efficiency by negating the need to routinely obtain baseline radiographs at the first post-operative visit. Quality baseline radiographs within the first few days of the procedure are also more useful in scrutinizing surgical technique than obtaining them weeks following the procedure.

This study is limited by its retrospective nature. First, we reviewed post-operative preferences for the two surgeons at our institution and understand there are many other post-operative imaging protocols which could be applied. Second, we chose to review the past 100 consecutive TSA cases. Our study population may not have been large enough to capture radiographs that would have changed patient management.

While no patient's post-operative course was altered based on radiographs in our study, there is a potential liability for missing a dislocation or fracture if radiographs are not obtained prior to discharge. Optimally, imaging would be performed prior to a patient being awakened from anesthesia to allow for any needed intervention prior to leaving the operating room. As this is often infeasible, we feel that, for this reason, radiographs should at least be completed and reviewed prior to discharge. If patients are undergoing same day discharge shoulder arthroplasty, we would recommend PACU radiographs followed by a complete series at their first post-operative visit to act as baseline radiographs. Alternatively, patients undergoing same day discharge may be able to obtain higher quality radiographs in the radiology suite prior to discharge depending on institutional capabilities. If patients are being admitted for observation, this study supports the practice of obtaining radiographs in the radiology suite on POD 1 rather than PACU radiographs.

CONCLUSION

Radiographs obtained in the post-anesthesia care unit (PACU) are often of poor quality and do not often alter decision making following shoulder arthroplasty. The results of this study support the use of x-rays obtained prior to patient discharge, in the radiology suite when possible. These x-rays are of higher quality and serve as better baseline radiographs following anatomic total shoulder arthroplasty.

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HIP DYSPLASIA TREATED WITH PERIACETABULAR OSTEOTOMY IN PATIENTS OVER 40 YEARS OLD: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Hip dysplasia is a leading cause of hip osteoarthritis. While periacetabular osteotomy (PAO) is effective for relieving pain and dysfunction caused by hip dysplasia in adolescents and young adults, there is concern that patients over 40 years of age will have an increased risk of persistent dysfunction and need for total hip arthroplasty. Current available evidence for PAO in older adults is limited and there is no systematic review in the literature focusing on this topic. The current systematic review offers insight into the demographics, patient-reported outcome measure (PROM) scores, and hip survivorship from total hip arthroplasty in patients over 40 years older treated for hip dysplasia with PAO.

Methods: The review was conducted under the guidelines for the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA). Databases that were searched included PubMed, OVID Medline, SCOPUS, Embase, Cochrane Library, and clinicaltrials.gov. Studies were screened based on predetermined inclusion and exclusion criteria.

Results: Five studies were included in this systematic review. Enrollment years were 1990-2013. In total, there were 335 hips with mean ages between 43.5-47.2 years. Mean follow up was 4-10.8 years. Most patients that underwent hip preservation had Tonnis osteoarthritis grade 0-1. There was contradicting evidence whether patients >40 years did better or worse compared to <40 years; although, most patients in the >40 years group had good outcomes after PAO. PAO survivorship ranged from 67-100% depending on the study. Complications ranged from 2-36% of cases depending on the study; although, none of these complications had lasting effects.

Conclusion: Patients over 40 years old appear to have positive outcomes when treated for hip dysplasia with PAO, though these patients were likely selected for no to minimal osteoarthritis, high functional status, and good health. PAO should be considered for patients with hip dysplasia over 40 years old without hip arthritis, though we recommend very selective indications.

Level of Evidence: II

Keywords: hip dysplasia, periacetabular osteotomy, adult, survivorship

INTRODUCTION

Pathologic joint mechanics due to hip dysplasia can lead to disability and eventually secondary osteoarthritis (OA) at young ages.[1,2] Typically, hip dysplasia is identified in adolescents and young adults; but occasionally patients above forty years of age present with pain and dysfunction without evidence of osteoarthritis (OA), leading to a controversial decision between non-operative treatment, total hip arthroplasty (THA), and periacetabular osteotomy (PAO).[3]

The Bernese periacetabular osteotomy (PAO) reorients the dysplastic acetabulum to increase femoral head coverage and stabilize the dysplastic hip.[4] This procedure has been proven to be effective for reducing pain and dysfunction and delaying progression to OA in the adolescent and young adult populations.[5] However, in older adults, its effectiveness is uncertain due to the increased prevalence of osteoarthritis (OA) and impaired healing potential with age.[6] As a result, PAO surgery to treat hip dysplasia is controversial in patients over 40 years of age.

To date, literature is scarce and there have been no systematic reviews that investigate the effectiveness of PAO in patients over 40 years old. The purpose of this systematic review was to (1) describe the baseline characteristics, (2) report the patient-reported outcome measures (PROM) before and after surgery, (3) report the survivorship from THA and OA progression, and (4) report the complications in patients over 40 years old treated with PAO surgery.

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METHODS

Search Strategy

The PICO(T) model was used (Population, Intervention, Comparison or control, Outcome, and Time period) to formulate a research question.[7] The PICO(T) question was "In patients over the age of 40 years (population), how does periacetabular osteotomy (intervention), compared with THA or patients <40 years (comparison, if present), influence patient-reported outcomes and/or survivability (outcome) over a 4-year mean follow-up clinical course (time period). This review was designed using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[8] Databases accessed were PubMed, OVID Medline, Embase, SCOPUS, Cochrane Central Register of Clinical Trials, and clinicaltrials.gov from their dates of inception to the literature search date of 12/9/23. Search terms included a combination of periacetabular, osteotomy, older, 40, and 50.

Selection criteria

For inclusion, articles were reviewed by two independent authors (K.P.O. and D.C.I). Studies included (1) a diagnosis of hip dysplasia, (2) no prior surgical intervention on the hip of interest, (3) mean follow-up of four years, and (4) clinical outcomes such as patient-reported outcomes and/or conversion to total hip arthroplasty (THA). Exclusion criteria included studies without all inclusion criteria, conference abstracts, technique papers, letters to editors, editorials, basic science studies, animal studies, guidelines, supplements, and non-English supplements.

Quality Assessment

Articles of interest were screened for using the Newcastle-Ottawa Scale (NOS).[9] For systematic reviews, this scale assesses the quality of non-randomized studies. Points are given for each question and with more points indicate a higher quality study. The maximum is 9 points per study (4 for selection, 2 for comparability, 3 for outcomes). Studies with ≥7 points were classified as "good", 2-6 points were "fair", and ≤1 was "poor" quality. Only studies with ≥7 points ("good" quality) were included in this report.

Data Extraction and Statistics

Data extraction was performed by two authors (K.P.O. and D.C.I.). Extracted data included demographic and clinical data. Demographic and clinical data were reported across studies. If there were demographic or clinical outcomes that were consistent across non-overlapping cohorts, then they were combined so that means and standard deviations could be reported for the overall cohort. For overlapping studies, pooled analyses were conducted using the most complete cohort.

RESULTS

Search Strategy and Quality Assessment

Figure 1 represents the PRISMA diagram for this study. A total of 469 studies were extracted from the databases. EndNote identified 235 duplicates and 206 studies were excluded based on titles and abstracts which left our search with 28 full texts. Fourteen were excluded based on cohorts that did not satisfy the age requirement, 1 study utilized an acetabular osteotomy that was not a Bernese periacetabular osteotomy, and 2 studies were inaccessible. Thus, we had 5 studies that underwent quality assessment. Using the NOS questionnaire, all 5 studies were good quality and thus were included in this systematic review (Table 1). For these studies, it is important to note overlap between three of the cohorts (Novais et al., Muffly et al., Millis et al.). Even though there was overlap, the study designs different, and each was able to offer unique results.

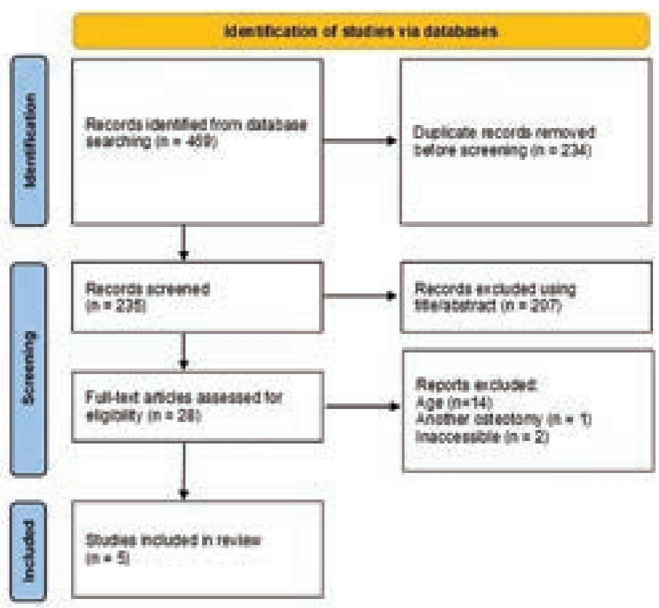

Figure 1. PRISMA diagram.

Demographic Data

For the five studies, the level of evidence included two level II studies, three level III studies, and one level IV study.[3,10-13] The years of enrollment was between 1995 and 2013. The mean age was 43.5-47.2 years. Female predominance ranged from 83-90%. Mean follow-up duration was 4-10.8 years. For comparison groups, one study had

Table 1. Newcastle-Ottawa Scale for Quality

Author	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Total *
Garbuz, 2008	*	*	*	*	**	*	*	*	9
Ito, 2011	*	*	*	*	**	*	*	*	9
Millis, 2009	*	*	*	*	*	*	*	*	9
Muffly, 2021	*	*	*	*	**	*	*	*	9
Novais, 2023	*	*	*	*	*	*	*	*	9

Table 2. Study and Demographic Data

Study	Year Published	Institution	Level of Evidence	Enrollment Years	Hips/ patients undergoing PAO	Mean Age	Female, % (n)	Mean Follow-up (years)	Comparison Group	OA
Garbuz	2008	Canada	III	1995-2003	28/28	45.4	90 (25)	4	THA	Tonnis 0-1
Ito	2011	Japan	III	1990-2004	41/36	47.2 (40-56)	83 (34)	10.8 (5-18.5)	<40 y/o	Tonnis 0-2
Millis	2009	Boston WashU Mayo	II	1996-2005	87/70	43.6 (40-51)	NA	4.9 (2-13)	None	Tonnis 0-2
Muffly	2021	Boston WashU ANCHOR	II	2008-2010	34/34	43.5±3.1	85 (29)	4.71	Ages <20, 20-29, 30-39	Tonnis 0-3
Novais	2023	Boston WashU	IV	1990-2013	145/145	43.9±3.1	90 (133)	9.6 (4.2-22.5)	NA	Tonnis 0-2

hips that underwent THA, two studies compared across age groups, and two studies did not have a comparison group and only reported outcomes for patients >40 years old. For the overlapping cohorts, Millis et al. has 4.9 years of follow-up, Muffly et al. has 4.7 years of follow-up, and Novais et al. provided a longer-term follow-up with 9.6 years (Table 2).[3,13,14]

Clinical Outcomes

All five studies reported PROM scores, but there were a variety of PROMs reported (Table 3).[3,10-13] Garbuz et al. compared patients undergoing PAO to treat hip dysplasia to patients undergoing THA.[10] He noted that patients undergoing PAO have lower postoperative PROMs compared to THA at a mean 4-year follow-up evaluation. For WOMAC Pain, the mean scores were 70.9 for PAO compared to 89.2 for THA. This resulted in rates of good results of 62% and 85%, respectively. For WOMAC Function, mean scores were 73.7 for PAO and 90.6 for THA. This resulted in rates of good results of 53% and 85%, respectively. For the SF-12 Physical Component, there were scores of 43.9 and 42.6, respectively. Overall satisfaction rates were 75% and 93.6%, respectively. High activity (UCLA ≥7) rates were 19% for PAO and 41% for THA.

Ito et al. compared patients >40 years to <40 years at a mean follow-up of 10.8 years.[11] The modified Harris Hip Score (mHHS) was similar between groups preoperatively at 68.9 and 70.1 and five-year after treatment at 91.4 and 92.0, respectively. At a mean of 10.8 years after treatment, the scores were slightly worse for patients >40 at 88.0 and 91.4, though this may not be a clinically significant difference. The remainder of the reported scores were only compared at the final follow-up evaluation (10.8 years). The mHHS pain was similar at 39.4 and 40.5. The mHHS function was lower for patients >40 at 89.1 and 92.3. WOMAC pain was lower at 89.1 and 92.3 and the WOMAC function was lower at 89.7 and 92.2 ($p<0.05$). Overall, this study found similar outcomes between patients over and under 40 years treated with PAO for hip dysplasia (conversion to THA outcomes discussed below).

Millis et al., Muffly et al., and Novais et al. were from the overlapping cohorts, although they measured different PROM scores at different follow-up evaluation time points (Millis: 4.9 years-, Muffley: 4.7 years-, Novais: 9.6 years-follow-up after PAO).[3,12,13] Millis et al. reported outcomes of 87 hips at a mean of 4.9 years follow up and Novais reported outcomes of 145 hips at a mean of 9.6 years follow for patients 40 years old and older

Table 3. Patient-Reported Outcome Measures

Study	Clinical Outcome Score Utilized	Postoperative Score at Latest Follow-up	% Good Results	Comparison Score	% Good Results Comparison
Garbuz	WOMAC Pain	70.9	62% (17/27)	89.2	85% (29/34)
	WOMAC Function	73.7	53% (15/28)	90.6	85% (29/34)
	SF-12 Physical Component	43.9	NA	52.6	NA
	Satisfaction	NA	75.0	NA	93.6
	UCLA ≥7	NA	19 (4/21)	NA	41% (12/29)
Ito	mHHS	Preop: 68.9±7.3 5 yr: 91.4±8.4 Last f/u: 88.0±11.7*	NA	Preop: 70.1±9.1 5 yr: 92.0±8.2 Last f/u: 91.4±9.6*	NA
	mHHS Pain	39.4±5.8	NA	40.5±5.6	NA
	mHHS Function	41.7±5.6*	NA	43.5±4.3*	NA
	WOMAC Pain	89.1±11.3*	NA	92.3±9.9*	NA
	WOMAC Function	89.7±10.8*	NA	92.2±10.8*	NA
Millis	mHHS	Preop: 60.2±11.4 Last f/u: 85.4±17.1	NA	NA	NA
	WOMAC Pain	Preop: 8.9±4.9 Postop: 3.9±4.9	NA	NA	NA
Muffly	HOOS Global	Preop: 45.5±8.8* Postop: 77.3±20.5*	NA	<20 group Preop: 54.7±16.6* Postop: 72.9±19.6* 20-29 group Preop: 51.8±12.2* Postop: 71.5±16.7* 30-39 group Preop: 51.1±12.3* Postop: 70.8±18.7*	NA
	WOMAC	Preop: 55.0±16.6* Postop: 88.1±16.0*	NA	<20 group Preop: 70.3±21.7* Postop: 86.5±18.2* 20-29 group Preop: 66.7±18.5* Postop: 86.9±15.9* 30-39 group Preop: 64.5±19.9* Postop: 84.5±19.1*	NA
Novais	WOMAC Pain	Preop: 9.6±4.3 ¥Postop: 8.8 §Postop: 2.8	NA	NA	NA
	WOMAC Stiffness	Preop: 3.7±1.9 ¥Postop: 3.6 §Postop: 1.7	NA	NA	NA
	WOMAC Function	Preop: 32.2±18.2 ¥Postop: 24.1 §Postop: 14	NA	NA	NA
	mHHS	Preop: 52.6±15.3 ¥Postop: 61 §Postop: 76.6	NA	NA	NA

*Statistically significant difference, ¥ Failed hips, §non-failed hips.

Table 4. Hip Survivorship

Study	Tonnis OA, %	Tonnis OA Comparison, %	Survival from Conversion to THA, %	Comparison	Clinical Survival Excluding THAs	Comparison	Survival from Progression of OA	Comparison
Ito	0: 24 1: 71 2: 5	0: 26 1: 71 2: 3	10 yr: 91.3% 15 yr: 91.3%	10 yr: 97.9% 15 yr: 92.7%	NA	NA	10 yr: 81.3%* 15 yr: 71.2%*	10 yr: 94.4%* 15 yr: 86.9%*
Millis	0: 37 1: 45 2: 18	NA	76% mean 5.2 yrs range 1.9-7.6	NA	NA	NA	NA	NA
Muffly	0: 57.6 1: 39.4 2: 3 3: 0	<20: 0: 50 1: 39.2 2: 10 3: 0.8 20-29: 0: 38.2 1: 53.9 2: 5.9 3: 2 30-39: 0: 40 1: 53.8 2: 4.6 3: 1.5	100%	<20: 97.7 20-29: 99 30-39: 95.4	NA	NA	NA	NA
Novais	0: 38 1: 51 2: 10	NA	67% Mean 8.5 yrs Range 0.6-25.3 5yr: 90% 10yr: 71% 15 yr: 54%	NA	87%	NA	NA	NA

*Statistically significant difference.

with hip dysplasia treated with PAO.[3,12] Both studies did not have a comparison group. After PAO, Millis et al. reported increase in average mHHS from 60.2 to 85.4 and Novais et al. reported increase in average mHHS from 52.6 to 76.6.[3,12]

Muffly et al. compared global HOOS and WOMAC scores to across patients that were grouped by age at 10-year increments at a mean of 4.7 years after PAO.[13] For HOOS global and WOMAC, patients >40 years have more improvement and better clinical outcomes compared to the other age groups. For patients >40, HOOS improved from 45.5 to 77.3 which compares to 54.7 to 72.9 (age <20), 51.8 to 71.5 (age 20-29), and 51.1 to 70.8 (age 30-39). For patients >40, WOMAC improved from 55 to 88.1 which compares to 70.3 to 86.5 (age <20), 66.7 to 86.9 (age 20-29), and 64.5 to 84.5 (age 30-39). Additionally, Novais et al. split the cohort into surviving (67%) and non-surviving hips (33%) (non-survival defined as conversion or recommendation for THA or WOMAC pain ≥10 at follow-up).[3] Finally, mHHS improved from 52.6 to 76.6 in surviving hips and 61 in non-surviving hips.

Survival from THA and Progression of Osteoarthritis

There were four studies that reported survival from conversion to THA (Table 4).[3,11-13] Ito et al. reported a 10-year survival rate of 91.3% for patients >40 years compared to 97.9% for patients <40 years.[11] For 15-year survival, the rates are similar at 91.3% and 92.7%, respectively. Millis et al. reported a survival rate of 76% at a mean of 5.2 years (range 1.9-7.6).[12] Muffly et al. reported a 100% survival rate 4.7 years after PAO and compared this to 97.7% (age <20), 99% (age 20-29), and 95.4% (age 30-39).[13] Lastly, Novais et al. reported a 67% survival rate at a mean 8.5 years (range 0.6-25.3) with a 90% 5-year-, 71% 10-year-, and 54% 15-year-survival rates.[3] One study that reported clinical success rates after excluding THAs: 87% of preserved hips met criteria for good function. Another reported rate of hips free from osteoarthritis progression. Ito et al. reported survival from radiographic osteoarthritis progression at 10- and 15- years post-PAO.[11] At ten years, survival rates were lower for patients >40 years at 81.3% compared to 94.4%. Similarly, at fifteen years, survival rates were lower for patients >40 years at 71.2% compared to 86.9%.

It is important to note that Tönnis grade had impact on the survival of hips as was described by Millis et al.[12] Their preoperative Tönnis breakdown was 37% for grade 0, 45% for grade 1, and 18% for grade 2. They noted that in their survival group, the breakdown was 44%, 42%, and 14% and for their THA group, the breakdown was 14%, 47%, and 38%, respectively. Similarly, in the study by Novais et al., they found that the survival group had Tönnis breakdown of 48% for grade 0, 49% for grade 1, and 3% for grade 2 and for their failure group, the breakdown was 24%, 55%, and 21%, respectively.[3] The other studies did not mention or did not find an association with preoperative osteoarthritis severity and hip failure.

Complications

The complications were reported in four studies, two of which had comparison groups (Table 5). Garbuz et al. had 10/28 (36%) complications in the PAO group and 1/34 (3%) complication in the THA group.[10] The complications for the PAO group included four lateral femoral cutaneous nerve paresthesias, two deep vein thromboses (DVT), one partial sciatic nerve injury, one nonunion of ischium, one disruption of the posterior column, and one wound infection. For their THA group, there was only one superficial wound infection. Ito et al. reported similar rates of complications with patients over 40 years having 6/41 (15%) complications and patients under 40 years having 12/117 (10%) complications.[11] For patients over 40 years undergoing PAO, the complications were one pulmonary embolus (PE), one osteonecrosis of the acetabular fragment, one displacement of the greater trochanter (likely not associated with the PAO), two ischial fractures, and one pubic nonunion. For patients under 40 years undergoing PAO, the complications were two osteonecrosis of the rotated fragment, three displacement of the greater trochanter, three ischial fractures, and four pubic nonunions. For Millis, they reported that patients over 40 years old undergoing PAO had 2/87 (2%) complications and there was one case of global nonunion associated with gastrointestinal (GI) sepsis and one sciatic nerve neuropraxia.[12] Novais et al. reported that patients over 40 years old undergoing PAO had 10/166 (6%) complications which included three nonunions, three stress fractures, one PE, one DVT, one infection, and one wound dehiscence.[3]

DISCUSSION

Hip dysplasia causes aberrant articular contact mechanics that lead to pre-mature OA.[1] PAO is an effective procedure to reduce pain and dysfunction and possibly prevent progression to OA.[4] Typically, PAO is performed in adolescents and young adults although, there are reports in the literature that describe effectiveness in patients over 40 years of age.[3,10-13] The current systematic review reported all available literature for this age group at mean follow-up duration range of 4-10.[8] years. In total, there were 5 studies included and 3 of these studies were from overlapping cohorts. Garbuz et al. compared PAO to THA and found that PAO had lower post-operative PROM scores (although possibly not clinically significant) and more complications (statistically and clinically significant) compared to THA.[10] Compared to patients <40 years old, Ito et al. found that patients >40 years old had lower post-operative mHHS, WOMAC pain, and WOMAC function although this was also potentially not clinically significant.[11] Muffly et al. compared multiple age groups and in contrast to the previous studies, the older patients had higher postoperative PROMs and larger improvement in PROMs after treatment.[13] For the remaining two studies (overlapping cohorts), there was no comparison group for the over 40-year-old patients; however, both studies reported significant improvements in PROMs.[3,12] Overall, patients >40 years did have significant improvement in pain and function after PAO, but they had slightly less improvement when compared to patients that underwent THA

Table 5. Complications

Study	Complications, n (%)	Description
Garbuz	PAO: 10/28 (36) THA: 1/34 (3)	PAO: 4 lateral femoral cutaneous nerve paresthesias, 2 DVT, 1 partial sciatic nerve injury, 1 nonunion of ischium, 1 disruption of posterior column, 1 wound infection THA: superficial wound infection
Ito	≥40: 6/41 (15) <40 12/117 (10)	≥40: 1 PE, 1 osteonecrosis of rotated fragment, 1 displacement of greater trochanter, 2 ischial fractures, 1 pubic nonunion <40: 2 osteonecrosis of rotated fragment, 3 displacement of greater trochanter, 3 ischial fractures, 4 pubic nonunion
Millis	2/87 (2)	1 global nonunion associated with GI sepsis, 1 sciatic neuropraxia
Muffly	NA	NA
Novais	10/166 (6)	3 nonunions, 3 stress fractures, 1 PE, 1 DVT, 1 infection, 1 wound dehiscence

or patients that underwent PAO at less than 40 years old in those respective studies. Though these series report generally positive outcomes, these are likely selected series of patients over 40 years old that underwent PAO to treat hip dysplasia with atypically healthy, non-arthritic hip joints given their age with above average health and function. Despite these generally positive outcomes, we recommend surgeons not indicate patients over 40 years of age with evidence of radiographic OA, elevated body mass, or comorbidities for PAO to treat hip dysplasia. Non-surgical treatment or THA should be considered in older adults with OA and hip dysplasia.

There are limitations to this systematic review. First, due to the high prevalence of OA in this age group with hip dysplasia, most patients over 40 years old are not treated with PAO, limiting the numbers to report in the literature. Multi-center studies with large cohorts would be required to make critical comparisons. Also, clinical failure with progression to OA may take longer than the mean follow-up durations included in this study. Due to the complexity and resources needed to perform PAO, the generalizability may be limited. There were not enough studies or data to conduct a meta-analysis; although, we were able to report the descriptive data from each of these studies.

For studies with comparator groups, Garbuz et al. demonstrated that patients undergoing PAO to treat hip dysplasia had worse mHHS and WOMAC scores when compared to THA.[10] Assuming that THA was performed for patients with established osteoarthritis and hip dysplasia, a limitation of this comparison is that the surgeries were not performed for comparable pathology. A comparison of outcomes when THA is performed to treat hip dysplasia with minimal to no OA would be more valid, though this may not be recommended in practice. In the study by Ito et al., patients over 40 years had worse PROM scores compared to under 40 years.[11] Even though there are these slight differences, most patients >40 years undergoing PAO had positive outcomes and the differences between the groups were likely not clinically significant. In contrast with the previous two studies, Novais et al. demonstrated that patients over40 years of age had greater postoperative improvement in PROMs and higher absolute PROMs compared to ages <20-, 20-29-, and 30-39-years age groups.[3] In the remaining two studies, despite the lack of comparison group, there were significant improvements in PROMs after PAO.[3,12] These improvement in PROMS were similar or slightly lower compared to previous studies that report outcomes of PAO surgery across all ages (mHHS of 76-88 for the studies presented in this paper compared to mHHS of 85-86 in large cohort studies).[15,16] Overall, most patients over40 years have good outcomes even though they may have less improvement in pain and function compared to their younger counterparts or compared to THA in other studies. It is important to note that most of the papers included in this review had no or mild osteoarthritis which mirrors the consensus that patients less osteoarthritis have better clinical outcomes after PAO.[6]

Survival from THA for patients >40 years was 67-100% in our systematic review depending on the study.[3,11-13] Current thought is that the main driver of the decision on whether to undergo PAO, is the absence or presence mild osteoarthritis (Tönnis ≤1). As a result, Ito et al. controlled for osteoarthritis grade with most hips having no arthritis or mild arthritis (Tonnis 0-1) and only a small number of hips having Tönnis grade 2 osteoarthritis.[11] The number of each grade were similar across groups. In this study, although the 10-year survival rate was higher for younger patients, the 15-year survival rate was similar for both groups. In the study by Millis et al., he noted that, as the preoperative Tönnis grade increased from 0 to 2, the rate of THA conversion increased.[12] Furthermore, the risk of THA was 2.2 times higher for hips with preoperative Tonnis grade 2 compared to grades 0 and 1 (HR= 2.19, CI: 1.01-4.77). For Muffly et al., the rates of Tonnis grade osteoarthritis were similar across groups with a majority being grades 0 or 1 with a minimal number of grade 2 and 3.[13] Survivorship rates from THA were similar across age groups. Finally, for Novais et al., they divided the cohort into patients with and without failed hips and found that there was a higher rate of PAO survival from THA for patients no or mild arthritis (Tonnis 0-1).[3] So, knowing that Tonnis grade significantly influences the decision on whether to perform PAO, we compared the rates of PAO >40 years to larger cohorts that do not divide based on age to see if the 67-100% survival rate compares to the general population. We wanted to include cohorts with similar rates of osteoarthritis. Recently, Parilla et al., compared patients undergoing PAO and THA to determine survivorship rates. In this study, patients undergoing PAOs underwent THA at a rate of 8.2% after a mean of 10.8 years after the index procedure and their preoperative Tonnis grade profile was like that of the studies that were included in this analysis.[15] In a similar large cohort study, survivorship rate was 86% at 10-years and 60% at 20-years.[17] Based on our literature review, it appears that patients above 40 years of age do not do as well as their younger counterparts; however, most patients in the older age group receive clinically significant benefits from PAO to treat hip dysplasia when indicated carefully for surgery.

There were complications associated with performing PAO in patients over 40 years of age. The overall rate of complications was 8.7% (28/322). The highest rate of complications was reported by Garbuz et al. with a rate of 36% (10/28) though most of these complications did not impact the long-term outcomes.[10] Of note there was a trend toward greater non-union rates in the older population across the studies. This is reflected in previous studies that associated increased age with superior ramus non-union after PAO.[18] The lowest rates of complications were reported by Millis and Novais et al. and the rates were 2% (2/87) and 6% (10/166).[3,12] Again, none of these complications were reported to have lasting effects.

CONCLUSION

In conclusion, most patients >40 years of age that undergo PAO to treat hip dysplasia have good clinical outcomes even if they do not have as significant improvement in pain and function as their younger counterparts or patients that undergo THA. PAO may be a reasonable hip preservation procedure to offer for carefully selected, healthy, high functioning patients without radiographic evidence of OA. The current systematic review summarized five articles of this patient population and gives insight into clinical outcomes of PAO surgery.

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MENSTRUAL CYCLE HORMONE RELAXIN AND ACL INJURIES IN FEMALE ATHLETES: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Female athletes are at increased risk for anterior cruciate ligament (ACL) injuries. The influence of hormonal variation on female ACL injury risk remains ill-defined. Recent data suggests that the collagen-degrading menstrual hormone relaxin may cyclically impact female ACL tissue quality. This review aims to identify any correlation between menstrual relaxin peaks and rates of female ACL injury.

Methods: A systematic review was performed, utilizing the MEDLINE, EMBASE, and CINAHL databases. Included studies had to directly address relaxin/female ACL interactions. The primary outcome variable was relaxin proteolysis of the ACL, at cellular, tissue, joint, and whole-organism levels. The secondary outcome variable was any discussed method of moderating relaxin levels, and the clinical results if available.

Results: The numerous relaxin receptors on female ACLs upregulate local collagenolysis and suppress local collagen production. Peak serum relaxin concentrations (SRC) occur during menstrual cycle days 21-24; a time phase associated with greater risk of ACL injury. Oral contraceptives (OCPs) reduce SRC, with a potential ACL-protective effect.

Conclusion: A reasonable correlative and plausible causative relationship exists between peak relaxin levels and increased risk of ACL injury in females, and further investigation is warranted.

Level of Evidence: III

Keywords: female athlete physiology, acl rupture, injury prevention, sex-based risk factors, sports medicine

INTRODUCTION

Anterior cruciate ligament (ACL) injuries result from unpredictable, variable situations and individual patient risk factors.[1] Women additionally have sex-specific risk factors contributing to their ACL injury rate two- to ten-fold higher than males.[2,3] Relative hamstring weakness, increased knee valgus (Q angle), and cyclic hormonal changes have been identified as fundamental female-specific risk factors predisposing women to this injury.[2,3]

Neuromuscular training has been designed for female athlete ACL tear prophylaxis, to mitigate harmful hamstring and Q angle biomechanics.[2,3] Hormonal fluctuations, however, remain a vaguely-described risk factor with little investigative research.[2-4] Recent studies show concurrent fluctuations in ACL tissue quality and menstrual cycle hormone peaks; the peptide hormone relaxin is specifically implicated (Figure 1).[5-8] G protein-coupled relaxin receptors trigger collagen degradation of female ACLs—male ACLs lack receptors.[5-8] Despite these findings, no ACL-hormone protective interventions have been comprehensively investigated.[5-8] Meanwhile, one in five female collegiate athletes suffer an ACL injury.[9]

A handful of observational studies associate peak relaxin levels and increased ACL injury risk, an additive risk per menstrual cycle (Figure 2).[6,10,11] High relaxin positively correlates with injury rates, increasing almost logarithmically when relaxin is very high.[6] As a corollary, artificially decreasing relaxin—by taking oral contraceptives (OCPS), for example— can decrease risk of ACL tear.[10,11] While these findings are helpful for building a causative hypothesis, advancing to interventional studies requires focused, high-quality clinical research. This review aims to summarize in a stepwise fashion the existing ACL/relaxin research to promote the development of future research questions.

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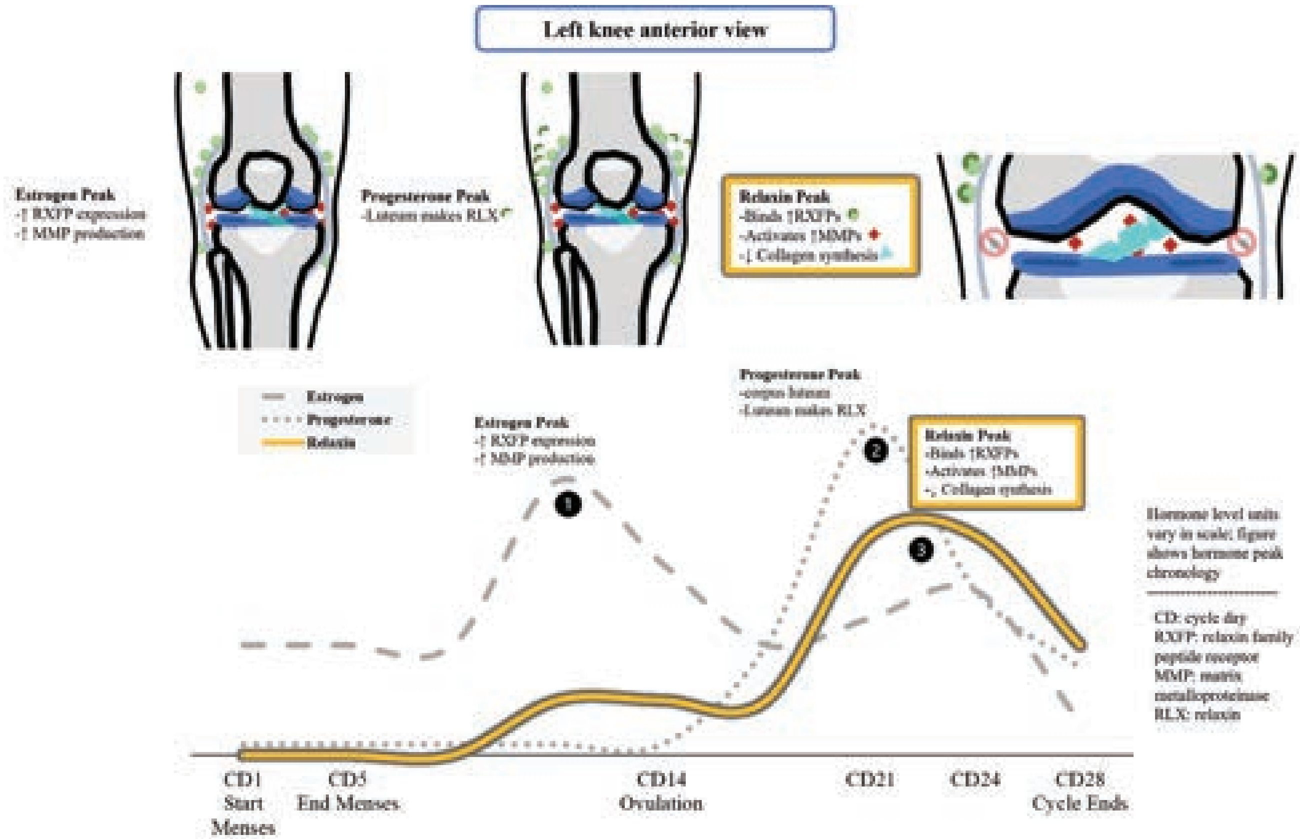

Figure 1. Menstrual Cycle Hormone Peaks, Molecular Effects. Estrogen levels peak first, increasing expression of relaxin receptors in the body and increasing global synthesis of MMPs. The drop in estrogen triggers ovulation, and the remains of that ovarian follicle form the corpus luteum. As a temporary endocrine body, the corpus luteum secretes progesterone to prepare the endometrium for pregnancy and to sustain itself. It also synthesizes and releases relaxin, which binds receptors and activates MMPs recently upregulated by estrogen while suppressing de novo collagen synthesis. Relaxin is active during the luteal phase, chiefly CD21-24.

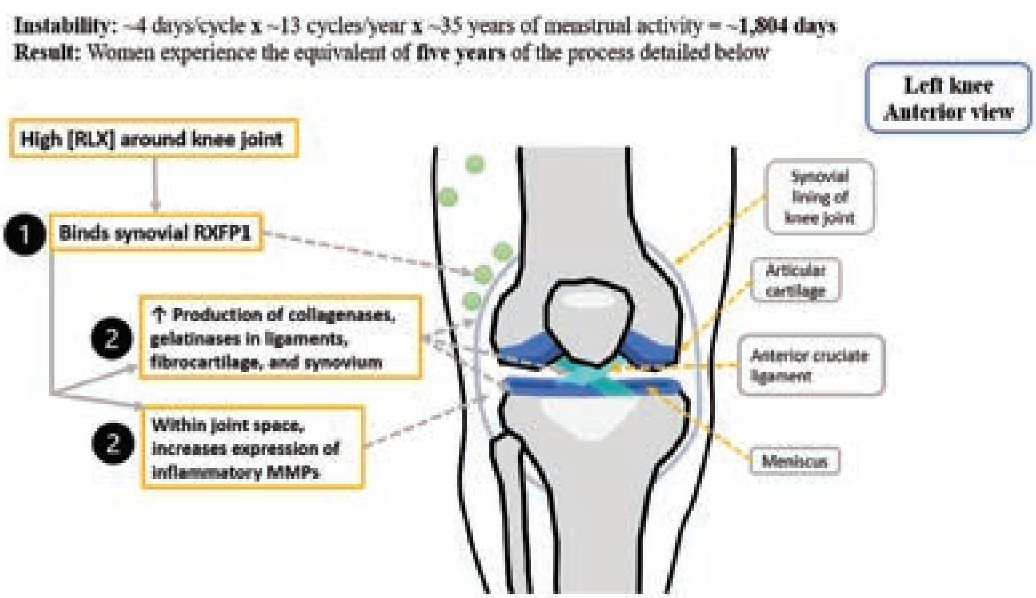

Figure 2. Estimated Lifetime Days of Relaxin-Induced Collagen Lysis, Female ACL Laxity. Relaxin, via G-protein coupled receptors, binds at the knee joint synovium to enact intra-articular changes. In stabilizing structures, the production of collagen-degrading enzymes is increased. Within the joint space, expression of inflammatory enzymes is also increased. This creates an environment not conducive to connective tissue stability, which recurs with each menstrual cycle and peak relaxin level.

METHODS

Literature Search

Literature searches had broad parameters, including any English-language literature discussing both relaxin and musculoskeletal pathology. A thorough screening process led to the present systematic review focusing on ACL health. Initial search strategies were developed by the authors and an orthopedic health sciences librarian with expertise in literature reviews in June 2020, with a repeat search performed by the authors in March/April 2022.

The initial search strategy was developed for MEDLINE. The first search string looked generally for musculoskeletal pathology, with MeSH terms such as "musculoskeletal injury", and text words and phrases including "ligament" and "cartilage". The second search string focused on female variations in relaxin hormone levels and activity, with MeSH terms such as "relaxin receptor", and text words and phrases including "cyclic hormonal variation" and "eumenorrheic". The full search strategy for MEDLINE can be found in Appendix Item 1. The strategy was adapted for EMBASE and CINAHL, available upon request.

The reference list was screened for additional source materials via SCOPUS. All identified citations were uploaded to EndNote (EndNote X9.2, Clarivate Analytics, PA, USA) and duplicates removed by a combination of software screening and manual review. The review process, following PERSiST guidance, was compliant with the framework outlined in the 2020 PRISMA statement (see Appendix Item II for the PRISMA 2020 Checklist).[12] Titles and abstracts were screened by two authors independently against the inclusion criteria. A full-text assessment was then performed to identify final inclusions, with any residual discrepancies screened by the senior author. This review was not registered.

The initial expansive screen yielded 82 studies, notable for several high-quality studies addressing relaxin and risk of ACL injury in women. This information was condensed and presented in a scoping review as supporting evidence for musculoskeletal impacts of relaxin, and thus was not separately explored or reported in the scoping review. The authors rigorously screened the 82 initial studies and additional works from the repeat search, selecting papers which specifically addressed the relaxin-ACL relationship. Lower quality literature such as case studies, and studies of animal subjects only were excluded. Screening was once more performed independently by two junior authors, supervised by the senior authors, per PRISMA standards.

Statistical Analyses

Excel v.1808 (Microsoft Inc, Redmond, WA) was utilized to perform basic demographic calculations and all Student's t-tests; which evaluated patient demographic data such as mean percent of female patients and mean patient age. Student's t-tests were also utilized for study outcome variable assessment if data was sufficient for an appropriately powered analysis.

Outcome Variables

The literature facilitated examination of successive relaxin effects at increasingly complex levels of female ACL health. Thus, our primary outcome was comprehensively detailing sequential relaxin activity; from a cellular level, to a tissue level, to an isolated joint level, and finally at the population level. The timing of relaxin concentration measurements did not exclusively capture peak levels (Figure 1). Cell and tissue effects had to be demonstrated rather than just hypothesized, via biopsies, immunohistochemical testing, etc. Similarly, knee joint manifestations had to be confirmed with a validated physical exam or imaging test, or intra-operatively confirmed.

The secondary outcome of interest was possible methods of suppressing relaxin levels described in the literature, looking at both effectiveness from a basic science level and any translation to clinical effects. The population-level studies of women allowed us to build upon data from our investigation of the primary outcome— the immediate consequences of cyclic relaxin peaks at smaller cohort analysis levels—to visualize the larger-scale, longer-term impacts of potential relaxin-induced female knee injuries, on a more heterogenous group of women.

As a separate, literature-focused outcome we highlighted the current research support behind each "step" correlating increased relaxin and increases in ACL injuries. Currently, ACL/relaxin research is present in published literature, but not cohesive nor pursued beyond the level of clinical correlation, even for aspects as simple as a cohort analysis of peak relaxin measurement versus incidence of injury. With this review we aimed to concisely synthesize prior correlational research, emphasize prior research proposing a causative relationship, and turn the focus towards potential researchable tissue quality interventions to prevent injury.

Study Quality

Study quality was evaluated by two authors independently, prior to reaching consensus scores on the Modified Coleman Criteria Scale (MCMS). Oversight was provided by the senior authors. The average MCMS was 39±9.7 (range: 25 to 55) with a bimodal distribution;

the lab studies and cross-sectional studies had scores between 25-30, while the prospective and retrospective cohort studies had scores between 45-55. There were no statistical MCMS score outliers within either of the two literature groups delineated by study type.

RESULTS

From the original and repeat search results for studies discussing relaxin and musculoskeletal health on a general level, we identified 12 qualifying studies (Table 1) specifically addressing the interaction of relaxin and the ACL.[5-8,10,11,13-19] While some modest overlap existed between studies, we were able to assess the literature according to the subcategories of basic science and clinical outcomes delineated within our outcome variables: the molecular level;[7,8,16] the level of the tissue and the joint (small study sizes);[6,13-15,18,19] and the level of the joint from a population perspective, along with any population differences attributed to relaxin concentration, variability, and/or moderation (Table 2).[10,11,14,17,18]

Average study size was calculated excluding data from DeFroda et al. and Rahr-Wagner et al.; both database-level analyses of population segments (165,748 and 13,335 patients, respectively) which skewed results.[10,11] The average study size of the remaining ten studies was 67.3±52.2 patients. Among all studies, average percent of female patients was 88.5%±19.7%. Average patient age was not available from DeFroda et al.,[10] and was extrapolated to be 20 years old for both Dragoo et al. studies examining only "college female athletes". With these adjustments, average patient age was 25.2±7.5.

In the twelve final studies, study design type was evenly dispersed: 25% of studies were case-control, 25% of studies were laboratory-based cross-sectional, 25% were prospective cohorts, and the remaining quarter were a retrospective cohort, a case series, and a non-laboratory cross-sectional study (Table 1). The properties of the population of interest were also divided in a fairly equal manner, with some study populations having more than one property specifically noted by researchers. In total, five studies (41.7%) focused on athletic participation, six studies (50%) focused on OCP use, six studies (50%) focused on current or past ACL injury status, and 3 studies (25%) focused on presence of generalized joint laxity (Table 1).

The most common properties examined in concert were athletic participation and OCP use, representing three of eight studies with more than one population property of interest (37.5%) (Table 1). It should be noted that both overlap studies which assessed OCP use plus current or former ACL injury were the population registry-based studies, providing a robust amount of data for this combination.[10,11] In reviewing all twelve studies, conclusions were drawn in the following categories: the SRC/joint laxity relationship (25% of studies), the SRC/OCP relationship (25% of studies), the ACL/RLX binding relationship (25% of studies), and the SRC/ACL injury or OCP use/ACL injury relationship (25% of studies) (Table 1).

Methodological errors related to orthopaedic and gynecologic concepts were identified in two of the twelve studies. Both studies detailed errors related to knee/ACL laxity testing; Arnold et al. and Pokorny et al. assessed ACL laxity by measuring anterior-posterior translation of the tibia relative to the femur.[13,19] As the majority of ACL tears occur secondary to torsional/rotational force, the shear force of anterior-posterior testing is not a valid substitute. Pokorny et al.[19] also describes sub-optimal timing for obtaining SRCs; only 8/25 control patients and 11/30 test group patients had SRC measured on a predicted peak day (cycle day 21-24) (Table 1).

DISCUSSION

This review aimed to efficiently present existing information regarding the effects of relaxin on ACL injury in women. Based on preliminary literature analysis, our review outcome variables were structured to assess molecular level, tissue level, joint level, and population level impact of relaxin—including variable concentrations and moderation—on incidence of ACL injury (Table 3). This focused synopsis was designed to direct future research on this topic towards promising options for mitigation of relaxin-induced ACL damage.

Overview of Relaxin, Matrix Metalloproteinases, and Collagen

An appropriate discussion of relaxin impacts in one focal area necessitates a working knowledge of the endocrine properties of the hormone outside of a reproductive context and location, the physiologic and pathophysiologic functions of downstream factors signaled by relaxin, and the normal structural properties of the tissues on which relaxin activity is focused. Select resources are cited for this purpose (Table 3).

Relaxin is a peptide hormone only active beyond the reproductive system in women, who produce large amounts from the corpus luteum immediately following menstrual cycle ovulation. Its paracrine profile means that widespread presence of receptors is more indicative of activity than circulating serum levels. Relaxin has endocrine and immunologic functions, and it works synergistically with estrogen to increase target tissue RLX binding and levels of relaxin-activated effectors such as matrix metalloproteinases (MMPs). Specifically relevant to joint health, female ligaments, chondroblasts, and fibrochondroblasts bind relaxin (Figure 1) (Table 3).

Table 1. Details of All Included Studies

Author, Year	Study Type	N (%F)	Age (Years)	Variable(s) of Interest	Outcome Variable(s)	Study Results
Arnold et al., 2002[13]	Prospective cohort	62 (92%)	M 20.2±2.2, F 19.3±1.5	Patient sex	SRC, knee anterior-posterior laxity	ANOVA showed a significant change to weekly SRC in women, but not in laxity of the knee.
DeFroda et al., 2019[10]	Retrospective cohort	165748 (100%)	15-19 (29.35% ACLR)	ACL reconstruction (ACLR)	Hormonal contraceptive (HCP) use	HCP use in 15-19-year-olds correlates with a 63% decrease in ACLRs; an OR of 0.37 (chi2 < 0.001, 95% CI 0.27-0.50) with NNT=6. In all age groups using HCPs, the ACLR OR was 0.82 (chi2 = 0.001, 95% CI 0.72-0.92).
Dragoo et al., 2011[6] (AJSM)	Prospective cohort	128 (100%)	Collegiate athletes	Serum relaxin level (SRC)	ACL tear	Cumulative ACL tear incidence was 21.9%, more likely with higher SRC, particularly >6pg/mL
Dragoo et al., 2011[14] (Int WJ)	Cross-sectional	169 (100%)	Collegiate athletes	Menstrual status	SRC	SRC was significantly lower in women using HCPs; the other groups were not significantly different
Dragoo et al., 2003[7]	Lab study; cross-sectional	10 (50%)	F 15-36; M 16-35	ACL relaxin receptors	Positive stain; stain characteristics	Only ACL remnants from women expressed relaxin receptors; binding was specific, saturable, and uniform
Em at al., 2015[15]	Case-control	BJHS 45; C 40 (100%)	BJHS 25.2±6.6; C 25.4±7.1	Benign Joint Hypermobility Syndrome (BJHS)	SRC, locomotor system exam findings	BJHS patients had non-significant elevation of SRC, with higher rates of arthralgia and myalgia (significant), and of pes planus and hyperkyphosis (strongly significant).
Faryniarz et al., 2006[16]	Lab study; cross-sectional	15 (53.3%)	Female 26.6; male 32.3	ACL estrogen, relaxin receptors	Positive stain; positional relationship of receptors	Estrogen receptor levels were similar between the sexes, but relaxin receptor concentration was significantly greater in women; 4 of 5 female ACLs bound relaxin vs. 1 of 5 male ACLs
Galey et al., 2003[8]	Lab Study	12 (66.7%)	46	ACL relaxin receptors	Positive stain; stain characteristics	ACL remnants from young female patients qualitatively demonstrated the most abundant hormone binding
Marshall-Gradisnik et al., 2004[17]	Conference abstract-case series	10 (100%)	20.8±2.2	Active women on OCPs	SRC on CD 2, 16, and 26	Women on OCPs do not have significant changes in SRC during their cycles
Nose-Ogura et al., 2017[18]	Prospective cohort	57 (100%)	24.4±4.6	Female athletes with luteal phase SRC>6.0pg/mL initiating HCPs	SRC during two subsequent menstrual cycle luteal phases	Of the 57 athletes, 36 (63.2%) had detectable luteal phase SRC. 21 (36.8%) had luteal phase SRC>6.0pg/mL. Five of these 21 started OCPs, and by their second cycle, SRC decreased below the detection limit of 0.26pg/mL (p<0.01)
Pokorny et al., 2000[19]	Case-control	55 (100%)	HCP 22.6±1.61; control 22.4±1.73	HCP use in women ages 20-25	Peripheral joint laxity; knee, 2nd digit DIP, 5th digit DIP	There was no significant difference in peripheral joint laxity with HCP use, including laxity of the knee. Laxity did not significantly differ by menstrual phase. Only 8 control and 11 test patients had an SRC drawn during the luteal phase.
Rahr-Wagner et al., 2014[11]	Case-control (population registry)	13355 (100%); 4497 ACLR	23.8	ACL reconstruction and HCP use	Correlation of HCP use versus ACLR risk	Between "ever" and "never" HCP users, the adjusted RR of ACLR was 0.82 (95% CI, 0.75-0.90). Among long-term and recently-started HCP users, the adjusted RR of ACLR was 0.80 (95% CI, 0.74-0.91) and 0.81 (95% CI, 0.72-0.89). Results indicate HCPs are protective against ACL injury.
Average ± StDev	*67.3±52.2 patients; 88.5±19.7% female		25.2±7.5 years	Assessed: Athletic status (41.7%), OCP use (50%), ACL injury status (50%), generalized joint laxity (25%)		Conclusions regarding: SRC/joint laxity (25%), SRC/OCP use (25%), ACL/RLX binding (25%), and joint injury/OCP use or joint injury/SRC (25%)

Table 2. Included Studies per Subcategory of Relaxin Level of Effect

Subcategory	Author, Year	Findings	Subjective Synthesis
Molecular level effects of relaxin on the ACL	Dragoo et al., 2003[7]	Only ACL remnants from women expressed relaxin receptors; binding was specific, saturable, and uniform	• Compared to male ACL remnants, female ACL remnants are significantly more likely to bind greater amounts of relaxin, in a specific, saturable, and uniform distribution, among receptors in synovial tissue cells
	Faryniarz et al., 2006[16]	Relaxin receptor concentration was significantly greater in women; 4 of 5 female ACLs bound relaxin	
	Galey et al., 2003[8]	ACL remnants from young female patients had abundant hormone binding	
Effects of relaxin at the tissue level and knee joint level (small sample sizes)	Arnold et al., 2002[13]	Women had a significant change to weekly SRC, but not anterior translation of the knee.	• Women with higher SRC (at baseline, and/or during the luteal phase peak) were not more likely to show increased joint laxity such as increased anterior knee translation (2 studies) or increased knee hyperextension (1 study) ◦ Neither maneuver assesses torsional resistance ◦ Some measurements were not taken during peak relaxin levels • However, higher peak levels of SRC were associated with increased ACL tear incidence • This suggests that the collagenolysis triggered by relaxin in certain joints may not increase sub-failure tissue laxity, or laxity in all planes of mechanical stress, while still decreasing loads required for catastrophic tissue failure • SRC is significantly lower among women using OCPs; OCPs appear to impact SRC within as little as two menstrual cycles
	Dragoo et al., 2011[6]	Cumulative ACL tear incidence was 21.9%, more likely with higher SRC, particularly >6pg/mL	
	Dragoo et al., 2011[14]	SRC was significantly lower in women using OCPs	
	Em et al., 2015[15]	Relaxin was non-significantly higher in BJHS patients, who had significantly higher rates of pes planus, hyperkyphosis	
	Nose-Ogura et al., 2017[18]	Roughly one-third of athletes had high luteal phase SRC (>6.0pg/mL). Five started OCPs and had SRCs <0.26pg/mL by their second cycle (p<0.01)	
	Pokorny et al., 2000[19]	There was no significant difference in peripheral joint laxity between users and non-users of OCPs. However, only one-third had measurements taken during the luteal phase relaxin peak (CD 21-24).	
Effects of relaxin at the knee joint level (large population studies), impact of relaxin concentration variability, and moderation on ACL injury	DeFroda et al., 2019[10]	Among all age groups, the OR for ACL tear on OCPs was 0.82 (chi2= 0.001, 95% CI 0.72-0.92). This was driven by the 15-19 age group (odds ratio 0.37 (chi2< 0.001, 95% CI 0.27-0.50) who had a 63% reduction in tear risk. The NNT for OCP usage in 15-19yos= 6.	• OCP use lowers baseline SRC in women and prevents luteal phase SRC peaks within a relatively short period of initiating treatment (2 menstrual cycles, ~2 months) • OCPs show a protective effect against ACL tears in adolescents (63% reduction in rate of tear) and non-adolescents alike (18-20% risk reduction) • The NNT with OCPs to prevent ACL tear in the 15-19yo age group is 6 patients; patients in all OCP studies did not report any serious adverse effects from OCP use
	Dragoo et al., 2011[14]	SRC was significantly lower in women using OCPs	
	Marshall-Gradisnik et al., 2004[10,11,14,17,18]	Women on OCPs do not have significant changes in SRC during their cycles	
	Nose-Ogura et al., 2017[18]	Of athletes with high SRC (>6.0pg/mL), two OCP cycles decreased SRC below the detection limit of 0.26pg/mL (p<0.01)	
	Rahr-Wagner et al., 2014[11]	RR of OCP use vs. ACL injury was 0.82 (95% CI, 0.75-0.90). RR of ACL injury was 0.80 (95% CI, 0.74-0.91) in long-term users and 0.81 (95% CI, 0.72-0.89) in recent users.	

Relaxin is known as the modulator of extracellular matrix (ECM) turnover due to its activation of MMPs, which collectively digest all protein components of the ECM. Specifically, relaxin upregulates active levels of collagenases (MMP-1/-13) which uniquely unwind the collagen triple helix, leaving it vulnerable to gelatinases (MMP-2/-9), also upregulated by relaxin. Collagen content decreases when relaxin is active, particularly type 1 collagen; targeted by MMP-1 for digestion while relaxin also suppresses de novo collagen synthesis (Table 3).

The type 1 collagen targeted by relaxin-activated MMP-1 is a major structural component of tendons and ligaments. When under stress, at the micro and macro level collagen transfers stress via the sliding fibril model to neighboring fibrils as shear force (interfibrillar shear). Interfibrillar shear causes the non-linear behavior of collagenous tissues under stress; the persistent decrease in tissue stiffness even when the load is removed. The collagen of the ACL predominantly fails from excess torsional forces (Figure 3), and joint motion patterns alter significantly following injury (Table 3).

Table 3. Resources on Relaxin Properties, Effects Beyond the Reproductive Tract

Subcategory	Author, Year	Relevant Findings
Properties of Relaxin and Relaxin Receptors	Bryant-Greenwood et al., 1982[5] Goldsmith et al., 1995[20] Grossman et al., 2010[21] Kapila et al., 1998[22] Kleine et al., 2017[23] Lubahn et al., 2006[24] MacLennan et al., 1983[25] Powell et al., 2015[26] Wolf et al., 2012[27] Wolf et al., 2013[28]	• Relaxin (RLX) is a peptide hormone in men and women, largely H2 relaxin which binds the prevalent relaxin family peptide receptor-1 (RXFP-1) with high affinity • The corpus luteum in women is the largest production site for relaxin in women • Relaxin preferentially exerts paracrine effects, meaning that location of receptors rather than serum levels reflect activity • Relaxin is biologically and immunologically active in pregnant and non-pregnant females, peaking during the luteal phase of the menstrual cycle • RXFP-1 expression is primed by estrogen to respond at SRC 10-100x lower than normal • Estrogen, progesterone, and relaxin receptors modulate MMP production and activity in chondroblasts, fibrochondroblasts, myofibroblasts, and ligaments
Functional and Physiologic Roles of Relaxin	Ando et al., 1960[29] Dragoo et al., 2003[7] Galey et al., 2003[8] Goldsmith et al., 1995[20] Grossman et al., 2010[21] Nose-Ogura et al., 2017[18] Powell et al., 2015[26]	• Relaxin controls extracellular matrix (ECM) turnover by stimulating collagenase (MMP-1/-13) and gelatinase (MMP-2/-9) expression, and suppressing collagen synthesis ◦ A major function of relaxin is increasing MMP-1 to degrade type 1 collagen while suppressing type 1 collagen de novo synthesis • MMP signaling through MAPK and NF-kB pathways triggers acetylation/methylation to impact transcription • MMP-1/-13 and -2/-9 synergistically digest collagen ◦ Fibrillar bundles dissociate, water uptake increases, and viscosity/density decreases ◦ Local total collagen decreases ◦ Degradation at nanoscale level means macro-level effects are not always ap preciable • Relaxin has dose-dependent and differential functioning; dependent on location and other hormones • Binding of estrogen, progesterone, and relaxin synovial joint receptors increases expression of inflammatory MMPs ◦ Relaxin also upregulates MMP-1/-13 and MMP-2/-9 In ligaments and fibrocar tilage
Physiology and Pathophysiology of Matrix Metalloproteinases	Klein et al., 2011[30]	• MMPs modulate and turnover ECM protein components, and in states of dysregulation, are linked to disease development • MMP-1: Collagenase-1; Interstitial collagenase ◦ One of few MMPs able to degrade fibrillar collagen, unwinding triple helix ◦ Key role in ECM turnover, excessive or insufficient action can cause fibrosis issues ◦ Local sampling (i.e. synovial fluid in RA patients) more accurate than serum levels • MMP-2: Gelatinase A; 72-kDa type IV collagenase ◦ Proteolyticallly degrades gelatine (denatured collagen), constitutive expression, not induced by most inflammatory stimuli • MMP-9: Gelatinase B; 92-kDa type IV collagenase ◦ Proteolytically degrades gelatine, activated by other MMPs/oxidative stress, attracts immune cells ◦ Crucial for multiple stages of female reproductive cycle, i.e. remodeling endometrial tissue during menstrual cycle • MMP-13: Collagenase-3 ◦ Preferential cleavage of type II collagen ◦ Involved in bone development and remodeling, has been linked to cartilage destruc tion in OA, RA
Mechanics of Collagen-Based Structures, Catastrophic ACL Failure	Fidler et al., 2018[31] Meyer et al., 2008[32] Szcesny et al., 2014[33] Shoulders et al., 2009[34]	• Major ECM component collagen is characterized by fundamentally important triple helix, with physical (steric) and chemical (hydrogen bonds) stability • Tendon/ligament composition: 20% fibroblast + 80% ECM ◦ The ECM is 60-70% fibres ▪ Ligament fibres are 70-80% T1 collagen ▪ Tendon fibres are 95-99% T1 collagen • Microscale and macroscale behavior of ex vivo ligaments shows collagen fibrils are loaded via interfibrillar shear, from sliding of fibrils, along with fibril elongation • Interfibrillar shear load transfer between discontinuous fibrils is underlying mechanism of tendon fascicle mechanics, producing post-yield drop in tissue stiffness ◦ Non-linear elastic response of collagenous tissues under uniaxial tension is due to fibrils • Roughly 90% of ACL injuries occur due to non-contact internal torsion of the tibia relative to the femur

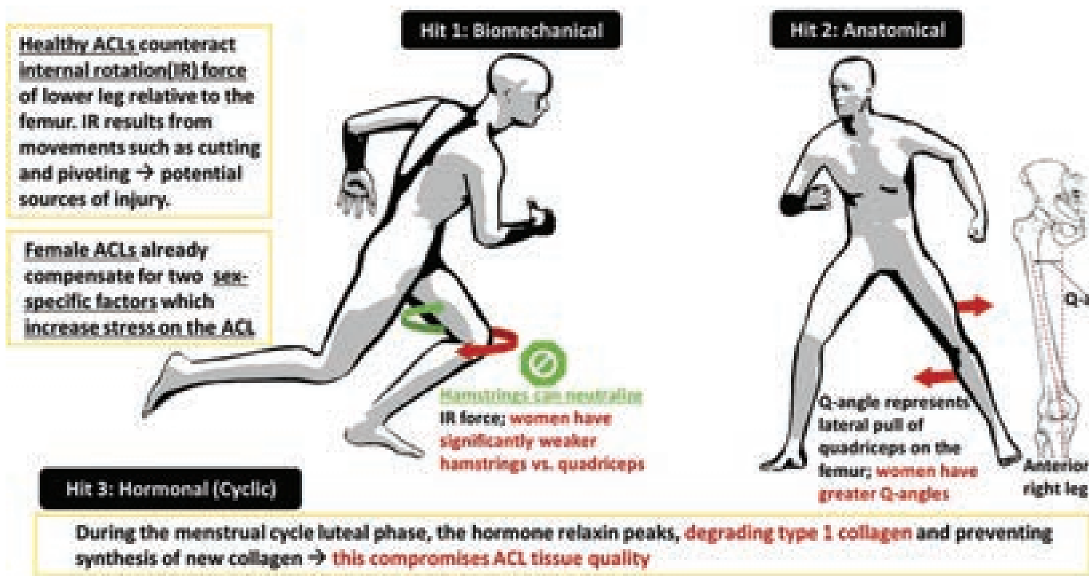

Figure 3. Hypothesized "Triple Hit" Scenario Resulting in Increased Female ACL Risk. The trio of factors which impact high rates of female ACL tear are biomechanical, anatomical, and hormonal. The biomechanical factor can be ascribed to relative weakness of hamstrings, and the anatomical factor is the result of an increased Q-angle. The hormonal factor has previously been ill-defined, but relaxin-induced degradation of collagen could be the major contributing component.

Molecular Effects of Relaxin on the Female ACL

Among all three studies of ACL remnants, harvested during ACL reconstruction procedures on males and females and immunostained for relaxin receptors, researchers found either exclusive or very heavily favored binding of relaxin to samples from female ACLs only. This finding laid the groundwork for considering relaxin's role in this injury with such a predominant sex-preference. The relaxin was noted to bind to synovial cells and fibroblasts contained in the samples, reinforcing hypotheses that relaxin receptors are located synovially, and that fibroblasts (along with chondrofibroblasts and ligaments) are a type of articular cell to which relaxin will bind (Tables 2,3).

Relaxin binding to the female ACL is pathologically significant because relaxin triggers collagen digestion and suppresses collagen synthesis in a paracrine manner. Thus, during the menstrual cycle, estrogen would peak and increase expression of relaxin receptors along with levels of relaxin-activated MMPs. When relaxin subsequently peaks, it binds to the upregulated receptors surrounding the knee and works by two mechanisms to degrade local collagen: activation of MMPs which will digest even triple-helical collagen, and transcription suppression to prevent synthesis of de novo collagen. Given that ligaments are between 42% to 56% type 1 collagen in composition, there is high availability of target tissue for MMPs to digest. Therefore, the micro-scale effects of relaxin on the female ACL are degradation of type 1 collagen, a major structural component of the ligament. The collagen loses density and viscosity, and the total amount decreases; all of which would be expected to decrease collagen strength (Tables 2,3).

Effects of Relaxin at the ACL Tissue Level, and Knee Joint Level of Small Studies

Two included studies assessed ACL laxity in patients at sub-failure stress levels, comparing it to SRC.[13,15] However, both studies utilized the anterior-posterior (AP) displacement of the tibia relative to the femur as a proxy for ACL laxity, when in fact this scenario would better demonstrate the "dashboard sign" of a PCL laceration. The most important component of ACL strength for resisting common injury mechanisms is torsional resistance/rotational strength, which AP testing does not assess. It may also be considered that the molecular changes to the ACL collagen do not cause corresponding linear changes in elasticity of the ligament. It is entirely possible that relaxin activity lowers the torsional force required for catastrophic tissue failure; thus obvious signs may not be present at sub-failure forces (Tables 2,3).

From a clinical correlation perspective, a longitudinal study of 128 collegiate female athletes in various sports by Dragoo et al.[6] showed a significant, positive correlation between peak relaxin levels and incidence of ACL tear. Collectively, one in five women completing a college athletics career suffered an ACL tear, which is a vast number when scale upwards to female athletes at numerous colleges across the country. When dividing this group by injury status, those with ACL tears had significantly greater peak SRC levels, even when athletes with undetectable SRC levels were not included in the statistical modeling. Furthermore, a subgroup analysis was performed on all athletes with detectable peak SRC (>0.26 pg/mL), showing that athletes with very high peak levels (>6.0 pg/mL) were, significantly, even more likely to suffer a tear than their peers with detectable SRC peaks below 6.0 pg/mL (Table 3).[18]

In fact, when an SRC > 6.0 pg/mL was utilized in post-hoc analysis as an ACL injury risk "cutoff value", researchers found that female athletes with a peak SRC > 6.0 had 4.4 times increased risk of an ACL tear (Table 3).[6] The positive correlation calculated in this study supports the hypothesis that molecular degeneration of the ACL from relaxin increases the risk of catastrophic tissue failure; the finding is bolstered by a second calculated positive correlation in which both variables have trended in the same direction; the increased SRC > 6.6 pg/mL significantly correlated with an even greater injury risk.[6] A cohort study on OCP use of female collegiate athletes by Nose-Ogura et al.[18] reinforces that female athletes with a 4.4 times increased risk of ACL tears are not uncommon; as 21.7% of their patients had an SRC of 6.0 pg/mL or higher (Table 3).[18]

Effects of Relaxin at Knee Joint Level of a Population, Variability and Moderation Effects

The inclusion in the review literature of two population registry-based studies helped greatly to assess the broader impact of relaxin on women's musculoskeletal health, and also provided data from large sample pools for evaluation of potential impacts of SRC moderation.[10,11] A number of smaller cohort studies were able to determine that SRC could be intentionally lowered with OCPs; Dragoo et al.,[14] Marshall-Gradisnik et al.,[17] Nose-Ogura et al.[18] So it was then a critical finding when both DeFroda et al.[10] and Rahr-Wagner et al.[11] found that lowering SRC via OCPs had a significant protective effect against ACL tears at a population level (Table 3).

Rahr-Wagner et al., using the statistical model of risk reduction (RR), found an adjusted RR of 0.82 (95% CI, 0.75-0.90) between women who had started an OCP at any point in the past and women who never used OCPs. Between these two groups, OCP use decreased the relative risk of an ACL tear by approximately 80%.[11] DeFroda et al. utilized an odds ratio (OR) model, comparing OCP use vs. non-use among patients undergoing ACL reconstruction. Among all age groups in the study, the odds ratio of requiring ACL reconstruction while taking an OCP was was 0.82 (chi^2= 0.001, 95% CI 0.72-0.92); OCP users were approximately 20% less likely to require surgery compared to their counterparts who did not take OCPs (Table 3).[10]

Researchers attributed much of this effect to the strong statistical findings among the 15-19 year-old age group where the OR for requiring ACL reconstruction while on OCPs was 0.37 (chi^2 < 0.001, 95% CI 0.27-0.50), or nearly 60% less likely. Given these findings, they calculated that the number of patients needed to treat (NNT) in the 15-19yo age group to prevent one ACL tear was six. So if OCPs were utilized to prevent ACL tears in girls between ages 15 and 19, six young women would need to be treated to prevent one ACL tear. (Table 3).[10]

How Can the Associated Risk Between Relaxin Levels and Female ACL Tears be Reduced?

Our secondary study outcome focused on potential approaches for moderating relaxin levels and thus ACL injury risk due to relaxin, and what the clinical effectiveness of these interventions might look like. In multiple studies in the present review, oral/hormonal contraceptives were selected as an intuitive intervention for an issue related to menstrual cycle hormones, and preliminary results show that their use can indeed reduce the risk of ACL injury.

However, it is recognized that OCPs are not a risk-free intervention, and that medical, social, and financial contraindications exist as likely barriers to widespread adoption. Still, the research performed using OCPs was very valuable for efforts to alleviate the sex disparity of this injury, for two main reasons: first, they demonstrate that SRC is a modifiable factor and that lowering it does not have adverse reproductive effects; and second, they demonstrate that lowering of the SRC is an approach which successfully reduces some of the risk of ACL injury (Table 3). Having these two important standards established is encouraging for future research on decreasing female ACL tear risk.

All included studies support and verify that peak relaxin levels occur during predictable days of the menstrual cycle, days 21-24. One way to build upon that is to follow the cohort studies which evaluated the use of a high SRC result as a "cutoff value". The significant results lend credence to the idea of a "risk stratification" approach.[6] For example, a female athlete with musculoskeletal pains during the luteal phase of her menstrual cycle may wish to obtain a peak SRC measurement. If the measurement is above the cutoff value, signifying increased risk, she then has more information when considering activity modification or OCP use.[9] Conversely, a teammate with occasional mild symptoms and a low peak SRC may feel more comfortable making the informed decision to not pursue a preventive route. Appendix Item III depicts an example risk stratification approach in further detail.

Pharmaceutical advances, the synovial location of relaxin receptors, and the innate properties of compounds such as testosterone to be "collagen-protective" in direct opposition to effects of relaxin raise the possibility of eventually developing a targeted/local intervention. However, there is no reason for not concurrently pursuing easy-access, low-cost interventions, such as menstrual cycle tracking, which requires only patient education. This could prove simple and effective for populations such as recreational athletes and women who exercise regularly without competing in a sport. Having access to data on which days their joint health may be more at risk would allow them to modify their activities accordingly.

LIMITATIONS

Limitations of this literature review mirror limitations on this research topic as a whole. Only a small number of lower quality studies were available for review, with no large and well-designed randomized control trials. There are multiple studies to confirm relaxin preferentially binding female ACLs (three studies; Dragoo et al., Faryniarz et al., Galey et al.[7,8,16]); relaxin levels cycling with other menstrual hormones and being suppressed by OCPs (four; Arnold et al., Dragoo et al., Marshall-Gradisnik et al., Nose-Ogura et al.[13,14,17,18]); and OCPs reducing the risk of ACL tear (two; DeFroda et al. and Rahr-Wagner et al.[10,11]

However, for the important conceptual linkage point of women with naturally elevated relaxin levels having an increased risk of ACL injury, there is only one study by Dragoo et al.[6] This study has not, since the time of its publication, been replicated. This pool of literature also supports high relaxin levels not only having a correlational relationship with high ACL injury incidence rates, but possibly a causal relationship as well. Yet in the three years since the most recently published study, by DeFroda et al.,[10] which showed a 63% risk reduction in ACL tear for teen girls using OCPs, not one interventional cohort study has gone to publication.

Additionally, because this topic crosses medical disciplines, it can be difficult to ensure that both major variables are measured in reliable and valid ways. For example, regarding ACL tension necessary to prevent ligament rupture, torsional strength is much more important than shear strength. However, studies in the present review assessed knee/ACL laxity by largely historical measures focused on anterior-posterior translation of the tibia relative to the femur, a shear force test, when the pivot-shift test of torsional force would have been more appropriate. Similarly, some studies in the present review measure SRC in women as though it were a static variable, rather than measuring the critically important peak SRC value by completing the test on CD21-24.

CONCLUSION

A reasonable correlative and plausible causative relationship exists between peak relaxin levels and increased risk of ACL injury in females, and further investigation is warranted.

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PAIN MANAGEMENT FOR PERIACETABULAR OSTEOTOMY: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Early post-operative pain control is essential to facilitate rapid recovery after orthopaedic surgery. Despite periacetabular osteotomy (PAO) being the gold standard treatment of pre-arthritic hip dysplasia, there is limited evidence assessing efficacy of early post-operative pain management strategies. Recent literature has focused on non-opioid supplemental treatments such as nerve blocks or local wound infiltration. The purpose of this systematic review was to assess efficacy of these interventions to reduce pain, facilitate mobilization, reduce length of stay after PAO surgery.

Methods: A systematic review was created under the guidance of PRISMA from databases that included PubMed, OVID Medline, Embase, SCOPUS, Cochrane Central Register of Clinical Trials, and clinicaltrials.gov from their creation dates to 12/21/23. These studies were screen based on predetermined inclusion and exclusion criteria.

Results: A total of six studies were included in this analysis from independent institutions. Three investigated nerve blocks (fascia iliaca, pericapsular, transversus abdominis), one investigated local wound infiltration with ropivacaine, one investigated high-dose dexamethasone, and the last investigated removal of the epidural catheter on postoperative (POD) 1 compared to POD 2. There were heterogeneous outcomes that were measured from these studies. In general, nerve blocks decreased opioid use, pain, and length of hospital stay. The local wound infiltration decreased pain on POD 3 and 4. Removing the epidural catheter on POD1 compared to POD 2 decreased pain and length of stay. High-dose dexamethasone use decreased opioid use on POD 1, otherwise, there was no difference in pain.

Conclusion: In summary, supplemental pain management strategies peri-operatively for PAO surgery can decrease pain, opioid use, and length of hospital stay, though there are few studies assessing these interventions. Limiting opioid use after surgery reduces known negative consequences of the medication and facilitates rapid recovery. Clinical trials are needed that assess efficacy of supplemental pain management strategies after PAO surgery.

Level of Evidence: II

Keywords: periacetabular osteotomy, pain management, systematic review

INTRODUCTION

Periacetabular osteotomy (PAO) is an open surgical procedure designed to improve pain and dysfunction caused by pre-arthritic hip dysplasia in young adults.[1] Early post-operative pain control is important to facilitate early mobilization and rehabilitation, limit opioid utilization, and facilitate early discharge from the hospital.[2,3] Current pain management strategies include opioids, non-steroidal anti-inflammatory drugs (NSAIDs), and other adjunct medications such as gabapentin.[4] Reduce early post-operative pain is associated with improved pain and function in orthopaedic surgeries other than PAO.[2,3,5]

Research investigating efficacy of interventions and protocols to reduce early post-operative pain after PAO is limited. Pre-operative medications often consist of NSAIDs such as naproxen, perioperative medications consist of medications such as local anesthetics and IV acetaminophen, and post-operative medications consist of a combination of NSAIDs and opioid medications.[6] Adjunctive treatments such as nerve blocks and wound infiltration that have been studied recently.[7,8] The purpose of the current systematic review was to (1) provide background information about the available studies about pain management for PAO, (2) provide a brief description of the protocols that clinicians offer their patients to reduce early post-surgical pain, (3) describe the pre-, peri-, and post-operative management, and (4) report the clinical outcomes for these studies.

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METHODS

Search Strategy

The PICO(T) model was applied (Population, Intervention, Comparison or control, Outcome, and Time period) using the prognosis or prediction question type. (PMID 30271283) The PICO(T) question was "In patients undergoing periacetabular osteotomy (population), how do pain management regimens (intervention) compare with older regimens, or no regimen, (comparison) affect clinical outcomes (outcome) during the preoperative, perioperative, and postoperative time periods (time period). We performed this review using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. (PMID 33782057) Databases searched were PubMed, OVID Medline, Embase, SCOPUS, Cochrane Central Register of Clinical Trials, and clinicaltrials.gov from their dates of creation to 12/21/23 (access date). Search terms were matched to our PICO(T) question and included a combination of periacetabular, osteotomy, pain, management, medications, anesthetic, and opioid.

Selection Criteria

For inclusion, articles were reviewed by two independent authors (K.P.O. and J.C.D.). Included articles were studies with (1) patients undergoing PAOs, (2) detailed pre-, peri-, and/or postoperative pain management regimen, (3) patient outcomes such as length of stay or pain levels, and (4) have a comparator group. Exclusion criteria included reports that did not satisfy all 4 inclusion criteria, basic science studies, animal studies, cadaver studies, case reports, technique papers, conference abstracts, letters to editors, supplements, guidelines, and non-English studies. If there were overlapping cohorts, the most complete or contemporary cohort was included.

Quality Assessment

Articles underwent quality screening using the Newcastle-Ottawa Scale (NOS). (PMID 20652370) This scale is a tool used for assessing the quality studies included in systematic reviews. Points are awarded for each question and the quality of the study is determined based on the total number of points. The maximum number of points are 9 (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 ≥7 points ("good" quality) were included in our systematic review.

Data Extraction

Data extraction was conducted by two independent authors (K.P.O. and J.C.D.). Data extracted included demographic and clinical data. The extracted data was placed into tables that describe the background information, pain management regimens (pre-, peri-, and postoperatively), short descriptions of the novel pain regimen proposition (if available), and outcome data (e.g., length of stay, pain levels, etc.).

RESULTS

Quality Assessment

Each of the studies underwent quality assessment using the Newcastle-Ottawa Scale (Supplemental Table 1). Four studies had 9 points and two studies had 8 points which means that all studies were good quality and included in the systematic review.

Background Information

Six studies were included in the systematic review (Table 1).[7-12] The studies had varying amounts of background, pain regimen description, and outcome data. The evidence level was 5 level II studies and 1 level III study consisting of independent institutions. Each of the studies had a "test group" and a "comparison group" to evaluate the impact of novel pain management strategies. These strategies consisted of nerve blocks, local anesthesia, use of high dose dexamethasone (48mg), and even earlier removal of epidural catheters that were used for pain management.

Description of Novel Treatments

Each study provided a brief description of their intervention (Table 2).[7-12] Albertz et al. described a multimodal fascia iliaca nerve block.[7] For this method, they described using methadone for a general anesthetic. Fascia iliaca block was performed using ultrasound to inject 0.2% ropivacaine 1 mL/kg for a maximum of 40 mL after induction and before the operation. An additional dose of methadone was given 12 hours after the previous dose. Bech et al. described a method of wound infiltration with ropivacaine just before closure.[8] They injected 75 mL (150 mg) into the surgical bed and left a catheter in place for a total of 5 more injections every 10 hours. Cunningham et al. described discontinuation of epidural catheters that were used for pain on post-operative day (POD) 1 compared to POD 2, which was their previous protocol.[9] For the epidural, they administered 0.2% ropivacaine and 2 µg/mL of fentanyl running continuously (from 8 to 10 mL/hour). As needed (PRN), the patient could self-administer 5mL boluses totaling up to 60mL over 4 hours. Ellis et al. described pericapsular nerve group (PENG) and transversus abdominis plane (TAP) blocks.[10] They used ultrasound in the preoperative area to place 20mL of ropivacaine between the pubic ramus and psoas tendon and between the internal oblique and transversus abdominis, respectively. Lochel et al. de-

Supplemental Table 1. Newcastle-Ottawa Questionnaire Results

Author	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Total *
Albertz	*	*	*	*	**	*	*	*	9
Bech	*	*	*	*	**	*	*	*	9
Cunningham	*	*	*	*	*	*	*	*	8
Ellis	*	*	*	*	**		*	*	8
Lochel	*	*	*	*	**	*	*	*	9
Steinthorsdottir	*	*	*	*	**	*	*	*	9

Table 1. Study Participant Information

Study	Year Published	Institution	Type of Study	Test Group	Comparison Group	Number of Participants	Outcome studied
Albertz	2020	Cincinnati	Prospective Cohort	MM-FICNB	Epidural Analgesia	16 vs 16	Length of stay
Bech	2014	Denmark	RCT	Ropivacaine wound infiltration	Saline wound infiltration	26 vs 27	Pain-controlled anesthesia for 5 days after wound closure
Cunningham	2020	North Carolina	Prospective Cohort (III)	Removing epidural catheter on POD 1	Removing epidural catheter on POD 2	87 vs 57	Length of stay, opioid usage (MME), NRS
Ellis	2023	UCSF	Prospective Cohort	PENG and TAP blocks	No block	15 vs 15	VAS score, opioid use during first 24 hours post-surgery
Lochel	2021	German	RCT	TAP	Standard care	21 vs 20	NRS pain
Steinthorsdottir	2021	Denmark	RCT	48mg dexamethasone	8mg dexamethasone	32 vs 32	NRS

MM-FICNB: Multimodal-Fascia Iliaca Compartment Nerve Block, MME: morphine milligram equivalents, NRS: pain numeric rating scale, PENG: pericapsular nerve group, TAP: Transversus abdominis plane.

Table 2. Short Summary of Protocol

Study	Protocol	Description
Albertz	Multimodal Fascia Iliaca Nerve Block	Protocol Specific Analgesics: Methadone 0.1 mg/kg (max 5mg), ultrasound guided, infrainguinal fascia iliaca nerve block single injection (while intubated and before incision) with 0.2% ropivacaine 1 ml/kg (max 40ml); POD0-1: Methadone 0.1mg/kg (max 5mg) 12h from previous intraoperative dose
Bech	Ropivacaine wound infiltration	75 mL (150mg) ropivacaine at wound closure and catheter left in place for a total of 5 injections q10h
Cunningham	Discontinuation of epidural catheter on POD 1 compared to POD 2	Dosing regimen for epidural was 0.2% ropivacaine and 2 μg/mL of fentanyl running continuously (from 8 to 10 mL/hour), 5mL patient-controlled boluses totaling up to 60 mL over 4 hours
Ellis	PENG and TAP blocks	Ultrasound-guided technique in preoperative holding area. For PENG block, needle placement was between pubic ramus and psoas tendon. For TAP block, needle placement was between internal oblique and transversus abdominis muscle. 20mL of ropivacaine injected for both blocks
Lochel	Transversus abdominis plane	Ultrasound-guided technique prior to surgery. 20mL of 0.75% ropivacaine
Steinthorsdottir	48mg dexamethasone vs 8mg dexamethasone	Injected after induction and 30 minutes before surgery

scribed the transversus abdominis plane block as well. Finally, Steinthorsdottir described the use of high dose dexamethasone (48mg) compared to low dose (8mg) that was injected after induction (30 minutes before surgery).[12]

Description of Pre-, Peri-, and Postoperative Pain Management

Studies had varying outcomes reported in the pre-, peri-, and postoperative time periods (Table 3).[7-12] The most comprehensive pain management protocol was provided by Albertz et al.[7] He suggests pregabalin, Celebrex, and PRN midazolam before surgery, IV acetaminophen and intubation specific drugs, and a comprehensive postoperative regimen consisting of narcotics, non-steroidal anti-inflammatory drugs, IV acetaminophen, and PRN medications. Their protocol specific medications were methadone during MM-FICNB and every 10 hours for 5 doses. Bech et al. described use of their protocol specific ropivacaine wound infiltration during closure and PRN long-acting opioids in post-anesthesia care unit (PACU). Then they provide 5 extra doses every 10 hours.[8] Ellis et al. described use of ultrasound-guided PENG and TAP blocks in preoperative holding area and nonspecific use of IV and oral pain medications. Lochel et al. also discussed a TAP block just prior to surgery.[10] Steinthorsdottir et al. described use of 48mg of dexamethasone prior to surgery compared to their 8mg standard and nonspecific use of postoperative narcotics.[12] Finally, Cunninham et al. reported on their change in institutional protocol when they went from removing the epidural catheter that was used for pain medications from POD 2 to POD 1.[9]

Clinical Outcomes

Each study demonstrated improvements in heterogenous outcomes and each of these demonstrated statistically significant differences from the comparator groups. Albertz et al. demonstrated improvements in time for fascia iliaca block (6 vs 15 minutes), decrease in length of stay (2.9 vs 4.4 days), increased morphine equivalent rate (MER) on POD 0 (8.7 vs 0 mcg/kg/h), decreased MER on POD 1 (0 vs 1.5 mcg/kg/h), decreased MER on POD 2 (0 vs 1.64 mcg/kg/h), decreased time to ambulation of a few steps (1 vs 2 days), decreased time to ambulation of 15 steps (2 vs 4 days), and decreased time until able to walk upstairs (2.5 vs 4 days).[7] Bech et al. demonstrated improvements in pain on the visual analog scale (VAS) on POD 3 (19 vs 31) and POD 4 (18 vs 28).[8] Cunningham et al. demonstrated improvements in POD 1 pain >7 (77% vs 96.5%), decreased MME on epidural removal day (130.7 vs 200.4), decreased MME on POD 0 (21.9 vs 31.9) and POD 2 (103.6 vs 200.4), total MME (333 vs 674.8), and decreased length of stay (3.4 vs 4.6 days).[9] Ellis et al. demonstrated improvement in VAS on the surgical floor (4.9 vs 5.8) and decreased total MME (154.0 vs 217.6).[10] Lochel et al. demonstrated better NRS at rest (2.9 vs 4.2) and in motion (5.9 vs 6.7) 24 hours after surgery.[11] Finally, Steinthorsdottir demonstrated decreased oral morphine equivalents on POD 1 (4 vs 15).[12] Albertz and Cunningham et al. conducted multivariable analyses (Table 1).[7,9] Albertz et al. demonstrated decreased length of stay in the MM-FICNB group (parameter estimate: -1.58, standard deviation: 0.37).[7] Cunningham et al. demonstrated decreased odds of POD 1 pain >7 of 10 on POD 1 (OR: 0.09, CI: 0.02-0.44), decreased additional mean pain on POD 1 (OR: 0.9, CI: 0.62, 1.2), lower mean pain on epidural removal day (OR: -0.26, CI: -0.51, -0.02), higher POD 1 additional MME (OR: 16.9, CI: 5.2, 28.6), lower POD 2 additional MME (OR: -36.3, CI: -49.4, -23.3), lower additional MME on epidural removal date (OR: -31.7, CI: -43.9, -19.5), lower total additional MME (-79.8, CI: -125.7, -34.0), and decreased length of stay (OR: -0.66, CI: -0.83, -0.48) with epidural catheter removal on POD 1. With gabapentin use, there are increased odds of POD 1 pain >7 of 10 (OR: 3.56, CI: 1.29, 9.86) and decreased odds of POD 0 additional MME (OR: -7.17, CI: -11.63, -2.71).[9]

DISCUSSION

Early post-operative pain management after PAO surgery is important to limit reliance on opioid pain medication and facilitate early mobilization.[2,3] Literature assessing efficacy of pain management strategies is limited for PAO surgery. The current systematic review summarized six articles that compared new strategies to address this limitation.[7-12] In summary, three articles discussed nerve blocks, one article discussed local wound infiltration with anesthetic, one article discussed use of high dose dexamethasone peri-operatively, and one article discussed earlier removal of epidural catheters compared to their previous protocol. Overall, these articles found improvements in clinical outcome scores, less opioid usage, shorter time to ambulation, and decreased length of hospital stay.

The advantages of surgical pain management are clear. Non-opioid pain reduction strategies became the forefront of many research endeavors due to the opioid crisis with many clinicians investigating alternative strategies. As a result, many articles have been published such as the ones that are mentioned in this systematic review.[7-12] In an interesting recent article, Hajewski et al. described a mobile messaging system that helps track opioid use and provides guidance and reassurance to patients in all phases of surgical care—preoperatively and postoperatively.[4] Postoperative communications are

Table 3. Preoperative, Perioperative, and Postoperative Management

Study	Medication
Preoperative	
Albertz	Pregabalin 50-75mg orally an hour before surgery
	Celebrex 200mg orally an hour before surgery
	Midazolam IV PRN
Perioperative	
Albertz	Induction: IV fentanyl, lidocaine propofol, muscle relaxant
	Maintenance: Inhalational anesthesia, muscle relaxants, PRN opioids
	After extubating: Diazepam 0.05mg/kg IV
	IV acetaminophen (15mg/kg) max 1000 mg; Ketorolac 0.5 mg/kg (maximum (15mg)
	Protocol Specific Analgesics: Methadone 0.1 mg/kg (max 5mg), ultrasound guided, infrainguinal fascia iliaca nerve block single injection (while intubated and before incision) with 0.2% ropivacaine 1 ml/kg (max 40ml)
Bech	Induction: 2mg/kg propofol, 1 μg/kg remifentanil
	Maintenance: 5 mg/kg/h, 0.5 μg/kg/min
	Recovery room: Long acting opiods PRN
	Protocol Specific Analgesics: 75 mL (150mg) ropivacaine at wound closure and catheter left in place for postoperative injections
Ellis	Protocol Specific Analgesics: Ultrasound-guided technique in preoperative holding area. For PENG block, needle placement was between pubic ramus and psoas tendon. For TAP block, needle placement was between internal oblique and transversus abdominis muscle. 20mL of ropivacaine injected for both blocks
Lochel	Induction: propofol 1-2.5mg/kg, fentanyl 0.5-1μg/kg, cisartracurium 0.1-0.2 mg/kg
	Maintenance: propofol 5-10mg/kg/hour, fentanyl, 0.1mg/kg piritramide, PCA 1.5 mg piritramide/bolus with 10 min lockout before PACU
	Protocol Specific Analgesics: Ultrasound-guide. Transversus abdominis plane block. 20mL of 0.75% ropivacaine.
Steinthorsdottir	Protocol Specific Analgesics: 48mg dexamethasone administered prior to surgery (compared to 8mg)
Postoperative	
Albertz	
POD 0-1	Pain service, early mobilization and PT/OT, spirometer 10x/hour while awake, Discontinue foley catheter
	Protocol Specific Analgesia: Methadone 0.1mg/kg (max 5mg) 12h from previous intraoperative dose
	Oxycodone orally 0.1mg/kg (5-7.5mg) q4h
	Acetaminophen 15mg/kg IV (max 1000mg) x3 doses followed by PO 15mg/kg (max 650mg) q6h max dose 3g/day
	Ketorolac 0.5mg/kg (max 10-15mg) IV q6h (unless on aspirin or enoxaparin)
	Diazepam 0.05mg/kg (max 5mg) IV q4h PRN muscle spasms
	Methocarbamol 15mg/kg (max 1000mg) q8h IV
	Hydromorphone 0.1 mcg/kg q4h IV PRN severe pain
	Opioid side effect management: PRN nausea/vomiting: ondansetron 4mg IV q6h PRN pruritis: nalbuphine 0.05mg/kg PRN respiratory depression/oversedation: naloxone 1-2 mcg/kg (for over-sedation); 10-20mcg/kg (for life threatening respiratory depression)

Table 3. Preoperative, Perioperative, and Postoperative Management (continued)

POD 2	Switch IV acetaminophen PO 650mg q6h (max 75mg/kg/day or 3g/day
	Switch IV to PO diazepam 0.05-0.075 mg/kg (max 5mg) q4h PRN muscle spasm
	Switch methocarbamol IV to PO 15mg/kg (500-1000) q8h
	Continue oxycodone PO q4h
	Hydromorphone 0.1mcg/kg q4h IV PRN severe pain
	Diet: regular; Bowel regimen (stool softener/senna)
	Activity: PT/OT, spirometer 10x/h while awake
	Drains/Foley: none
	Discharge planning: Discharge home once PT goals completed
POD 3 to discharge	Continue activity; Continue incentive spirometry; continue bowel regimen and diet; home if excellent mobilization and pain control with PO oxycodone, acetaminophen, and diazepam
Bech	
POD 0-2	Protocol Specific Analgesia: 5 postoperative bolus injections of 20 mL (50mg) ropivacaine q10h
	PRNs: 10 mg metoclopramide for nausea, 10 mg bisacodyl for laxative treatment
POD 0-4	Oral paracetamil 1 g qid
	PRNs: 5mg immediate release oxycodone without restrictions
Cunningham	
Nonspecific timeframe	NSAIDs, aspirin, acetaminophen, gabapentin, hydromorphone IV, oxycodone PO
POD 0-1	PCA IV hydromorphone
POD 1-nonspecific timeframe	PRN PO oxycodone and IV hydromorphone: 5mg oxycodone q3-4h for pain 3-4/10, 10mg for pain 5-6, and 15 mg for pain 7-10
Ellis	
POD 0-nonspecific timeframe	PT, IV and oral pain meds (nonspecific), partial weight bearing x6 weeks
Lochel	
POD 0	Daily metamizole (4x1g), etoricoxib (1x90mg), IV ondansetron (4x4mg)
Steinthorsdottir	
POD 0-nonspecific	PRN 5mg oxycodone PO

more frequent closer after surgery and steadily decrease throughout the postoperative course. Technology, such as this mobile messaging system, will help clinicians better understand their patients' clinical courses. Using a high-frequency communication system, such as this, while implementing novel pain management regimens will help improve feedback and patient care. While not included in this review due to lack of comparator group, Pascual-Garrido et al. published a recent article detailing the medications used throughout the PAO process.[13] She used Naprosyn and scopolamine before surgery, IV Tylenol and IV Toradol during surgery, and scheduled oxycodone, Zofran, and IV narcotics for breakthrough pain. On discharge, she recommended Naprosyn, Percocet as needed, and Hydrocodone as needed.

For the articles included in this review, most were focused on nerve blocks or use of non-opioid medications.[7-12] This is important to investigate as generalized opioid dependence has increased and the use of opioids in the hospital have been shown to delay discharge and increase morbidity and mortality.[14,15] For the regimens described in this review, four decreased opioid use and two decreased lengths of stay.[7-12] Furthermore, patients appear to have less pain and increased mobility during their hospital stay; both of which can decrease healthcare costs and length of stay.

For Bech et al., they tested wound infiltration with ropivacaine followed by scheduled doses through a catheter that was left in place.[8] Interestingly, there were no differences in pain between the ropivacaine group and the saline group until POD 3 and 4. At that time, the initial larger dose of ropivacaine that was administered at the time of surgery had likely dissipated and the much smaller doses that were administered every 10 hours would less likely influence pain. It is possible that general anesthesia took two days to dissipate at which time they noticed the differences.

For Cunningham et al., in their change-of-practice study, they removed the epidural catheter on POD 1 rather than POD 2.[9] This led to less pain on the day of epidural removal and decreased length of stay. More specifically, length of stay decreased by approximately a third. This could be due to the negative effects of epidural analgesia which includes decreased lower extremity motor function and urinary retention. This study, by design, did not follow patients beyond the hospital admission.

For Ellis et al., they demonstrated that using a PENG and TAP block significantly decreased the amount of opioid utilization by patients and that there were no block-related complications.[10] The first to describe the TAP block for PAO was Lochel et al. who demonstrated decreased pain 6-, 24-, and 48- hours after surgery.[11] However, only the 24-hour decrease was significant. Albertz et al. described the fascia iliacus block which decreased length of stay and opioid use.[7] These studies demonstrated the feasibility of blocks to improve peri- and post-operative pain management and there were no complications. Finally, Steinthorsdottir et al. utilized high-dose, compared to low-dose, dexamethasone and found that there was only a decrease in opioid consumption on POD 1; otherwise, there was no decrease on the other days up to POD 4, which was around the time of discharge.[12] There were no complications related to high-dose steroid use in this study although there are the well-established complications of steroid use including insomnia, hyperglycemia, and psychosis. Future clinical trials should include larger cohorts with longer follow up to assess risk of avascular necrosis.

There are limitations in this systematic review. The first is that there are only six studies that investigate pain management in the setting of PAO with comparator groups. Future clinical trials should be dedicated to investigating pain reduction interventions. Next, it may be difficult to determine whether the studies that did not show differences in length hospital stays to truly show the benefit of the tested intervention. In other words, hospitals typically have teams devoted to maximizing the efficiency of discharging patients after treatment. So, it is possible that this effect was not picked up in some of the studies. Next, there are many pain management systems that are not published due to current established practices. For example, many institutions use a form of multi-modal pain medications such as NSAIDs, opioids, and gabapentin.

CONCLUSION

Early post-op pain management after PAO typically relies on a regimen of opioid and non-opioid medications. Now, there are adjunctive treatments that are available to help ease the reliance on opioid medications potentially decreasing risk of opioid dependence as well as length of hospital stay. The six studies presented in this paper offer supplemental pain management modalities that can be used to decrease opioid use. Further studies should investigate these modalities with larger cohorts.

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POSTERIOR CRUCIATE LIGAMENT INJURIES IN VERY YOUNG CHILDREN - A CASE REPORT AND MODERN REVIEW

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ABSTRACT

Background: Posterior cruciate ligament (PCL) tears in young children are rare and optimal treatment is poorly described. Diagnosis may prove challenging as young children may not be able to verbalize a complete history of injury, may be difficult to examine, and plane film radiographs often appear within normal limits. Surgical treatment carries a risk of physeal arrest, but non-operative treatment may lead to recurrent instability and pain.

Methods: We present a case report of a four-year-old child with a PCL avulsion off the femoral insertion who received an open reduction and internal fixation (ORIF) with combined arthroscopic synovial debridement. We performed a literature review which compared the mechanism, location, concomitant injuries, work up and management of PCL injuries in children under the age of ten compared to adolescents and adults.

Results: Nineteen months following surgery, physical examination revealed full knee range of motion and return to baseline function. Imaging studies confirmed there was no evidence of physeal arrest.

Conclusion: ORIF with arthroscopy can be an effective method to treat PCL avulsions in children under the age of 10 years. This is similar to other case reports which reported positive outcomes with ORIF in this population. Large studies are needed to best understand optimal treatment modalities for PCL injuries in very young children.

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INTRODUCTION

Injuries to the posterior cruciate ligament in very young children are rare and optimal treatment is still controversial. We present a case report of a four-year-old child with a posterior cruciate ligament (PCL) avulsion off of the femoral insertion. We also performed a review of the literature evaluating the mechanisms of injury, anatomic location, concomitant injuries, work up, and treatment for patients who sustain PCL injuries under the age of 10.

CASE REPORT

Presentation

A four-year-old, otherwise healthy, male presented to the orthopaedic surgery clinic approximately two weeks after injuring his right knee. The injury occurred while the boy was playing with his cousin under a mattress. While laying supine, the child supported a mattress above him with his legs. His cousin jumped on top of the mattress, forcing the child's knees into hyperextension. The patient experienced immediate pain and swelling in his right knee. Prior to his referral to our clinic, the patient had seen two different providers and had been given a knee immobilizer brace. Despite compliant use of the brace, the parents reported that the child had constant swelling, pain, and inability to bear weight on the right leg.

Examination at our clinic revealed a moderate right knee effusion and generalized tenderness to palpation over the distal femur and proximal tibia. The exam was somewhat limited by the child's anxiety, however, ligament testing of the right knee revealed instability with anterior and posterior stress compared to his contralateral side. There was no obvious posterior sag. He had full knee extension and 75 degrees of knee flexion. Radiographic imaging of his right knee did not reveal any osseous lesions (Figure 1A and 1B). Blood work obtained to rule out an infection was essentially normal. His C - reactive protein (CRP) was normal, and his erythrocyte sedimentation rate (ESR) was mildly elevated at 13mm/hr.

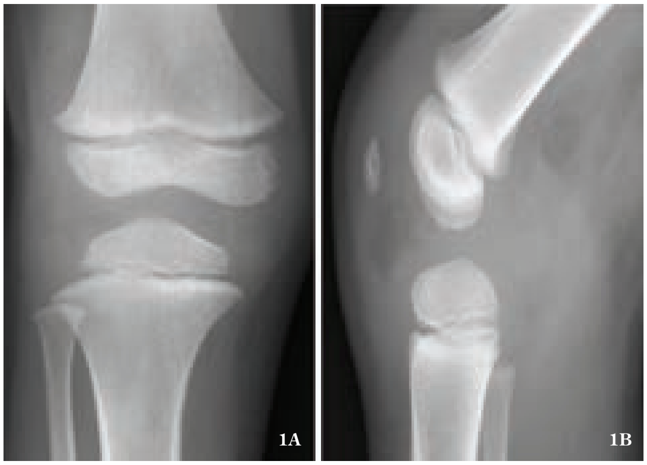

Figure 1A to 1B. The initial anteroposterior (1A) and lateral (1B) radiographs showed no osseous lesion.

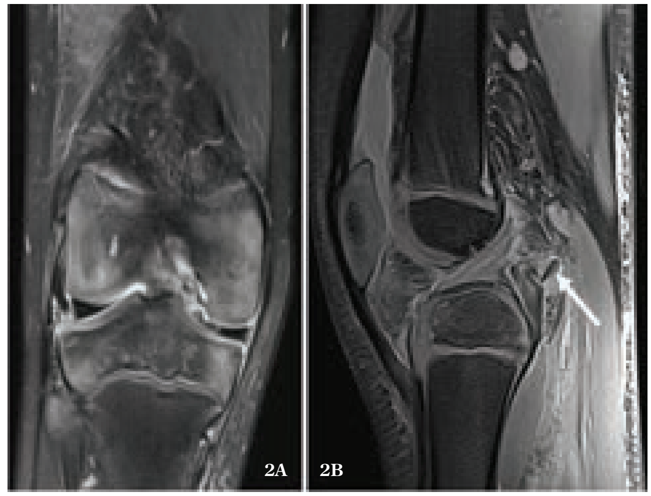

Figure 2A to 2B. MRI coronal view (2A) and sagittal view (2B) demonstrating a PCL avulsion of the distal femur attachment.

Given the acute hyperextension mechanism of injury paired with the rapid development of pain, swelling, joint laxity, and persistent effusion, an intra-articular injury was suspected. As such, a subsequent Magnetic Resonance Imaging (MRI) study was obtained. The MRI revealed a right knee PCL avulsion off the distal femur with a possible concomitant radial tear of the medial meniscus (Figure 2A and 2B).

Surgery

Examination under anesthesia revealed a grade III posterior drawer test. There was a negative Lachman's test. In a prone position, a vertical incision was made over the proximomedial aspect of the gastrocnemius muscle and extended laterally across the popliteal fossa (Figure 3A and 3B). The gastrocnemius and semimembranosus muscles were identified and the interval between them was used to dissect down to the joint capsule. The capsule was then exposed widely. An incision was made into the capsule near the midline which revealed clear synovial fluid and minimal blood. The avulsed PCL fragment off of the medial femoral condyle had retracted distally but was well visualized and chondral in nature. Dissection over the medial femoral condyle allowed for visualization of the original insertion site.

The avulsed PCL fragment was then reattached to the medial femoral condyle insertion site using a 2.3 mm suture anchor and a modified Kessler technique. A repeat posterior drawer test performed under anesthesia revealed improved stability with minimal translation compared to preoperative exam. The joint capsule and skin were closed.

After wound closure, the patient was switched to a supine position for arthroscopic evaluation. There was a considerable amount of synovitis over the medial meniscus which was debrided. There was no underlying medial meniscus tear.

Follow up

At his one-week postoperative visit the child had no complaints of pain. There was minimal post-operative swelling and no neurovascular concerns distally. A non-weight bearing long leg cast was then applied with his knee flexed to 20 degrees.

At the one-month postoperative visit, the patient's family reported that he had begun walking in his long-leg cast while at home. With this cast removed, he had full knee extension and 40 degrees of flexion. The patient was then transitioned into a pediatric hinged knee brace starting at 0-40 degrees of flexion with the plan to increase flexion by 10 degrees weekly with weight bearing allowed.

He did not show up to the three-month postoperative visit, however a phone call to the patient's mother indicated he had stopped using the hinged brace and started running. The family did not utilize physical therapy but reported the patient regained full strength.

The patient was seen for final follow up 19 months postoperatively. The child denied any residual complaints of the injury. The parents reported high levels of daily activity, endorsing a return to baseline function. On examination, the child had full knee range of motion and could perform two legged squats. His quadriceps muscles appeared equal in size with no signs of atrophy.

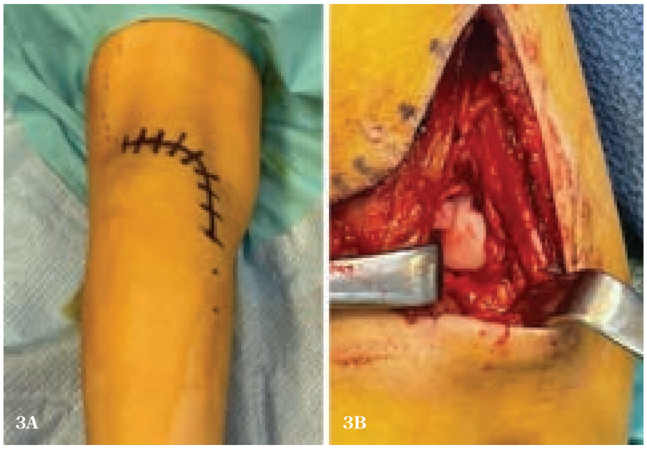

Figure 3A to 3B. Prone position with (3A) planned incision over the medial proximal gastrocnemius extending proximal and then transversely over the popliteal fossa and (3B) incision with interval between the gastrocnemius and semitendinosus muscles, and capsular incision revealing the PCL avulsion fracture.

Figure 4. The incision was well healed without residual findings.

There was no evidence of valgus or varus deformity. The suture sites were well healed without erythema, swelling, or tenderness (Figure 4). Posterior drawer and Lachman's test revealed mild PCL laxity when compared to the contralateral side; however, there were no clinical complaints related to the laxity. Radiographic imaging, (Figure 5, A and B) revealed an open physis with no evidence of growth arrest or angular deformity of the right knee.

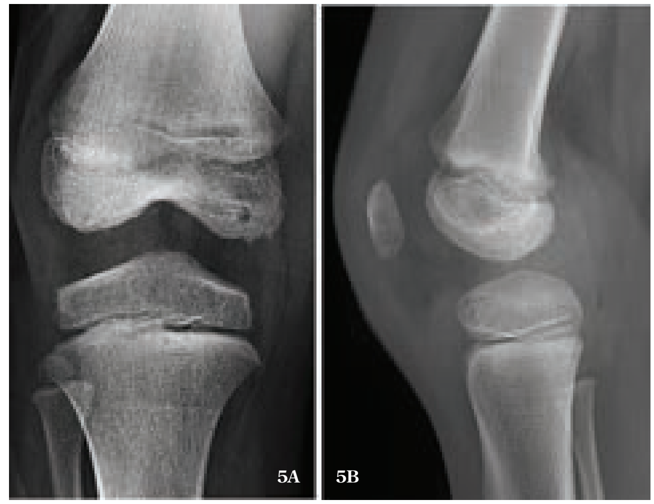

Figure 5A to 5B. The final anteroposterior (5A) and lateral (5B) radiographs showed no physeal arrest or angular deformity.

DISCUSSION

Incidence

In general, PCL injuries in children are uncommon and even rarer in very young children. Injuries to the PCL in children are most often avulsion fractures, but the incidence of these avulsions in very young children is unknown with most published literature limited to case reports.[1,2,3] One study evaluated the tensile forces of knee ligaments and found posterior cruciate ligaments were weaker in the pediatric population compared to the adult population.[4] The researchers suggested that young children may have a greater risk of developing PCL avulsion fractures.[4] Despite a proposed increased risk of PCL avulsion fractures in the young pediatric population, literature regarding posterior cruciate ligament injuries in pediatric patients is far more scarce compared to that of adults.

We conducted a literature review of PCL injuries in children under the age of ten, dating from 1980 to 2021. (Table 1) Most of the cases, but not all, were avulsion fractures. Case reports that did not provide information regarding the mechanism of injury, treatment provided, and return to sport timeline were excluded from the review. We found eight cases of PCL femoral avulsions and two instances of intrasubstance PCL tears. The mean age was 6.0 ± 1.8 years.

Mechanism of Injury

There is variability in the mechanism of injury between adult and pediatric PCL injuries. Among adults and adolescents, motor vehicle accidents (MVA) and sport related trauma are the most common. This typically occurs as the result of a forceful posterior displacement

Table 1. Summary of Reported PCL Avulsions in Pediatric Patients Under the Gge 10

Author, Year	Age	Injury	Treatment	Return
Sanders, 1980[5]	6	Femoral Cartilage Avulsion from a hyperextension on the merry-go-round	Arthrotomy with Osteosuture	2 years
Sanders, 1980[5]	8	Femoral Cartilage Avulsion from a hyperextension on the merry-go-round	Arthrotomy with Osteosuture	N/A
Frank and Strother, 1989[6]	7	Femoral Cartilage Avulsion from a ski accident	Surgical Approach	3.5 years
Lobenhoffer, 1997[7]	3	Femoral Cartilage Avulsion	Arthroscopic Repair by transosse-ous suture	2 years
MacDonald, 2003[8]	6	PCL Insufficiency falling off a trampo-line	Conservative Management	5 year follow up, chronic tear in PCL
Hesse, 2006[9]	9	Femoral Avulsion Fracture of the PCL	Trans osseous femoral fixation	1 year
Shen, 2007[10]	5	Femoral Chondral Avulsion of the PCL during motorcycle collision	PCL reattachment to insertion site	4 years
Scott and Murray, 2011[3]	4	Intrasubstance PCL tear from hyperex-tension on trampoline	Non-operative management with physiotherapy	8 months
Pacull, 2021[1]	6	Femoral cartilage avulsion after trampo-line accident with lesion on PHMM	Arthroscopic ligament reinsertion and meniscal repair	3 years
Pacull, 2021[1]	6	Femoral cartilaginous avulsion on water toboggan trauma	Arthroscopic assisted reinsertion	1.5 years

of the tibia on a flexed knee such as impacting the dashboard in MVAs or falling on a flexed knee with the foot in plantar flexion during sports activity. In young pediatric patients, hyperextension injuries are more commonly reported mechanisms of PCL injuries.[5,7,11]

Anatomic Location

While both adults and pediatric populations experience PCL tears, the respective anatomic site tends to vary by age. Adults and adolescents are more likely to sustain midsubtance PCL tears or avulsions off of the tibia. Meanwhile pediatric populations are more likely to experience PCL avulsions arising from the distal femur with osteochondral fragments.[5,7,10]

In children, the chondro-osseous junction of the femoral attachment is weakest at the PCL.[5] Variability in the setting of knee injuries in pediatric and adult patients may be attributable to the internal strength of the physis in pediatric patients. Skeletally immature patients are predisposed to osteochondral avulsions as ligament strength is often greater than the load to failure of the developing epiphysis.[12]

In our review, eight patients under the age of 10 had femoral avulsions of the PCL compared to two patients who had tears of the ligament. The greater incidence of avulsions arising from the femoral site may warrant further studies evaluating discrepancies in the attachment strength of the PCL.[13] Pacull et al., suggests that differences in PCL avulsion site may also be explained by the mechanism of trauma.[1] Specifically, young children tend to have more domestic accidents or low energy trauma on extended knees compared to the high energy trauma imposed on flexed knees in adults.[1] The energy of trauma and leg positioning may play role in the anatomic location of PCL avulsions.

Work Up

The work up for PCL injuries may be challenging in young children. Patient history is not always known, and physical exam can be difficult in a young child secondary to pain and anxiety. Radiographic imaging often appears unremarkable. MRI is the diagnostic imaging choice for its visualization of soft tissue injuries. Upon arriving at the correct diagnosis, optimal treatment is often challenging due to the lack of a universally agreed upon management in this population.[1,14]

Concomitant Injuries

PCL injuries in adults have a high prevalence of concomitant cartilage injury or meniscal lesion.[15] One study evaluated adult patients who underwent PCL reconstruction found that 26% of patients had a concomitant cartilage lesion and 21% had a meniscal lesion.[15] Comparatively, another study found that 51% of young pediatric patients with confirmed PCL injuries sustained concomitant injuries.[2] As such, clinicians should be cautiously aware of additional injuries when suspecting PCL injuries in young pediatric populations.

Treatment

Non-operative management in young children with isolated PCL injuries may be adequate, however, possible long term ligament laxity may lead to decreased function and further injury. Operative treatment in young children has reported positive results with ligament repair as the most described surgical modality. In our review, two patients received ligament repair. Both patients returned to functional baseline at two to three years of postoperative follow up.[1,7] This contrasts with ligament reconstruction, which is often required for adolescents and adults.[6] Repair of the PCL in young children may restore normal anatomy, function, and provide a stable knee for the growing child.

Perhaps the greatest concern in surgical management of young children is the risk of physeal arrest.[2] To mitigate the risk of physeal arrest, clinicians may consider non-operative treatment in skeletally immature patients.[3,7,8] Surgical treatment should be consciously considered for skeletally immature patients with complete intrasubstance tears or avulsion fractures.[16]

When considering operative intervention, acute treatment of avulsion fractures has been reported with favorable outcomes using open reduction and internal fixation (ORIF), primary repair, pullout suture repair, and a bioabsorbable suture anchor.[13] With skeletally immature patients, an arthroscopic approach may be challenging due to the limited visualization of the operation, making an ORIF approach more preferrable.[17] In a recent case report by Kanayama et al., a pediatric patient with a PCL avulsion returned to full sport activity, without physeal arrest, following treatment with ORIF.[17] Another study evaluated growth disturbances after surgical PCL treatment and suggested using a steep tibial tunnel drilling angle of a minimum 60 degrees to minimize risk of injury to the physis.[18]

Despite concerns of physeal arrest, there are few published case reports of growth arrest following operative intervention for PCL avulsions.[7,8] This is consistent with our review which revealed all eight cases of PCL avulsions treated operatively resulted in return to play without growth arrest. Based on our literature review, surgical intervention for PCL avulsions in young patients is an effective and relatively safe treatment option when indicated.

CONCLUSION

PCL injuries in children are uncommon and even rarer in the very young child. The mechanism of injury, location of tear, work up, concomitant injuries and treatment differ from those of adolescents and adults. A thorough patient history, careful physical examination, appropriate imaging studies, and an elevated index of suspicion for a ligament injury is critical for arriving at the correct diagnosis and providing optimal treatment. While sparse, the literature regarding treatment outcomes in very young children generally supports PCL repair, leading to stable functional knees later in life.

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PREDICTIVE FACTORS FOR INTRAOPERATIVE DETERMINATION FOR THE NEED OF FEMORAL OSTEOCHONDROPLASTY AFTER PERIACETABULAR OSTEOTOMY FOR ACETABULAR DYSPLASIA

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ABSTRACT

Background: Determination of need for osteochondroplasty (OCP) during periacetabular osteotomy (PAO) commonly relies on intraoperative assessment of internal rotation at 90° flexion (IRF). Performing an OCP helps decrease the risk of iatrogenic femoroacetabular impingement from PAO reduction. Avoiding impingement helps decrease risks of accelerated secondary osteoarthritis. The literature is limited for factors that predict need for OCPs during PAOs. The purpose of this study was to (1) define the characteristics of patients needing concurrent OCP and provide OCP rate based on IRF and femoral version and (2) identify predictive factors (clinical, radiographic) associated with need for OCP during PAO. As some surgeons determine need for OCP pre-operatively, predictive factors would aid decision making.

Methods: This was a prospective cohort of 224 hips (207 patients) who underwent PAO for symptomatic acetabular dysplasia, of which 154 hips (69%) underwent OCP between years 2013 and 2017. Patients underwent OCP if they had restrictions in motion or impingement intra-operatively. Pre-operative factors such as age, sex, BMI, and CT findings were recorded that underwent univariate and multivariable analyses. Multivariable analysis found predictors that were described using odds ratios and 95% confidence intervals. IRF>30° and femoral version 10°-25° were used as the reference groups during categorical analysis. P-values ≤0.05 were considered significant.

Results: Alpha angles >55° (OR= 2.20, CI: 1.08-4.52, p= 0.03), IRF≤20° (OR: 9.52, CI: 3.87-23.40, p<0.001), IRF >20°-30° (OR: 2.68, CI: 1.08-6.62, p=0.03), and femoral version <10° (OR: 5.26, CI: 1.09-25.30, p=0.04) were associated with increased odds of OCP. On continuous modeling, decreasing femoral version (OR: 1.07, CI: 1.02-1.12, p=0.002) and IRF (OR: 1.06, CI: 1.03-1.09, p<0.001) were associated with increased chance of OCP. For 5° changes, the chance of OCP increased by 40% (OR: 1.40, CI: 1.13-1.73, p=0.002) and 35% (OR: 1.35, IC: 1.16-1.57, p<0.001), respectively.

Conclusion: Awareness of need for OCP may be valuable in peri-operative planning for these patients especially since some surgeons perform this technique arthroscopically before PAO. Factors associated with increased chances of OCP were alpha angles >55°, decreased IRF, and decreased femoral version. More studies in the future would help determine how OCP affects patient outcomes.

Level of Evidence: III

Keywords: hip dysplasia, osteochondroplasty, periacetabular osteotomy, predictors

INTRODUCTION

Acetabular dysplasia is a condition of considerable prevalence defined by insufficient acetabular coverage of the femoral head.[1] Deformities of the proximal femur involving abnormalities of femoral version and head-neck offset are also common.[1] In addition to variable hip instability, this morphology has been associated with increased loading of the acetabular rim, local chondrolabral injury, and frequent progression to more global secondary osteoarthritis. The periacetabular osteotomy (PAO) attempts to correct the acetabular coverage deficiencies and versional abnormalities through a mobilization and reorientation of the acetabulum relative to the femoral head.[2-7] Though reported results have generally been good, rates of complication (6-37%) and early reoperation (3-10%) have varied.[8-10] Post-PAO femoroacetabular impingement (FAI) is a well-recognized complication and may contribute to poor outcomes and need for reoperation if not addressed at the initial surgery.[11-13] It can occur secondary to acetabular overcoverage, proximal femoral head-neck offset deformities, decreased femoral version, or any combination of these and other factors.[14] Risk of post-PAO FAI can be minimized through accurate

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acetabular reorientation and femoral osteochondroplasty (OCP) when needed. In severe cases of femoral retroversion, OCP may be inadequate alone to avoid FAI and may require proximal femoral osteotomy.[2] For indicated patients, concurrent OCP may slow progression of osteoarthritis and improve long-term survivorship.[1,15]

The decision of whether to perform OCP is generally surgeon dependent with some deciding based on intraoperative assessment after PAO, while others decide preoperatively based on preoperative range of motion and radiographic cam morphology. Preoperatively, some surgeons decide that they will perform the osteoplasty arthroscopically prior to the PAO. On the other hand, with intraoperative assessment, femoral osteoplasty may be avoided in some cases where a radiographic cam morphology is present but unlikely to impinge. With this approach, following acetabular reorientation, internal rotation of the hip is assessed in 90° flexion (IRF). This assessment remains a critical time to stop and check to mitigate post-PAO FAI. If IRF is limited, femoral osteochondroplasty can easily be performed through open arthrotomy using the same PAO incision. Some surgeons also perform this arthroscopically before the PAO correction if they believe the risk of post-PAO impingement is high.[16] An improved understanding of the preoperative factors associated with intraoperative determination of need for OCP could assist surgeons in preoperative planning for both arthroscopic and open femoral OCP.

The purpose of the current study was (1) to compare the pre-operative clinical and radiographic characteristics of patients who underwent PAO with and without OCP and provide OCP rates for hips based on internal rotation and femoral version and (2) to identify preoperative characteristics, physical exam findings, and radiographic-/CT-imaging factors that predict intraoperative determination of need for OCP using multivariable models.

METHODS

A prospective institutional hip preservation registry was retrospectively reviewed for all patients of a single surgeon (BLINDED) who underwent PAO for symptomatic acetabular dysplasia between 2013 and 2017. Of the 330 identified hips, 82 were excluded for diagnosis other than hip dysplasia (n=40) or for prior ipsilateral hip surgery (n=42). An additional 24 hips were excluded for concomitant proximal femoral osteotomy (n=2), unavailable preoperative CT images of the hip (n=13), or poor-quality CT images (n=9). The remaining 224 hips (207 patients) were the focus of this study. [Figure 1]

In assessing preoperative factors potentially associated with need for OCP, parameters of interest included patient characteristics [age, sex, body mass index (BMI)], preoperative physical exam findings (Trendelenburg sign, internal rotation in 90° flexion), and plain radiographic and CT-imaging findings. All imaging measurements were performed by a single observer other than the treating surgeon with experience in radiographic evaluation of the young adult hip. The reliability of a single observer has been validated for young adult hip disorders.[17]

Preoperative alpha angles were measured on each of three radiographic views (AP, Dunn, Frog-lateral). For each patient, the maximum measured alpha angle across these views was categorized as either ≤55° or >55°. Preoperative femoral version measurements were obtained from CT images using the Yoshioka oblique method (PMID 3819914), and preoperative internal rotation in flexion (IRF) ranges were obtained from recorded physical exam findings of the treating surgeon. Femoral version and IRF were analyzed and tested as both categorical and continuous variables. For categorical analyses, femoral version measurements were categorized as <10°, 10-25°, and >25°. IRF measurements were categorized as ≤20°, >20-30°, and >30°.

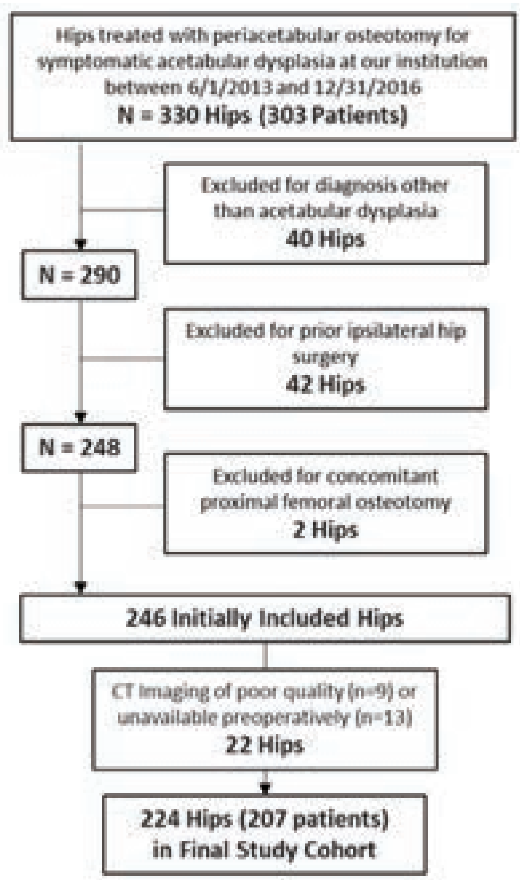

Figure 1. Patient inclusion and exclusion.

Intraoperatively, a standardized approach was used to determine which hips underwent femoral osteochondroplasty (OCP). Following PAO reduction and fixation, internal rotation in flexion was assessed in all patients. All patients with limited (≤20°) internal rotation in 90° flexion underwent OCP.

T-tests and chi-squared tests (substituted Fisher's exact test as necessary) were used to assess parameter differences between hips that underwent OCP and hips that did not. Univariate analyses were used on parameters found to be significantly associated with OCP. A forward Wald analysis was utilized for the multivariable models. If independent variables were not significant, they were excluded from the model. The area under the receiver operator curve (AUC) was used to determine fit of the models. Odds ratios (OR) and 95% confidence intervals (CI) were used to describe the predictors. P values ≤0.05 were significant.

Table 1. Demographic and Radiographic Parameters by OCP Versus No OCP

Parameter	Received OCP (n = 154)	Did not Receive OCP (n = 70)	P Value
Age, years, mean±SD	25.6±8.7	23.3±8.2	0.07
Sex, n (%)			
Female	130 (66%)	66 (34%)	0.04
Male	24 (86%)	4 (14%)	0.04
BMI, kg/m2, mean±SD	24.4±3.6	23.5±3.7	0.08
Femur Version, °, mean±SD	15.8±10.3	24.6±8.0	<0.001
Femoral Version Group, °, n (%)			
<10	39 (95%)	2 (5%)	<0.001
10-25	87 (73%)	33 (27%)	<0.001
>25	24 (44%)	31 (56%)	<0.001
IRF, °, mean±SD	20.3±12.3	35.2±16.0	<0.001
IRF Group, n (%)			
≤20	106 (88%)	15 (12%)	<0.001
>20-30	27 (55%)	22 (45%)	<0.001
>30	20 (38%)	33 (62%)	<0.001
Trendelenberg	81 (60%)	53 (40%)	0.002
Max Alpha Angle (°)	63.2±19.0	59.1±20.2	0.007
Max Alpha Angle > 55	85 (76%)	27 (24%)	0.021

RESULTS

OCP was performed in 154 (69%) hips and OCP was not performed in 70 (31%) hips. Relevant preoperative factors were compared between hips that underwent OCP versus hips that only underwent PAO using univariate analysis. Many of these factors were different between groups (Table 1). Age was similar between groups at 25.6±8.7 years and 23.3±8.2 years, respectively (p=0.07). BMI was also similar between groups at 24.4±3.6 kg/m^2 and 23.5±3.7 kg/m^2, respectively (p=0.08). Males underwent OCP at a higher rate at 24/28 (86%) compared to females at 130/196 (66%). Hips with a Trendelenburg sign on preoperative exam underwent OCP at a higher rate at 81/134 (60%) compared to 53/134 (40%) (p=0.002). Those that underwent OCP also had less internal rotation in flexion on the pre-operative clinical exam (20.3° vs 35.2°, p<0.001), lower femoral version (15.8° vs 24.6°, p<0.001), a higher max alpha angle (63.2° vs 59.1, p=0.007). When maximum alpha angle was >55°, 85/112 (76%) underwent OCP and 27/112 (24%) did not undergo OCP (p=0.021). When femoral version was <10°, 39/41 (95%) underwent OCP, when femoral version was 10°-25°, 87/120 (73%) underwent OCP, and when femoral version >25°, 24/55 (44%) underwent OCP (p<0.001). When preoperative IRF was ≤20, 106/122 (88%) underwent OCP, when IRF was >20-30, 27/49 (55%) underwent OCP, and when IRF >30, 20/53 (38%) underwent OCP (p<0.001). Rates of OCP were affected by internal rotation and femoral version (Table 2a and 2b).

Table 2a. Rate of OCP by IRF and Femoral Version When Alpha Angle >55°

	FV <10	FV 10-25	FV>25
IRF≤20	20/21 (95)	36/39 (92)	4/4 (100)
IRF>20-30	1/1 (100)	8/11 (73)	2/4 (50)
IRF>30	1/1 (100)	6/12 (50)	4/14 (29)

IRF: internal rotation in 90° flexion, FV: femoral version.

Table 2b. Rate of OCP by IRF and Femoral Version When Alpha Angle ≤55°

	FV <10	FV 10-25	FV>25
IRF≤20	15/16 (94)	24/32 (75)	6/7 (86)
IRF>20-30	**	11/20 (55)	4/10 (40)
IRF>30	2/2 (100)	2/6 (33)	3/15 (20)

**no hips were present in this category. IRF: internal rotation in 90° flexion, FV: femoral version.

In the primary (categorical) multivariable model, femoral version, alpha angles, and IRF were found to be predictors of OCP (Table 3). Maximum alpha angles >55° were associated with 2 times increased chance of OCP (OR: 2.20, CI: 1.08-4.52, p=0.03). IRF ≤20 was associated with a 10 times increased chance (OR: 9.52, CI: 3.87-23.40, p<0.001) and IRF >20-30 was associated with a 3 times increased chance (OR: 2.68, CI: 1.08-6.62, p=0.03) of OCP when compared to IRF>30. Femoral version <10° was associated with a 5 times increased chance of OCP when compared to femoral version 10°-25° (OR: 5.26, CI: 1.09-25.30, p=0.04). In the secondary multivariable model, we used continuous values for femoral version, alpha angles, and IRF (Table 4). Decreasing femoral version (OR: 1.07, CI: 1.02-1.12, p=0.002) and decreasing IRF (OR: 1.06, CI: 1.03-1.09, p<0.001) were predictors of OCP. To improve understanding of how the continuous variables affect rates of OCP, femoral version and IRF were used in 5° increments in the model. Decreasing femoral version by 5° increased the chances of OCP by 40% (OR: 1.40, CI: 1.13-1.73, p=0.002) and decreasing IRF by 5° increased the chances of OCP by 35% (OR:1.35, CI: 1.16-1.57, p<0.001).

Table 3: Multivariable Analysis for Predictors of OCP (AUC=0.823)

Predictor	Odds Ratio	95% Confidence Interval	P-value
Alpha Angle >55°	2.20	1.08-4.52	0.03
IRF≤20 (ref >30)	9.52	3.87-23.40	<0.001
IRF>20-30 (ref >30)	2.68	1.08-6.62	0.03
Femoral Version <10° (ref 10°-25°)	5.26	1.09-25.30	0.04

Input: alpha angle >55, IRF≤20, >20-30, >30, and femoral version <10, 10-25, >25. IRF: internal rotation in 90° flexion; ref: reference group.

Table 4: Multivariable analysis for Predictors of OCP (AUC=0.820)

Predictor	Odds Ratio	95% Confidence Interval	P-value
Decreasing Femoral Version (°)	1.07	1.02-1.12	0.002
Decreasing IRF (°)	1.06	1.03-1.09	<0.001
Decreasing Femoral Version (5°)	1.40	1.13-1.73	0.002
Decreasing IRF (5°)	1.35	1.16-1.57	<0.001

Input: continuous alpha angle, continuous IRF, continuous femoral version. IRF: internal rotation in 90° flexion.

DISCUSSION

The benefits of femoral OCP in appropriately indicated PAO patients are well-documented.[1] Failure to correct impingement between the reoriented acetabulum and the femoral head/neck junction (defined as a "compromise" of internal rotation in 90° flexion) has been identified as a key cause of poor patient outcomes.[1] To date, assessment of need for OCP has generally relied on intraoperative exam, and preoperative indicators of likely need for OCP have remained poorly characterized. This study provides an important update to the literature and highlights the strong association preoperative IRF, femoral version, and alpha angle with intraoperative determination of need for OCP which will help peri-operative decision making.

This study has several limitations. Numerous factors can contribute to post-PAO FAI and some factors may affect patients differently. Additionally, the associations we have reported are those only for patients who underwent OCP by one specific definition of need (≤20° internal rotation in 90° flexion after PAO reduction). Furthermore, our model for risk as continuous functions of femoral version and IRF may be of limited clinical utility beyond certain femoral version and IRF thresholds. Finally, it is worth noting that while concurrent femoral osteochondroplasty has been associated with delayed osteoarthritis progression and improved hip survivorship in appropriately indicated patients, its performance may not prevent post-PAO FAI – particularly, perhaps, in some higher-risk groups that remain to be better defined. In the future, an improved understanding of the physiologic determinants of symptomatic post-PAO FAI development may help refine criteria for performance of OCP and other concurrent procedures. While exact intraoperative criteria may change, the current study demonstrates that routinely collected preoperative data points can be valuable indicators for whether intraoperative criteria for a procedure such as OCP are likely to be met.

Our descriptive data demonstrated that males compared to females, lower femoral version, lower preoperative IRF, and alpha angles >55° underwent OCP at higher rates. The importance of performing a concurrent OCPs during periacetabular osteotomies relates to the importance of avoiding iatrogenic femoroacetabular impingement that can be caused from reorienting the acetabulum during PAO. To determine whether patients undergo OCPs, restrictions in hip motion and impingement intra-operatively necessitate the use of these procedures. Femoroacetabular impingement has been extensively demonstrated in the literature to be associated with poor patient outcomes.[18-20] Understanding that the characteristics mentioned above are related to needed OCPs are helpful in identifying patients who will benefit from these procedures as decisions to perform OCPs can be made pre-operatively and OCPs can be conducted arthroscopically before PAOs. A particular limitation of univariate analysis is the potential for confounding and clustering of variables, so the descriptors mentioned above are meant to describe the overall population.

Furthermore, the multivariable model confirmed that pre-operative decreased IRF, lower femoral version, and alpha angles >55° were associated with increased chances of need for OCP. Foreknowledge of likely need for OCP offers several advantages. First, it encourages more careful intraoperative impingement assessment in patients at high risk and helps ensure that indicated patients appropriately undergo osteochondroplasty. In some cases, knowledge of likely impingement induction at typical reorientation targets may help inform reduction goals and encourage the early consideration of additional procedures (acetabuloplasty, etc.) in the overall operative plan for patients in whom these may be beneficial. Also, effective perioperative planning involves consideration of not only the surgical plan, but the logistical plan to optimize resource utilization (preparation of appropriate equipment, allotment of OR time, etc.). The value of such efficiency advantages can be considerable, particularly at smaller surgical centers. Lastly, some surgeons perform OCP arthroscopically, before the PAO, based on peri-operative clinical judgement. Knowing pre-operative factors associated with FAI would assist this clinical decision making.

In conclusion, several preoperative factors were strongly associated with intraoperative determination of need for femoral OCP in patients undergoing PAO for acetabular dysplasia. Though factors such as age and male sex were associated with OCP performance on univariate analysis, the only factors significantly associated with OCP performance on multivariable modeling were preoperative decreased internal rotation in flexion, decreased femoral version, and alpha angles >55°.

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PREVALENCE OF RADIOGRAPHIC HIP DYSPLASIA IN THE GENERAL ADULT POPULATION: A SYSTEMATIC REVIEW

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ABSTRACT

Background: Acetabular dysplasia has a wide range of prevalence reported in the literature. This variation is likely due to differences in the population under investigation and studies focusing on cohorts with hip pain and osteoarthritis. There are reports of radiographic hip dysplasia prevalence for adults without hip pain but there is no systematic review of these studies to document the incidence in the general population. The purpose of this systematic review was to provide a full summary of all studies that report prevalence of hip dysplasia in adults without hip pain.

Methods: PRISMA guidelines were utilized as an outline for this systematic review. Articles were pulled from PubMed, OVID Medline, Embase, SCOPUS, Cochrane Central Register of Clinical Trials, and clinicaltrials.gov from their inception dates to 1/7/24. Studies were included if participants were asymptomatic and reported rates of prevalence.

Results: Fourteen studies were included in this systematic review. There were 10,998 hips from 5,506 participants included in this analysis. The overall prevalence of radiographic hip dysplasia was 2.3%. Eight studies of 5,930 hips reported the prevalence of hip dysplasia by sex. The prevalence rate in these studies was 3.8% in females and 2.7% in males.

Conclusion: Acetabular dysplasia based on radiographic measurements is relatively common in the general adult population. Furthermore, females have a higher prevalence rate when compared to males. It is important to recognize the incidence of hip dysplasia in the asymptomatic adult population as we recommend surgical treatment for patients who present with hip pain and dysplasia. Further studies should investigate the natural history of untreated and treated hip dysplasia.

Level of Evidence: III

Keywords: hip dysplasia, adult, radiographs, asymptomatic

INTRODUCTION

Acetabular dysplasia is a common cause of secondary osteoarthritis in young individuals.[1,2] Adolescents and young adults often present with hip pain prior to developing osteoarthritis, but hip dysplasia is also common in the young, asymptomatic population. Documenting the prevalence of hip dysplasia in the general population is necessary to understand characteristics associated with development of pain and later progression to osteoarthritis.

Hip dysplasia is a spectrum of disease that spans infants with unstable or dislocated hips to adults after skeletal maturity with radiographic undercoverage of the femoral head. The prevalence of hip dysplasia in infants is well-documented but the prevalence of hip dysplasia after skeletal maturity is difficult to assess given that hip dysplasia can be asymptomatic.[3] Additionally, there are broadly accepted screening programs for hip dysplasia in infants which likely increases recognition of the condition in this population. In the existing literature, the prevalence of hip dysplasia is dependent on the population that is sampled. Previous studies have focused on homogenous samples with low diversity.

Previous, independent studies portray prevalence rates of 1-20% depending on populations with variable sample sizes, diversity, symptom states and/or sex.[4-7] Currently, there are no systematic reviews that report prevalence of hip dysplasia for the general population after skeletal maturity. This systematic review will (1) report the overall prevalence for asymptomatic adults and (2) compare differences in prevalence between females and males.

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METHODS

Search Strategy

The PO model was used (Patient, Outcome) to determine the best clinical question for this cross-sectional study.[8] The PO question was "In participants without hip symptoms (population), what is the rate of acetabular dysplasia as defined by lateral center-edge angle (LCEA) <20° (issue of interest). The review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[9] Databases queried were PubMed, OVID Medline, Embase, SCOPUS, Cochrane Central Register of Clinical Trials, and clinicaltrials.gov from their dates of inception to date that the literature search was conducted which was 1/7/24. Search terms were prevalence, incidence, hip, and dysplasia and the search results were screened using the PO question.

Selection criteria

Two independent authors (K.P.O. and J.M.D) evaluated the search results for inclusion. Inclusion criteria were (1) participants diagnosed with acetabular dysplasia defined as LCEA <20°, (2) no hip symptoms, and (3) reported prevalence rates. Exclusion criteria included studies that did not satisfy the 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. There was one overlapping cohort, and the more complete dataset was included in this review.[10]

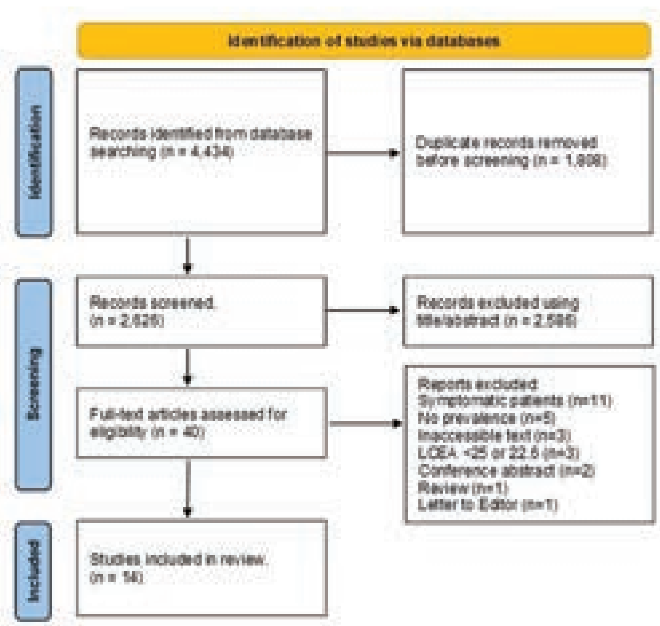

Figure 1. PRISMA diagram.

Quality Assessment

Quality was assessed using the NIH Quality Assessment Tool for cross-sectional studies. All studies reported prevalence rates for asymptomatic participants for general populations or clearly defined populations. For the studies that had symptomatic patients, they reported details for their asymptomatic participants separately. All study qualities were good.

Data Extraction and Statistics

Two independent authors (K.P.O. and J.M.D.) extracted data. Demographic, descriptive, and prevalence rates were pooled to best represent the overall prevalence rate. For the studies that reported rates based on sex, these rates were also pooled to find differences between females and males.

RESULTS

Search Strategy and Quality Assessment

The PRISMA diagram is depicted in Figure 1. There were 4,434 studies that were extracted from all databases. After duplicate removal, there were 2,626 abstracts that underwent evaluation. After abstract removal, there were 40 full texts. After screening all full texts, fourteen studies fit our inclusion criteria, and all were good quality.

Table 1. Study Details

Author	Year	Location	Study Population	Imaging Obtained
Anderson	2016	USA	Senior athletes	Radiographs
Busato	2021	Brazil	Abdominal complaints	CT scans
Croft	1991	England	Pyelograms	Radiographs
Goker	2005	Turkey	Pyelograms	Radiographs
Hassa	2023	Turkey	Not specific	CT scans
Heerey	2021	Australia	Soccer players	Radiographs
Husein	2022	Sudan	KUB	CT scans
Jeremic (researchgate)	2011	Serbia	Not specific	Radiographs
Kim	2019	Asia	Not specific	Radiographs
Leide	2021	Sweden	Not specific	Radiographs
Mimura	2017	Japan	Not specific	CT scans
Paramesh	2022	India	Not specific	Radiographs
Paul	2021	India	Not specific	CT scans
Umer	2009	Pakistan	Pyelograms	Radiographs

Data Extraction

All fourteen studies were cross-sectional in design and were published between 1991 and 2022 (Table 1).[10-23] Twelve of these studies acquired imaging of the hip joints from regional scans for other indications and two of these studies looked at specific populations (senior athletes and asymptomatic soccer players). Of the twelve studies that acquired imaging of the hip for non-hip related reasons, one obtained imaging for abdominal complaints, one obtained KUBs (abdominal or urinary complaints), three obtained pyelograms for urinary symptoms, and seven obtained imaging for non-specific reasons. Nine studies obtained radiographs and five studies obtained computerized tomography (CT) scans that were analyzed for radiographic hip dysplasia.

The radiographic criteria to diagnose hip dysplasia varied between studies. All studies used a center edge angle of <20° to define dysplasia. Borderline dysplasia (center edge angle between 20° – 25°) was not classified as hip dysplasia in these cohorts.[10-23]

Overall, there were 10,998 hips (5,506 participants) that were available for analysis (Table 2). Mean age was 52 years and 2,195/5,412 (40.6%) were female. The overall prevalence of hip dysplasia per hip was 252/10,998 (2.3%). Due to the differences in hip dysplasia prevalence between sexes, females and males were reported separately in nine studies (Table 3). However, in one of these studies, the actual number of participants that were female or male was not reported and only the overall prevalence was reported; therefore, this study could not be pooled with the other eight studies. Between the eight studies, the female prevalence rate was 3.8% (129/3,366 hips) and the male prevalence rate was 2.7% (68/2,564 hips). Croft et al. had one of the largest cohorts with 2,604 hips and noted a 1% prevalence rate which had the largest influence on the overall prevalence rate.[10] This study did not analyze female and male prevalence rates and was thus excluded from that analysis. This explains why the overall prevalence rate was lower compared to both the female and male rates.

DISCUSSION

Radiographic hip dysplasia is common in the asymptomatic general adult population.[10-23] Most studies included in this systematic review obtained hip imaging from scans that were acquired for other indications not specifically related to hip pain. Overall, the combined prevalence rate was 2.3%. When analyzed by sex the female prevalence rate was found to be slightly higher, at 3.8%, than the prevalence rate in the male cohort of 2.7%. The prevalence of hip dysplasia in the general asymptomatic population is lower than the prevalence of hip dysplasia in participants presenting with hip pain or osteoarthritis. For example, in a study that assessed the prevalence of hip dysplasia in patients 50 years old and younger treated with total hip arthroplasty, nearly 50%

Table 2. Study Demographics and Overall Prevalence Rate of Dysplasia (LCEA <20)

Author	N hips/ N participants	Mean age	N (%) Female	Prevalence of dysplasia in all hips
Anderson	1081/547	67±8	246 (45)	30 (3)
Busato	400/200	49±20	86 (43)	12 (6) *
Croft	2604/1302	60-75	0 (0)	26 (1)
Goker	184/92	64±7	27 (29)	5 (2.7)
Hassa	252/126	45±12	73 (58)	2 (1.6) *
Heerey	110/55	26 (23-31)	14 (25)	2 (4) *
Husein	240/120	35	NA	4 (1.7)
Jeremic	740/370	50.8 (21-65)	148 (40)	11 (3.0) *
Kim	400/200	35±7	127 (64)	Sourcil: 60 (15) Bony edge: 29 (7.3)
Leide	3740/1870	53 (20-70)	1171 (63)	121 (3.2)
Mimura	103/52	59±14	23 (44)	6 (11.5) *
Paramesh	400/200	20-60	100 (50)	23 (11.5) *
Paul	244/122	64±17	60 (49)	4 (3.2) *
Umer	500/250	38 (15-78)	114 (46)	7 (1.4)
Overall	10998/5506	52	2189 (41)	252 (2.3)

*Prevalence reported by participant and not by hip.

Table 3. Prevalence Rates of Dysplasia Between Females and Males

	Female	Male				
Author	N hips/N participants	Mean Age	Prevalence, n (%)	N hips/N participants	Mean Age	Prevalence, n (%)
Goker	54/27	NA	0 (0)	130/65	NA	3 (2.3)
Hassa	146/73	NA	1 (1.4) *	106/53	NA	1 (1.9) *
Heerey	28/14	NA	2 (14) *	82/41	NA	0 (0) *
Husein	NA	NA	NA (2.4)	NA	NA	NA (1.3)
Jeremic	296/148	NA	6 (3.6) *	444/222	NA	5 (2.2) *
Kim	254/127	36.0±7.4	Sourcil: 43 (16.9) Bony edge:19 (7.5)	146/73	32.4±6.4	Sourcil: 17 (11.6) Bony edge: 10 (6.8)
Leide	2342/1171	NA	84 (3.6)	1398/699	NA	37 (2.6)
Mimura	46/23	58.2±15.3	3 (13) *	58/29	60.3±14.7	3 (10.3) *
Paramesh	200/100	NA	14 (14) *	200/100	NA	9 (9) *

*Prevalence reported by participant and not by hip.

of the patients with osteoarthritis had radiographic signs of hip dysplasia.[1] These results are mirrored by multiple other studies.[4-7] While asymptomatic adults do not have as high of a prevalence of hip dysplasia compared to patients presenting with hip pain and/or osteoarthritis, a substantial portion of the population without pain has clinically silent radiographic signs of hip dysplasia that likely predisposes them to future degeneration of the hip joint.

While most studies presented in this systematic review included adults with imaging studies obtained for non-hip related reasons, there were two studies that reported prevalence from specific populations.[11,15] Anderson, et al., demonstrated that the prevalence of dysplasia was 2.8% in senior athletes which was defined by age >65 years and 55% were male.[11] This prevalence rate was similar to the overall prevalence rate when all studies were pooled (2.3%). This rate was slightly higher compared to the other studies that reported senior prevalence rates which were 1% (Croft et al.),[10] 2.7% (Goker et al.),[13] and 1.6% (Paul et al.).[22] In this study, although there was no mention of pain in this population, there was a 17% prevalence of Tonnis Grade 2-3 osteoarthritis which may have influenced the rate of dysplasia. Alternatively, Heerey et al., looked at a group of sub-elite competitive soccer players which were recruited by public advertising or information sessions.[15] The mean age was 23.0 years (23-31) and 74% were male. These participants had a prevalence rate of 4% which was higher than the overall prevalence rate from our pooled statistics. This prevalence identified in a group of soccer players who denied hip pain and had a negative FADIR test. Therefore, this population appears to behave like the thirteen studies where imaging was obtained for indications outside of those relating to the hip. The incidence of hip dysplasia has been reported in other athlete population studies. For example, in a series of collegiate female athletes, hip dysplasia defined as center edge angle <20°, was documented on AP pelvis radiographs in 21% of hips. This study was not included in the systematic review because 21% (26/124) of these female athletes had hip pain on exam.[24]

There are limitations of this paper. These studies incorporated a wide range of geographical populations, in which none individually were able to assess the prevalence of a specific race or ethnicity. Overall, when combined in a large systematic review such as this, their individual data becomes more broadly applicable to a more diverse global population. Next, in one of the studies, there was not an explicit statement that individuals included were asymptomatic. However, in this paper, there was no osteoarthritis or other bony abnormality noted outside of dysplasia. So, these hips were assumed to be asymptomatic. Finally, this study represents cross-sectional studies. Therefore, it only provides disease at the single time point and does not provide changes in the disease state over time.

CONCLUSION

In conclusion, prevalence of hip dysplasia in asymptomatic adults was 2.3% in the pooled analysis. Females had a higher rate of acetabular dysplasia at 3.8% compared to 2.7% in males in studies that reported prevalence of hip dysplasia by sex. Although this is not as high as the reported rate for symptomatic patients, asymptomatic acetabular dysplasia is common and should be recognized as a risk factor for secondary progressive osteoarthritis. Further studies should investigate the natural history of hip dysplasia to identify individuals at risk for developing pain and progression to osteoarthritis.

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HEALTH LITERACY IN SHOULDER ARTHROSCOPY: A QUANTITATIVE ASSESSMENT OF THE UNDERSTANDABILITY AND READABILITY OF ONLINE PATIENT EDUCATION MATERIAL

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ABSTRACT

Background: The National Institutes of Health (NIH) and American Medical Association (AMA) recommend that online health information be written at a maximum 6th grade reading level. The aim was to evaluate online resources regarding shoulder arthroscopy utilizing measures of readability, understandability, and actionability, using syntax reading grade level and the Patient Education Materials Assessment Tool (PEMAT-P).

Methods: An online Google™ search utilizing "shoulder arthroscopy" was performed. From the top 50 results, websites directed at educating patients were included. News and scientific articles, audiovisual materials, industry websites, and unrelated materials were excluded. Readability was calculated using objective algorithms: Flesch-Kincaid Grade-Level (FKGL), Simple Measure of Gobbledygook (SMOG) grade, Coleman-Liau Index (CLI), and Gunning-Fog Index (GFI). The PEMAT-P was used to assess understandability and actionability, with a 70% score threshold. Scores were compared across academic institutions, private practices, and commercial health publishers. The correlation between search rank and readability, understandability, and actionability was calculated.

Results: Two independent searches yielded 53 websites, with 44 (83.02%) meeting inclusion criteria. No mean readability score performed below a 10th grade reading level. Only one website scored at or below 6th grade reading level. Mean understandability and actionability scores were 63.02%±12.09 and 29.77%±20.63, neither of which met the PEMAT threshold. Twelve (27.27%) websites met the understandability threshold, while none met the actionability threshold. Institution categories scored similarly in understandability (61.71%, 62.68%, 63.67%) among academic, private practice, and commercial health publishers respectively (p=0.9536). No readability or PEMAT score correlated with search rank.

Conclusion: Online shoulder arthroscopy patient education materials score poorly in readability, understandability, and actionability. One website scored at the NIH and AMA recommended reading level, and 27.27% of websites scored above the 70% PEMAT score for understandability. None met the actionability threshold. Future efforts should improve online resources to optimize patient education and facilitate informed decision-making.

Level of Evidence: IV

Keywords: shoulder arthroscopy, patient education, health information, readability

INTRODUCTION

Advances in shoulder arthroscopy techniques have allowed the procedure to supplant open shoulder surgery as the preferred method for managing key pathologies such as shoulder instability, shoulder impingement, rotator cuff tears, and labral injuries.[1-4] Shoulder arthroscopy is less invasive and often performed on an outpatient procedure,[1] provides better visualization, reduces the risk of complications, and improves recovery time.[4] However, risks of the procedure include neurovascular injury, postoperative stiffness and pain, and positional complications such as cerebral hypoperfusion.[1,4] Furthermore, patient selection is critical for outpatient surgery to optimize outcomes and reduce the risk of complications requiring admission.[1] Patient education and patient selection is therefore a critical component of preoperative preparation.

The internet is an increasingly popular patient education resource, with 80% of internet users accessing health information online.[5] For patients undergoing surgical procedures, such as shoulder arthroscopy, the internet is an important source of information.[6] To maximize accessibility, the American Medical Association (AMA) and National Institutes of Health (NIH) recommend that health information be written at or below a six-grade reading level.[7,8] Readability of online health

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materials may be assessed utilizing validated readability algorithms, which assess word difficulty, quantity of sentences, and sentence length to determine corresponding grade levels.[9-11] While several studies using these algorithms have highlighted that online health information often exceeds the AMA and NIH's recommendations,[7,12,13] these readability indices are limited in their ability to capture other key components of comprehension. In response to these limitations and to better characterize health resources, the Patient Education Materials Assessment Tool (PEMAT) was developed to assess understandability and actionability of online materials.[14]

The aim of this study was to utilize the PEMAT and validated readability algorithms to quantify readability, understandability, and actionability of online shoulder arthroscopy patient education resources. We hypothesize that the existing shoulder arthroscopy resources will score poorly on the readability, understandability, and actionability metrics.

METHODS

Educational Materials

Patient education materials were identified using the Google™ search engine. Google™ search engine was utilized because Google™ searches comprised 88-92% of online search market share at the time of this study.[15,16] On 3/21/20, the average 12-month popularity of the following key words were compared using the Google Trends™ tool:[17] "shoulder arthroscopy," "shoulder scope," and "shoulder scope surgery." "Shoulder arthroscopy" resulted the highest search volume score and was chosen for our search term for material identification.

Two internal Google™ searches were independently performed on 3/21/20 and 3/23/20 (O.C.O., M.K.S.). The first 50 results were recorded. Earlier click-through-rate analyses demonstrate that roughly 70% or more of "clicks" are limited to the first 10 search results.[18-20] Previous PEMAT studies target the first 10 to 50 websites.[21-23] After comparing both searches, duplicate results were removed, the remaining resources were compiled into a unique list of websites. Exclusion criteria included: news articles; personal anecdotes; primarily audiovisual-based materials (videos); written for reference by health care professionals; peer-review journal studies; focused primarily on the advertisement of a product or service without patient education; articles without patient-oriented tone; or unrelated to shoulder arthroscopy. Audiovisual-based PEMs could not undergo readability analysis, and therefore were excluded. All search results not meeting exclusion criteria were included.

Analysis of Materials

Qualitative Analysis

Two reviewers subjected the included PEMs to content review. The qualitative analysis included: discussion of operative management including mention of a specific intervention (ex. rotator cuff repair); discussion of non-operative management; advertisement of a physician or group which completed the treatments described; discussion of general background information (anatomy, pathology, prognosis, risk factors); discussion of injury prevention; discussion of work-up or activities related to diagnosis/pre-operative management; discussion of post-operative management; discussion of complications and/or risks of operative management, and type of publisher (health information publication, academic practice, private practice). Advertisements of medical providers were defined as mention of a specific institution or group who provided the treatments described or a treatment related to shoulder pathology within the main text of the educational material.

Readability

Readability of PEMs was evaluated with multiple objective measures previously utilized in existing readability literature:[9,24-30] Flesch Reading Ease, Flesch-Kincaid Grade Level (FKGL), SMOG (Simple Measure of Gobbledygook) Grade, Coleman-Liau Index (CLI), and Gunning-Fog Index (GFI). Interpretation for each readability measure is described in Appendix 1. These were completed using open-source readability software (https://www.webfx.com/tools/read-able/check.php). Any text present on the webpage that was unrelated to patient education, including copyright, references, and links outside of main text, was excluded.

Understandability and Actionability

The understandability and actionability of print and audiovisual patient education materials has been reliably assessed using PEMAT, previously validated in existing literature.[9,28,29] Each material reviewed with the PEMAT scoring system produces an understandability score as well as an actionability score. Each score is scaled 0-100%, with a higher score signifying the more likely a patient is to understand the material, as well as the ability to act on the information presented. A score of 70% or higher is the standard for acceptable understandability and actionability.[14] Two reviewers (O.C.O., M.K.S.) individually reviewed each PEM for understandability and actionability using the PEMAT-P form.[31] Cohen's Kappa was used to determine interrater reliability. The magnitude of the kappa statistic was interpreted by criteria set by Landis et al.,[32] as these criteria were used by PEMAT developers and later evaluators to measure reliability of PEMAT scoring.[14,33]

Additional Statistical Analysis

Google™ search engine ranking determined by averaging the position at which the website appeared in the search from the two independently conducted queries. Correlation between variables including search ranking, readability, understandability, and actionability was determined using Spearman's rho. Statistical significance was defined as $p < 0.05$.

RESULTS

Two independent searches yielded 53 unique websites. A total of 44 websites (83.02%) met inclusion criteria. Exclusion reasoning for the nine sites involved: scientific articles, book chapters, or technique guides directed toward medical personnel (6), audiovisual materials (2); and registration of a clinical trial (1). Publication sources included 63.63% private practice (28/44), 20.45% commercial health information publishers (9/44), and 15.91% academic practice (7/44).

Qualitative Analysis

All resources contained content pertaining to operative intervention. The majority of materials (95.45%) included background information on shoulder anatomy, pathology, or risk factors. Eight websites discussed non-operative management, and even fewer described injury prevention (2/44, 4.54%). Of note, both resources describing injury prevention were published by private practitioners. All resources provided by health information publishers described potential complications, compared to 46.43% and 42.86% of those offered by private practice and academic institutions, respectively. Advertisements for physicians or groups providing the described surgical intervention were ubiquitous in materials provided by academic institutions and private practice, while relatively scarce on websites from health information publishers (1/9, 11.11%).

Readability

The mean FKGL was 11.68±2.78, corresponding to high school junior reading level. No mean readability score performed below a high school sophomore (10th grade) reading level, with the majority of scores rating above high school senior reading level (Table 1). Eight websites (18.18%) scored at the junior-high school reading level. Only one website scored at or below 6th grade reading level, describing postoperative instructions after shoulder arthroscopy. Health information publishers scored better on all readability measures compared to private or academic practice PEMs. No readability score correlated with Google™ search rank (ρ = -0.1628 – 0.0499).

Understandability and Actionability

Mean understandability and actionability scores were 63.02%±12.09 and 29.77%±20.63 across all resources, neither of which meet the PEMAT threshold of 70%. A total of 12 (27.27%) websites met or exceeded the PEMAT score threshold for understandability, while no website met the minimum threshold for actionability (Figure 1). The three publication source categories scored similarly in understandability, including 61.71%, 62.68%, and 63.67% for academic practice, private practice, and commercial health publishers, respectively. These were not statistically significant (p = 0.954). Although commercial health publishers scored highest in actionability (43.75%), it was well below the acceptable PEMAT threshold and approached but did not reach statistical significance (p = 0.062). No understandability (ρ = -0.0475) nor actionability (ρ = -0.0268) score was significantly associated with search result rank. Interrater agreement was 78.14%, with a Cohen's kappa of 0.56, indicating moderate agreement among raters.

DISCUSSION

The existing shoulder arthroscopy online patient education materials perform poorly on assessments of readability, understandability, and actionability, as exemplified by the current study. Previous studies have examined the readability of educational resources related to shoulder surgery, and have found a similar poor performance in readability.[34-37] Akinleye et al. compared readability of five common orthopaedic pathologies treated with arthroscopy, demonstrating the top

Table 1. Readability Measures

Readability Measure	Score (± standard deviation)	Correlation with search rank (ρ)
Flesch-Kincaid Reading Ease (FKRE)	45.12 (± 13.60)	0.0499
Flesch-Kincaid Grade Level (FKGL)	11.68 (± 2.78)	-0.0830
Simple Measure of Gobbledygook Grade (SMOG)	10.8 (± 2.42)	0.0146
Coleman-Liau Index (CLI)	12.23 (± 2.10)	0.0009
Gunning-Fog Index (GFI)	14.63 (± 2.76)	-0.1638
Automated Reading Index (ARI)	12.14 (± 3.38)	0.0009

Mean readability scores of online materials and correlation with search rank, in which no score performed below the reading level of a 10th grade student.

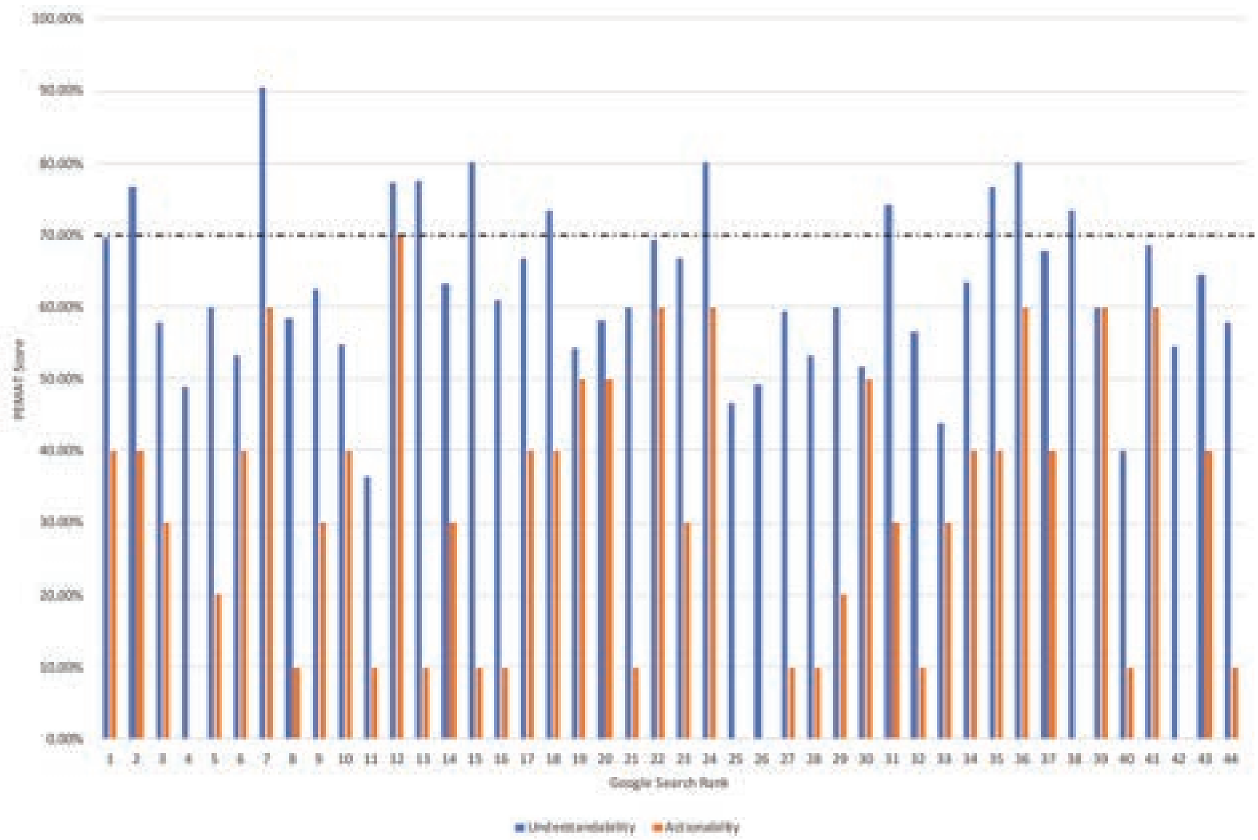

Figure 1. Understandability and Actionability by Google™ Search Rank. PEMAT understandability and actionability scores by website, in order of discoverability on Google™. Only 27.27% of websites meet or exceed the PEMAT threshold score for understandability, and no website met the score threshold for actionability.

ten websites providing education for "shoulder labral tear" and "rotator cuff tear" to exhibit a mean FKGL of 10.12 and 9.47, respectively.[34] The current study found a mean of 11.68±2.78 in the top 50 websites evaluated, demonstrating readability remains above the level recommended by the NIH and AMA. These studies cannot be directly compared, however, as they used related albeit different search terms.

The field of orthopaedic surgery has a relatively poor history of providing educational materials that meet current readability recommendations. Readability of patient resources published by The American Academy of Orthopaedic Surgeons (AAOS) was first evaluated in 2008, with only 2% of articles meeting a 6th grade reading level.[38] In 2015, Eltorai et al. reviewed 260/261 of PEMS provided by AAOS, finding 97% of those studied to exceed the 6th grade reading level recommend by the AMA and NIH, and 81% exceeding an 8th grade reading level, the average of U.S. adults at the time of the study.[39] In terms of progress, in 2016 Roberts et al. referenced the original Sabharwhal et al. 2008 study and reevaluated the online materials offered by AAOS, demonstrating minimal improvement in readability (3.9% of articles read at a 6th grade reading level, compared to 2% in 2008).[28] The mean FGKL had decreased to 9.3 from 10.4, however this continues to exceed the recommended reading level by three grades. Apart from the AAOS, the American Shoulder and Elbow Society education materials have also been evaluated, with shoulder arthroscopy related handouts scoring at collegiate reading levels. The pamphlet entitled "Arthroscopy of the Shoulder and Elbow" demonstrated FKGL, SMOG, CLI and GFI scores exceeding the reading level of a high school senior.[36] As these institutional resources are specifically designed to educate patients about the surgical process, it may sow concern in providers that utilize these materials, and thus these materials may not fulfill their intended purpose.

The current study found commercial health publishers (ex. WebMD™) provide materials that perform better on readability than academic or private practice health resources, though this did not reach statistical significance. Sood et al. previously compared PEMs specific to shoulder surgery published by medical institutions against those from non-institutional sources, and found a statistically significantly higher average readability score in information provided by medical institutions.[37] This seems counterintuitive, as medical institutions are involved in direct patient care, and many are also academic centers, to which they reasonably would be expected to communicate well with patients. However, Sood et al. refer to a study performed in 2008 which found doctors overestimate the reading level of patients frequently, which could lend an explanation to this phenomenon.[40] Many studies across orthopedic literature also demonstrate health literacy as an obstacle to patient understanding of orthopedic procedures. Regardless of source, the current study proved that the majority of the top Google™ search results perform poorly on readability, understandability, and actionability, which can have downstream effects in patient communication and understanding of their orthopedic conditions, as well as their surgical options.

Limitations

There are limitations to the study at hand. The study is based on a single query performed using a public search engine at a unique point in time, and arguably repeated searches at different time points may elicit unique results. This analysis also reflects the search results of one term ("shoulder arthroscopy") and may not reflect other search terms used which may be more colloquial (for example, "shoulder scope"). However, attempting to collect all associated terms and combine results would like provide heterogenous data that is difficult to interpret. The searches were performed after clearing search history, cookies, and cache in an attempt to remove any user bias from previous search history, but other modes of data analysis utilized by the search engine, e.g. location data, may not be addressed by these attempted preventative measures. Also, it is difficult to assess the current results in related to the field of literature, as each study selects different search terms, eliminating the ability to make a completely accurate direct comparison. The readability, understandability, and actionability measures utilized do not assess the content for medical accuracy, which is crucial to patient education. While the readability studies remain objective based on word content, the PEMAT-P analysis is subjective, relying on the evaluator to grade each resource to their discretion. This bias unfortunately cannot be eliminated, but the attempt to temper is exhibited by dual analysis by two authors. In addition, PEMAT, while a validated tool, is relatively unexplored in the current orthopaedic literature. Further study is needed to evaluate its use in relation to orthopaedic pathology.

CONCLUSION

Online patient education materials related to shoulder arthroscopy perform poorly on assessments of readability, understandability, and actionability. Only one of the top Google™ search results for "shoulder arthroscopy" meets the NIH and AMA recommended 6th grade reading level for the general public. Few resources met the PEMAT threshold for understandability, and none the threshold for actionability. These types of resources can leave patients with more questions than answers, or worse, the wrong answers. In order to better serve patients and increase overall health literacy, online resources should be designed to be cater to the literacy of the community at large.

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APPENDIX Table 1.

Appendix Table 1. Interpretation and Calculation of Readability Statistics

Statistic	Calculation	Interpretation
Flesch Reading Ease (FRE)	206.835 - 1.015 x (words/sentences) - 84.6 x (syllables/words)	90.1-100.0 = 5th-grade material
		70.1-80.0 = 7th-grade material
		50.1-60.0 = 10th-12th grade material
		0.0-30.0 = college graduate material
Flesch-Kincaid Grade Level (FKGL)	0.39 (words/sentences) + 11.8 (syllables/words) – 15.59	Estimates grade level of material
SMOG Readability Formula (SMOG)	1.0430 x square-root(30 x words with ≥3 syllables/sentences) + 3.1291	Estimates grade level of material
Gunning Fog Index (GFI)	0.4 (words/sentences + words with ≥3 syllables/words)	Estimates grade level of material
Automated Readability Index (ARI)	4.71 (characters/words) + 0.5 (words/sentences)	Estimates grade level of material
Coleman-Liau Index (CLI)	0.0588 (Letters per 100 words) – 0.3 (sentences per 100 words) – 15.8	Estimates grade level of material

PERI-OPERATIVE MANAGEMENT OF PERIACETABULAR OSTEOTOMY: A REPORT OF CURRENT PRACTICES FROM THE ANCHOR GROUP, SUPPORTING LITERATURE, AND AREAS FOR FUTURE INVESTIGATION

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ABSTRACT

Background: Periacetabular osteotomy (PAO) is a well-established surgical treatment for hip dysplasia, but very few studies report the impact of peri-operative management strategies on early pain and function. The purpose of this study is to describe peri-operative management variability among a group of experienced surgeons and review the literature supporting these practice patterns.

Methods: We surveyed 16 surgeons that perform PAO to document various aspects of peri-operative management at four stages: pre-operative, intra-operative, post-operative in the hospital, and at discharge. Our goal was to report current surgical pain management strategies, adjunct medications, type of anesthesia, deep venous thrombosis and heterotopic ossification prophylaxis strategies, initiation of physical therapy, and use of continuous passive motion (CPM). We reviewed current literature to identify studies supporting these peri-operative strategies and identify knowledge gaps that would benefit from further investigation.

Results: Of the 16 surgeons surveyed, 75% had been in practice greater than 10 years and most had not altered their post-operative protocol for more than 3 years. 15/16 surgeons felt that length of stay could be reduced at their institution with improved peri-operative pain management. 6/16 were considering or had already implemented outpatient PAO as a part of their practice. We found significant variability in the pain medications provided at all peri-operative stages. 14/16 utilized general anesthesia, and many utilized epidural or peripheral nerve blocks. 6/16 surgeons utilized surgical field block (also referred to as periarticular block). These surgeons advocated that surgical field block was an effective intervention with no/minimal complication risk. There is very little literature critically evaluating efficacy of these peri-operative management strategies for PAO.

Conclusion: There is significant practice variability in peri-operative management of PAO surgery. We report various strategies utilized by a group of experienced surgeons and review supporting literature. There are significant knowledge gaps in best surgical pain management strategies, adjunct medications, surgical field blocks, and use of CPM that need further investigation.

Level of Evidence: IV

Keywords: periacetabular osteotomy, hip dysplasia, peri-operative management, PAO, opioids, fascia iliaca block

INTRODUCTION

Periacetabular osteotomy (PAO) is a well-established treatment for pre-arthritic hip dysplasia in adolescents and young adults. At mid-term and long-term follow up, PAO delays progression to osteoarthritis and improves pain and function in the dysplastic hip.[1-9] Despite extensive reporting of clinical outcomes, there is limited investigation into to the efficacy of alternative peri-operative management strategies to reduce surgical pain and improve outcomes. There is substantial variability in practice patterns for pain management, venous thromboembolism (VTE) and heterotopic ossification (HO) prophylaxis, use of continuous passive motion machine (CPM), and initiation of formal physical therapy.

Recent effort has been dedicated to reducing reliance on opioid medications for peri-operative management of surgical pain.[10] Non-opioid pain medication strategies, surgical field blocks (peri-articular block), and early

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mobilization, are shown to be effective for many elective and non-elective orthopaedic surgeries.[11-14] Using these strategies, outpatient hip and knee arthroplasty is now common.[15] Despite advances in management of surgical pain, there are very few investigations assessing the impact of these interventions on early outcomes of PAO.[16-23] Additionally there is substantial variability in practice patterns for use of VTE and HO prophylaxis and CPM to initiate early motion. We need to report the variability in current practice patterns so that we can begin to investigate the efficacy of these interventions in clinical trials.

Our purpose is to report variability in current PAO peri-operative management by experienced surgeons. We aim to report medication prescribing patterns, type of anesthesia, use of non-opioid pain medications, and use of adjunct therapies to improve early outcomes. Additionally, we review current literature supporting these practice patterns and highlight knowledge gaps regarding the impact of these interventions. This review is designed to provide surgeons with a summary of current practice patterns and supporting literature to guide PAO peri-operative management.

METHODS

After institutional review board approval, we enlisted 16 surgeon members of the Academic Network of Conservational Hip Outcomes Research (ANCHOR) network to complete a survey describing current practice patterns for peri-operative management of PAO. The survey was distributed through Research Electronic Data Capture® (REDCap®) and is included as a supplemental attachment. The survey was completed in five sections: 1) general information about time in practice and interest in standardizing peri-operative management strategies, 2) pre-operative, day of surgery, pain management interventions, 3) intra-operative, 4) early post-operative while admitted to the hospital, and 5) discharge. The survey was designed to capture medications administered at each time point, alternative non-opioid medications utilized, type of anesthesia and blocks dispensed, initiation of physical therapy, use of CPM, and prophylaxis for VTE and HO. Our goal was to assess variability in peri-operative practice patterns. Literature review was performed for investigations evaluating these aspects of peri-operative management relevant for the discussion. We report proportions of survey responses and further statistical analysis was not necessary.

RESULTS

All 16 eligible surgeons completed the survey. The majority (12/16) were in practice for longer than 10 years and 12/16 had not changed their peri-operative protocol in more than 3 years. A two-night length of stay after PAO was most common and 15/16 felt that length of stay could be reduced with a standardized protocol (1 undecided). Most had reservations about considering outpatient surgery, although 6/16 were considering or had already implemented outpatient PAO as a part of their practice (Table 1).

Pre-Operative Protocols

The majority of surgeons used a multi-model approach for pre-operative pain and nausea management. Nearly half (7/16) administered non-steroidal anti-inflammatory medications (NSAIDs) preoperatively. The most commonly used NSAID was celecoxib. Tylenol, oral anti-emetics (metoclopramide or ondansetron), scopolamine, gabapentin, and opioids were used by less than half of surgeons (Table 2).

Intra-Operative Protocols

General anesthesia was used for PAO by the majority of surgeons (14/16). 5/16 of surgeons also used either epidural or spinal anesthetic. Peripheral nerve blocks were used by 6/16 surgeons. Peri-incisional or surgical field block (also referred to as periarticular block) was used by 6/16 surgeons. These surgeons reported the composition of the peri-incisional injections and there was minimal agreement in the composition, timing, or location of the injection. One surgeon gave an 8mg dose of dexamethasone intra-operatively (Table 3).

Post-Operative Protocols

Half (8/16) utilized a CPM and the majority continued CPM until discharge. One surgeon only used CPM for patients that underwent concurrent arthroscopy. Most surgeons reported initiating ambulation with physical therapy on post-operative day one. There was a wide variety in utilization of NSAIDs, acetaminophen, gabapentin, and opioids after surgery. The majority used ice or cold therapy (Table 4).

Discharge Protocols

6/16 surgeons recommended home CPM for their patients. One surgeon recommended home CPM only for patients that underwent concurrent hip arthroscopy. The average (standard deviation) for number of days CPM was used after surgery was 24 ± 6.4 days. The average recommended duration of CPM use was 3.3 ± 2.0 hours per day. Many utilized multi-model medications for pain control after surgery. 5/16 surgeons recommended altering management for patients with chronic pain and further recommendations varied from pre-operative referral to a pain specialist to "more likely to recommend an epidural" and "leave the epidural in place for another day" for patients with chronic pain issues (Table 5).

Table 1. PAO Practice and Perception

	n (%)
Time in clinical practice	
5-10 years	4/16 (25%)
11-20 years	7/16 (44%)
> 20 years	5/16 (31%)
How long using current peri-operative protocol?	
< 1 year	1/16 (6%)
1-2 years	3/16 (19%)
3-5 years	5/16 (31%)
> 5 years	7/16 (44%)
Estimated average length of stay after PAO surgery.	
1 night	2/16 (13%)
2 nights	9/16 (56%)
3 nights	4/16 (25%)
4 or more nights	1/16 (6%)
Is there potential to reduce length of stay after surgery?	
Strongly agree	8/16 (50%)
Agree	7/16 (44%)
Undecided	1/16 (6%)
Disagree	0/16 (0%)
Strongly Disagree	0/16 (0%)
Outpatient PAO possible?	
Strongly agree	2/16 (12%)
Agree	4/16 (25%)
Undecided	3/16 (19%)
Disagree	6/16 (38%)
Strongly Disagree	1/16 (6%)
Comments	Surgeons that expressed concerns about outpatient PAO specifically highlighted concerns about pain management including need for intra-venous pain medications for the first 12 hours, concerns about "patient satisfaction" and "patient and nursing expectations", "physical therapy availability", inability to arrange durable medical equipment in one day after surgery, and "long distance patient's travel for surgery".

This survey was completed by 16 surgeons in the Academic Network of Conservational Hip Outcomes Research (ANCHOR) group that perform periacetabular osteotomy.

VTE and HO Prophylaxis Protocols, Physical Therapy, and Education

14/16 surgeons used aspirin for VTE prophylaxis. Enoxaparin was used by 5/16 surgeons. 10/16 used pharmacologic HO prophylaxis, with naproxen being most common, but ketorolac, indomethacin, and celecoxib were also reported. One surgeon recommended adding naproxen for HO prophylaxis only in patients that underwent hip arthroscopy with PAO (twice daily for 10 days). Another surgeon recommended losartan for prevention of adhesions in patients that had undergone previous hip arthroscopy.

6/16 surgeons recommended pre-operative rehabilitation for their patients. Only one surgeon had implemented a formal pre-operative education course outside of the pre-operative visit for their patients. This education course was led by nursing staff and helped patients anticipate aspects of the hospital stay and post-operative protocol.

DISCUSSION

Long-term clinical outcomes of hip dysplasia treated with PAO has been extensively reported, but there is limited investigation into many aspects of peri-operative care. We surveyed a group of experienced surgeons who perform PAO and found substantial variability in practice patterns. Though all surgeons had well established protocols for peri-operative management, there were many different approaches to pre-operative education, anesthesia, pain management, physical therapy, and VTE and HO prophylaxis. We report current variability in practice patterns among these surgeons and potential areas for standardization.

There is very limited investigation into the efficacy of peri-operative management strategies for PAO surgery. This likely contributes to the substantial practice variability. Though surgeons who perform PAO have established protocols, there is little evidence supporting these practices. This discussion includes a summary of current literature on these interventions.

Peri-Incisional or Surgical Field Block (Periarticular Block)

Many surgeons in our group utilized a surgical field block for early post-operative pain control. Surgical field block has been shown to be effective in total joint arthroplasty[24] and fracture fixation[11,12] to reduce early post-operative pain and opioid utilization. However, there is limited investigation into the efficacy of a surgical field block in PAO surgery. Bech et al. performed a randomized controlled trial of surgical field block in 53 patients that underwent PAO.[17] A multi-hole sub-facial catheter was placed during surgery and subjects received an

Table 2. Pre-Operative Medications

	n (%)
Pre-operatively administered medications	
NSAIDs	7/16 (44%)
Ketorolac	1/7 (14%)
Ibuprofen	1/7 (14%)
Celecoxib	6/7 (86%)
Acetaminophen	11/16 (69%)
Anti-emetics	4/16 (25%)
Ondansetron	4/4 (100%)
Metoclopramide	1/4 (25%)
Gabapentin	5/16 (31%)
Opioids	6/16 (38%)
Oxycodone	4/6 (67%)
Not specified	2/6 (33%)
Scopolamine Patch	7/16 (44%)
No medications provided by protocol	4/16 (25%)

Non-steroidal anti-inflammatory drugs (NSAIDs).

Table 3. Type of Anesthesia and Blocks

	n (%)
Type of Anesthesia	
General Anesthesia	14/16 (88%)
Epidural	4 /16 (25%)
Peripheral Nerve Block	6/16 (38%)
Lumbar plexus block	3/6 (50%)
Fascia iliaca block	3/6 (50%)
Spinal Anesthesia	1/16 (6%)
Peri-Incisional or Surgical Field Block	6/16 (38%)
Components of injection reported by surgeon	Morphine 4g, ketorolac 30mg, epinephrine 1 mcg, Bupivacaine 20 ml of 0.5% injected in soft tissues around hip abductors, hip flexors and peri-incisional.
	Bupivacaine, epinephrine, clonidine, ketorolac injected around the sciatic, obturator, and pericapsular tissues
	Ropivacaine, epinephrine, and ketorolac and weight based
	Ropivacaine, ketorolac 15mg, epinephrine 0.2mg injection. 10 cc near pubic cut, 10cc near ischial cut, 10cc in abductors
	Morphine, epinephrine, ropivacaine, ketorolac. Total volume 100cc. Injection at the conclusion of the procedure. Infiltrated in all periarticular tissues.
	Marcaine without epinephrine, ketorolac

Table 4. Post-Operative Medications

	n (%)
Urinary catheter used for surgery.	15/16 (94%)
When is urinary catheter removed?	
Day of surgery	3/15 (20%)
Post-operative day 1	10/15 (67%)
Post-operative day 2	2/15 (13%)
First mobilization with physical therapy after surgery.	
Day of surgery	4 /16 (25%)
Post-operative day 1	12/16 (75%)
Use CPM in hospital?	8/16 (50%)
Day of surgery	6/8 (75%)
Post-operative day 1	2/8 (25%)
When is CPM stopped?	
Post-operative day 2	1/8 (12%)
On discharge	5/8 (62%)
Not specified	2/8 (25%)
Pain Medications	
NSAIDS	12/16 (75%)
Ketorolac	7/12 (58%)
Ibuprofen	3/12 (25%)
Naproxen	5/12 (42%)
Indomethacin	1/12 (8%)
Celecoxib	1/12 (8%)
Acetaminophen	11/16 (69%)
Anti-emetics	13/16 (81%)
Ondansetron	13/13 (100%)
Metoclopramide	2/13 (15%)
Gabapentin	4/16 (25%)
Hydroxyzine	2/16 (13%)
Opioids	15/16 (94%)
Oxycodone	12/15 (80%)
Hydromorphone	3/15 (20%)
Hydrocodone	3/15 (20%)
Morphine	2/15 (13%)
Tramadol	1/15 (7%)
Opioid PCA	4/16 (25%)
Ice or Cryotherapy	10/16 (63%)
Dexamethasone	1/16 (6%)

Continuous passive motion (CPM) and Non-steroidal anti-inflammatory drugs (NSAIDs).

Table 5. Discharge Protocols

	n (%)
Home CPM?	6/16 (38%)
Discharge Medications	
NSAIDS	11/16 (69%)
Ibuprofen	3/11 (27%)
Naproxen	6/11 (55%)
Indomethacin	1/11 (9%)
Celecoxib	1 /11 (9%)
Acetaminophen	9/16 (56%)
Anti-emetics	5/16 (31%)
Ondansetron	4/5 (80%)
Metoclopramide	1/5 (20%)
Gabapentin	3/16 (19%)
Hydroxyzine	2/16 (13%)
Opioids	16/16 (100%)
Oxycodone	12/16 (75%)
Hydromorphone	3/16 (19%)
Hydrocodone	4/16 (25%)
Morphine	2/16 (13%)
Muscle Relaxant	5/16 (31%)

Continuous passive motion (CPM) and Non-steroidal anti-inflammatory drugs (NSAIDs).

intra-operative injection and five post-operative injections at 10 hour intervals of either ropivacaine or saline. They did not find a difference in post-operative pain or opioid utilization up to four days after surgery with or without the local anesthetic.

None of the surgeons in our group agreed on the components of the surgical field block, but all utilized multi-modal injection. All used a local anesthetic and had variable additions of morphine, ketorolac, clonidine, and epinephrine. One surgeon performed the injections during the surgical exposure and the rest performed the injection after fascial closure. There may be benefits of pre-emptive injection, during the surgical exposure, to reduce narcotic requirements, especially when spinal anesthetic is not used for anesthesia. One surgeon recommended subfascial injection with a pediatric feeding tube after fascial closure to prevent loss of the injection volume. The efficacy related to both the composition and timing of surgical field block needs further investigation.

General Anesthesia, Epidural/Spinal, and Nerve Block

Though almost all surgeons utilized general anesthesia for PAO surgery (14/16), epidural anesthesia was also used by a quarter of our group. Use of epidural has been reported in the literature, but only related to timing of discontinuation and not efficacy of pain control with or without epidural. Cunningham et al. performed a change in practice study comparing discontinuation of the epidural catheter on post-operative day one versus day two.[19] Early discontinuation resulted in reduced pain, opioid usage, and length of stay. There was no difference in complications comparing early and late discontinuation. Spinal anesthetic leads to improved pain control and reduced opioid requirements compared to general anesthesia in primary and revision total hip arthroplasty,[25,26] but these results were not reproduced in the hip fracture population.[27]

Efficacy of fascia iliaca nerve block has been compared to epidural anesthesia for PAO. Pain, length of stay, mobilization, and opioid usage was compared for patients that received a fascia iliaca block with ropivacaine prior to surgical incision and patients that received a lumbar epidural placed prior to general anesthesia that remained in place until post-operative day two.[16] Patients with fascia iliaca block had reduced length of stay and improved mobility with similar pain scores and opioid usage. Efficacy of fascial iliaca block has been extensively demonstrated in geriatric patients with hip fracture,[28] but investigation after PAO surgery is limited to this single study.

The transversus abdominus plane block has also been described for pain management peri-operatively for PAO surgery. The block has been shown to reduce intra-operative opioid usage,[22] pain scores up to 24 hours after surgery, and opioid usage up to 6 and 24 hours after surgery.[29] Also, the advantages and disadvantages of single shot and continuous lumbar plexus block has been discussed without firm conclusions.[18] Lumbar plexus block and fascia iliaca block were used by some surgeons in our group. Transversus abdominus plane block use was not reported.

Dexamethasone

One surgeon in our group did utilize dexamethasone as part of their peri-operative protocol for PAO. Dexamethasone has been investigated as an intervention to reduce opioid usage and nausea, reduce length of stay, and improve range of motion after total hip and knee arthroplasty[30-32] though efficacy is not always consistent.[33,34] Investigation in patients undergoing PAO is limited. A randomized trial of 64 patients indicated for PAO surgery compared a single 8 mg dose to a 48 mg dose of dexamethasone immediately after induction of anesthesia.[23] They found reduced total opioid consumption in the first four days after surgery with higher dose dexamethasone, but did not see lower pain scores. They did not find a difference in complications but did not report long-term follow up. Further investigation is needed to test safety and efficacy in this population.

Managing Post-Operative Opioid Usage

Limiting post-operative opioid usage prevents sedative effects, allowing for better mobilization, while reducing medication side effects including nausea, pruritus, and urinary retention. Efforts to reduce opioid usage has been extensively documented in many orthopaedic surgeries including hip and knee arthroplasty.[35] There are limited reports of efforts to reduce opioid usage in PAO surgery. A quality improvement effort documented by Donado et al. assessed the impact of opioid prescribing guidelines for musculoskeletal pain in pediatric patients.[20] They specifically evaluated the impact of the guidelines on opioid prescribing patterns for PAO surgery. They found that a standardized opioid prescribing protocol result in 85% compliance with opioid prescriptions by the surgical team, less than 40 doses, improved from 43% prior to the protocol. Another study prospectively monitored opioid dosing up to six weeks after PAO surgery using an automated text messaging platform.[21] In 29 patients, they found that the platform effectively documented visual analog pain scale and opioid utilization. Post-operative pain peaked on day nine after surgery and average opioid usage steadily declined and stopped by six weeks after surgery.

Continuous Passive Motion, Venous Thrombus Embolism, and Heterotopic Ossification

8/16 surgeons prescribed CPM after PAO surgery. There was wide variation in the time each surgeon recommended utilization of CPM after surgery, and one only recommended CPM for patients that underwent hip arthroscopy with PAO. The goal of CPM is to initiate early motion after surgery to prevent adhesion formation and promote patient's confidence with range of motion. In patients that undergo total knee arthroplasty, CPM may improve range of motion early after surgery and prevent need for manipulation under anesthesia, but does not improve range of motion at long term follow up.[36]

10/16 surgeons prescribed NSAIDs for HO prophylaxis and 14/16 prescribed aspirin for VTE prophylaxis. Naproxen was most commonly prescribed for HO prophylaxis, but some surgeons utilized ketorolac, indomethacin, and celecoxib. The efficacy of these interventions has very limited previous investigation. One study assessed the impact of naproxen retrospectively on development of HO after hip arthroscopy and PAO surgeries.[37] Consistent with previous literature, HO formation was more common in male patients, but the overall rate of HO formation was very low, 1.5%. There was no difference in the incidence of HO with or without naproxen. Our literature review found no prospective studies evaluating the efficacy of CPM and VTE prophylaxis in PAO surgery.

Losartan was also recommended by one surgeon for patients that had undergone previous hip arthroscopy. Capsulolabral adhesions are a concern after hip arthroscopy that has been implicated as a cause of persistent pain.[38] Efficacy of losartan as not been assessed after PAO and is a target for future investigations.

CONCLUSION

Among 16 experienced orthopaedic surgeons that perform PAO surgery, we found significant practice variability in peri-operative pain management, anesthesia, physical therapy, and VTE and HO prophylaxis. Though these practices were well-established, the majority of surgeons agree that standardization of peri-operative management with evidence-based guidelines could improve early mobilization and reduce length of hospital stay. Future clinical trials should be dedicated to assessing the efficacy of these peri-operative interventions.

NOTE

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LAG SCREW EXCHANGE FOR IMPINGING LATERAL HARDWARE FOLLOWING INTRAMEDULLARY NAILING OF INTERTROCHANTERIC HIP FRACTURES – A CASE SERIES DEMONSTRATING EFFICACY

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ABSTRACT

Background: This study aimed to demonstrate the feasibility of lag screw exchange for painful lateral soft tissue impingement in patients initially treated with cephalomedullary nailing (CMN) for an intertrochanteric hip fracture.

Methods: Ten patients initially treated with CMN for unstable intertrochanteric fractures presenting with persistent pain and radiographic evidence of lag screw lateral migration were treated with exchange of original screw with shorter lag screw buried in the lateral cortex to prevent impingement. Patients were evaluated for resolution of pain and achievement of pre-fracture ambulatory status at 6 months post-operatively.

Results: Average age was 71.5 years (range: 62-88). Average length of follow-up was 24.9 months. All patients were female, with an average Charlson Comorbidity Index of 1.0 (0-3) and average Body Mass Index of 22.2 (16.0-31.1). Five of ten patients (50.0%) were treated with a cortisone injection in the trochanteric bursa prior to screw exchange with temporary pain relief. Five (50.0%) patients presented with limited range of hip motion. Five (50.0%) had history of prior or current bisphosphonate use. Average lag screw prominence was noted to be 12.2mm (7.9-17.6mm) on radiographic evaluation. Screw exchange was performed at an average of 18.6 months (5.4-44.9 months) following the index procedure. Average operating time of the screw exchange procedure was 45.3 minutes (34-69 minutes) and blood loss was <50mL in all cases. Replacement lag screws were an average of 16.0mm (10-25mm) shorter than the initial screw. All patients achieved complete or significant resolution of lateral thigh pain, and nine (90%) returned to pre-fracture ambulatory status by eight weeks after screw exchange. All patients remained pain free at six months after screw exchange.

Conclusion: Lag screw exchange is a efficacious method to address the mechanical irritation of laterally protruding lag screws following IT hip fracture, while also prophylaxing against subsequent femoral neck fractures.

Level of Evidence: IV

Keywords: lag screw, screw exchange, impingement, cephalomedullary nailing, intertrochanteric fracture

INTRODUCTION

Proximal femur fractures are the third most common orthopedic injury in adults, following distal radius fractures and metacarpal fractures.[1] An estimated 18% of women and 6% of men will sustain a hip fracture during their lifetime.[2] The vast majority are repaired surgically, with non-operative treatment reserved for non-ambulatory patients or those who cannot tolerate anesthesia. There are a variety of implants available depending on the fracture pattern. Intertrochanteric fractures, which account for roughly half of proximal femur fractures, are commonly fixed with either sliding hip screw (SHS) or intramedullary nail (IMN). While both methods demonstrate favorable outcomes, surgical treatment of intertrochanteric fractures has trended towards increasing use of IMN over the last several years,[3] with IMN usage rising from just 3% of cases in 1988 to 67% in 2006.[4] Advantages of IMN over SHS include better post-operative function, the potential to be minimally invasive, and more versatility.[3,4]

Most hip fracture repairs heal uneventfully, however unwanted outcomes and complications, including pain secondary to prominent implants, may occur.[5] While lateral lag screw slide is a critical aspect of fracture impaction and healing, the negative mechanical effects of excessive slide have been reported and attempts to minimize these effects have been sought. A randomized controlled trial reported a greater incidence of lateral lag screw slide with single lag screw devices compared to dual lag screw constructs, although this difference was not found to be significant.[6] Removal of painful instru-

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mentation following IMN is reported between 5.4% and 8.8%.[7,8] Excessive lateral lag screw migration has been attributed to a number of mechanical processes, including auto-dynamization, varus fracture collapse, and incorrect lag screw placement[9-12] and may cause persistent pain following intramedullary nailing.[5,6,13] Lang et al. reported lag screw lateralization between 3.5-14.5%, depending on the type of intramedullary nail used.[9] Not all cases of lateralization must be treated, but rather management is determined by patient symptoms.

Younger and independently ambulatory patients who undergo elective implant removal have higher self-reported quality of life scores post-operatively.[14] The majority of patients who undergo intramedullary nailing, however, are elderly females with pre-existing osteoporosis. The combination of poor bone quality and bone defects secondary to prior osteosynthesis may result in secondary fracture.[15-18] Thus, it seems practical to reinforce the femoral neck when removing symptomatic lag screws.[16]

The purpose of this case series is to demonstrate the feasibility of a heretofore undescribed approach to treatment of this problem. We report on ten patients with refractory lateral thigh pain following cephalomedullary nailing of unstable intertrochanteric hip fractures who were successfully treated with hip lag screw exchange.

METHODS

This study was approved by the University's Institutional Review Board. A single surgeon's records were reviewed for patients treated for unstable intertrochanteric fracture pattern (AO/ OTA types 31A1.3, 31A2 and 31A3).[20] Between January 1 2015 and March 1 2021, 170 patients were treated for an intertrochanteric hip fracture with a CMN (Gamma 3 Nail, Stryker Mahwah, N.J.) . Of the 170 patients who met criteria, 10 (6%) patients presented at some point in follow up with refractory lateral thigh pain following bony union who were treated with lag screw exchange. Demographic data, including patient age, gender, Charlson Comorbidity Index (CCI),[19] original fracture classification, BMI, history of cortisone injection treatment, and history of bisphosphonate use were collected. Preoperative radiographs were used to measure the amount of screw prominence, measured form the lateral cortex to the tip of the cephalad lag screw, with the measurement corrected using the known length of the lag screw (Figure 1). Operative data, including time from index procedure to lag screw replacement, change in length of lag screw, estimated blood loss, length of surgery, and type of anesthesia were collected as well.

All exchange surgeries were performed on an elective outpatient basis. All screw exchange surgeries were performed under regional block anesthesia. The previous proximal hip incisions were reopened, and muscle and soft tissue was elevated off of the set and cephalad lag screws. Once the set screw was loosened with a screwdriver, a guide wire was used to cannulate the existing lag screw. Using the appropriate driver, the lag screw was removed and measured, and a substitute lag screw placed over the wire. The length of the new screw was shorter than the original screw at least the length of the lateral protrusion. Because no further lateral slide was expected, the lateral edge of the new lag screw was buried in the lateral cortex of the femur to prevent subsequent soft tissue irritation (Figure 2). The final position of the new lag screw was confirmed with intraoperative fluoroscopy. Weightbearing status following this procedure was as tolerated. Patients were followed for a minimum 6 months following lag screw exchange.

RESULTS

All ten patients treated initially sustained an intertrochanteric fracture. Average follow-up for the cohort was 24.9 months. All patients were treated with an intramedullary nail with a single lag screw. Patients returned to the outpatient clinic with complaints of lateral thigh pain, point tenderness over the lag screw, decreased range of hip motion, or difficulty ambulating. Average age was 71.5 years (range: 62-88 years). All patients were female and healthy with an average CCI[19] of 1.0 (Range: 0-3). Body Mass Index (BMI) ranged from 16.0 to 31.1, with an average of 22.2. Five of ten (50.0%) patients had a history of prior or current bisphosphonate use. Five of ten (50.0%) patients were treated with cortisone injection in the trochanteric bursa prior to screw removal with temporary relief of pain prior to screw exchange. One patient was offered a cortisone injection but declined due to chronic steroid use. Radiographic evaluation demonstrated an average lag screw prominence of 12.2mm (Range: 7.9-17.6mm).

Patients underwent screw exchange at an average of 18.7 months following index surgery (range: 5.4 - 44.9 months). Average operative time was 45.3 minutes (range: 34-69). Estimated blood loss was <50mL in all cases. Lag screws were replaced with screws that were an average of 16.0mm shorter (range: 10-25mm). Replacement lag screws were inserted within the lateral cortex to prevent potential future femoral neck fracture and lateral impingement. All patients had uncomplicated postoperative courses. All ten patients experienced significant or complete resolution of pain by 8 weeks postoperatively. Nine of ten patients (90%) were able to return to their baseline ambulatory status prior to the original hip fracture by 8 weeks postoperatively. One patient still required the use of a cane at 8 weeks. No patients sustained a recurrent hip fracture nor any postoperative complication. All patients remained pain free at latest postoperative timepoint.

Figure 1. A 67 year-old female presented following IMN for unstable IT fracture with lateral thigh pain and difficulty ambulating. AP radiograph demonstrating lateralization of lag screw with 11mm of protrusion at 6 months postoperative. By 19 months post-operative the patient was symptomatic and could not tolerate her status and opted for ROH and screw exchange.

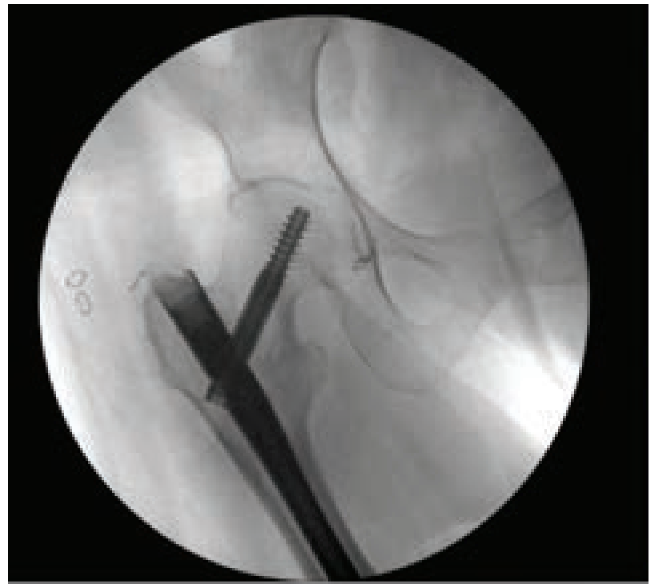

Figure 2. Intraoperative radiographs demonstrating lag screw exchange with 80mm screw buried within the lateral cortex.

DISCUSSION

We describe the concept of lag screw exchange for symptomatic thigh pain related to prominent lag screws following healing of an unstable intertrochanteric hip fracture. This situation was prevalent in a small number of patients following initial treatment. The condition tended to present itself in older females with low BMI's. These ten cases of elderly female patients experiencing persistent lateral hip pain following hip fracture intramedullary nailing were successfully treated with removal and exchange of lag screw following fracture healing to a shorter lag screw buried within the lateral cortex in each case. Following healing, no further fracture site compression and screw slide is expected and thus the ability to 'bury' the screw within the lateral cortex was now an option not available at initial surgery.

Implant exchange has been proposed as a method to treat nonunion[21,22] and infected instrumentation, but to our knowledge, there is no data on prophylactic screw exchange for soft tissue irritation following intramedullary nailing of proximal femur fractures. The goal of performing a lag screw exchange as opposed to a complete removal in these situations is to prevent subsequent femoral neck fracture in a weakened femoral neck in an osteoporotic hip. Elderly women are at increased risk for hip fractures, and patients with prior orthopedic trauma are more likely to sustain a fracture following implant removal.[15] Despite the potential complications, patients electing to undergo removal of painful implants report higher quality of life and higher satisfaction with care. All patients who underwent screw exchange experienced improvement or complete resolution of symptoms with treatment, with no complications following surgery.

Removal of femoral neck screws alone has been associated with significant complications, and is reported at a rate between 9.0-14.5%.[14,15,18] Barquet et al. presented 45 cases of femoral neck fracture following implant removal in healed trochanteric fractures due to persistent pain or difficulty with activities of daily living, and reported an overall incidence of 14.5% for complications following non-medically indicated (i.e. nonunion, infection, or implant failure) implant removal after intertrochanteric fractures.[15] This is consistent with other data reporting an incidence of spontaneous femoral neck fractures after implant removal of at least 15%.[11] Risk factors include pre-existing osteoporosis, local osteoporosis as a result of preloading and subsequent stress shielding by the fixation device, and implant removal from the femoral neck. The majority (87.5%) of these cases were spontaneous and unrelated to trauma. Ultimately, patients who sustain a secondary hip fracture after undergoing removal of hip instrumentation are likely to require hip arthroplasty.[11,15] Driessen et al. reported five patients with spontaneous femoral neck fracture following CMN removal.[11] Authors found that multifragmentary pertrochanteric fractures

(AO/OTA 31-A2) were associated with a greater degree of dynamization and lateralization and thus more pain. Another study reported 67 (11.2%) experiencing femoral neck fracture out of 598 initially treated with compression hip screw and subsequent implant removal.[18] They found that the inferior thread-to-cortex distance was significantly associated with femoral neck fractures and recommend careful selection of patients to undergo implant removal. Despite the challenges that implant removal alone may present, data demonstrates that patients are typically satisfied with the results, and many would opt for treatment again.[14]

Another strategy for treatment in these cases would be screw removal and void filling with calcium phosphate cement. Strauss et al. studied the use of calcium phosphate cement for augmentation for the femoral neck following dynamic hip screw removal.[23] Their biomechanical model demonstrated cement augmentation of osteoporotic cadaveric femurs to significantly increase the mean load to failure (femoral neck fracture) from 3995 N in untreated femurs to 4819 N in augmented femurs. The effect of cement augmentation was most pronounced in femurs with the lowest bone mineral density. This method of treatment may also decrease the incidence of complications such as refracture or spontaneous fracture following hip screw removal. This procedure is a good option for surgeons who deem screw exchange to be inappropriate but still wish to augment the femoral neck following screw removal.

Although all patients included in this series were treated with lag screw exchange following intramedullary nailing for intertrochanteric fractures, one may also apply these treatment principles to patients with femoral neck fractures treated with cancellous screws or intertrochanteric fractures treated with dynamic hip screw that present with painful lateral instrumentation.

CONCLUSION

We used static lag screw exchange as a method to treat painful lateral impingement following fracture healing of an intertrochanteric hip fracture in a series of older, healthy, active female patients who presented with persistent lateral thigh pain. The procedure is performed under regional anesthetic as an ambulatory case, with minimal blood loss and risk for complication. The described technique addresses the inciting mechanical irritation while also prophylaxing against subsequent femoral neck fractures. We propose that screw exchange is a reasonable alternative to screw removal alone in patients experiencing persistent pain who are at risk for recurrent hip fracture.

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PREOPERATIVE CT SCAN IS NOT ASSOCIATED WITH SHORTER SURGICAL TIME OR IMPROVED PATIENT OUTCOMES FOR TRIMALLEOLAR ANKLE FRACTURES

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ABSTRACT

Background: Posterior malleolar involvement can drastically affect patient outcomes. Literature has supported the use of preoperative Computed Tomography (CT) to assess posterior malleolar fracture morphology. The purpose of this study is to determine whether preoperative CT is associated with significant improvement in surgical time, postoperative complications, reoperation rates in trimalleolar ankle fractures. Surgeons were also asked to complete survey regarding use of CT scans to gauge utility preoperatively.

Methods: Adult patients with trimalleolar ankle fractures who underwent operative fixation between 2018-2020 were retrospectively reviewed. Primary outcomes included surgical time, postoperative complications, and reoperations. Secondary outcome was presence of posterior malleolar fixation. 15 surgeons who performed ankle ORIF were surveyed to gain information regarding why or why not preoperative CT scan was obtained.

Results: 288 patients with trimalleolar ankle fractures were included, 94 had preoperative CT scans (32.6%). No significant differences found in patient age, gender, BMI, smoking status between the groups that did and did not have preoperative CT scan. No significant differences were observed in AO/OTA classification between groups. Average surgical time was significantly higher in group that received a preoperative CT (114 without CT vs. 145 with CT, $p<0.05$). Complications (10.3% no CT vs 7.4% with CT, $p=0.55$) and reoperations (6.7% without CT vs. 7.4% with CT, $p=0.16$) not significantly different between groups. No significant difference was observed in rate of posterior malleolus fixation between groups (43.8% without CT vs 39.4% with CT; $p=0.52$). Of surveyed surgeons, 87% reported they don't routinely obtain preoperative CT scan for trimalleolar ankle fractures. Most common reasons for preoperative scans were deciding on approach/positioning, assessing for impaction, determining the size of the posterior malleolus.

Conclusion: Although preoperative CT scans are obtained in one third of patients with operative trimalleolar ankle fractures, we did not find an improvement in surgical time, complications, and reoperation.

Level of Evidence: III

Keywords: trimalleolar fractures, ankle, ct scan, patient reported outcomes, preoperative, surgical time, complications, reoperation

INTRODUCTION

Ankle fractures are a commonly treated fracture, with an annual incidence of >100 per 100,000 respectively.[2,7,8] Certain variants of these fractures involve the posterior rim of the distal tibial joint surface, commonly referred to as the posterior malleolus. The posterior malleolus is involved in 7-44% of ankle fractures.[2,6] Injury to this area of the joint can drastically affect patient outcomes.[3,4,6]

The management of posterior malleolus fractures has been an area of disagreement and evolution in the orthopedic community.[2] Additionally, there are concerns about the ability of plain radiographs to adequately characterize posterior malleolar fragments, specifically with regards to size.[2,6,9] Specifically, with posteromedial posterior malleolar fragments (Haraguchi type II) plain radiographs may misjudge the articular involvement, comminution, and impaction.[12,14] Due to these concerns, Computed Tomography (CT) scans are commonly used to help further characterize the size and morphology of these fracture fragments in addition to the degree of

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marginal impaction.[2,10-11,15] Though the exact role of the preoperative CT in surgical planning remains unclear, there is increasing literature to support its use in ankle fractures.[2,4,14]

Despite the benefit of a more accurate assessment of posterior malleolar morphology, there is no literature that demonstrates the intra and postoperative benefits of obtaining this scan. Therefore, it is the aim of our study to determine whether a preoperative CT scan is associated with a significant improvement in reoperation rates, surgical time, or postoperative complications. By doing this, we can better assess whether imparting the cost and radiation associated with a preoperative CT scan is translated into better patient outcomes and decreased operative time. This information has the potential to impact CT utilization in the treatment of ankle fractures with an associated posterior malleolus.

METHODS

After institutional review board approval, a retrospective chart review was completed of adult ankle fractures that occurred over the period between 2018 and 2020 in our healthcare system utilizing CPT codes 27822 (trimalleolar ankle fracture fixation not including the posterior malleolus) and 27823 (trimalleolar ankle fracture fixation including the posterior malleolus fixation). Patients were included if they had at least 6 months of follow-up after operative fixation, had a rotational ankle injury with posterior malleolus involvement, and were 18 years of age or older. Patients were excluded if they had pilon fractures (characterized as 43C according to the AO/OTA fractures classification system) and those patients with fracture patterns that did not involve the posterior malleolus.[5]

Chart review was utilized to determine patient demographic data (age, sex, body mass index [BMI], smoking status, alcohol use), injury characteristics (mechanism of injury and Gustillo-Anderson open fracture classification), duration of follow-up, complications, reoperation rates, surgical times, and patient positioning. Ankle radiographs were reviewed and the fractures were characterized according to the AO/OTA classification by two independent reviewers. When there were disagreements, the radiographs were reviewed by the senior author.

Primary outcomes included complications and surgical time. Complications included re-operations within the study period and representations to the emergency department for evaluation of a surgical issue. Specifically, these other complications included superficial infections not requiring irrigation and debridement, postoperative pain, postoperative wound issues (not infection), and deep venous thrombosis. Surgical time was the time from incision to time of closure completion. Reoperations included those for infection, for implant removal and for revision surgery.

Patients were divided into two groups, those who received preoperative CT scans and those who did not. Fisher's exact test and paired t-tests were utilized to assess the primary outcomes as appropriate utilizing GraphPad software (San Diego, CA).

Additionally, a Qualtrics survey was delivered to surgeons whose patients were included in the retrospective study (Figure 1). These were used to assess if routine use of preoperative CT scan was used in trimalleolar ankle fractures and reasons for its use.

RESULTS

Two-hundred and eighty-eight patients with trimalleolar ankle fractures met inclusion criteria over this two-year period; the average follow-up period was 1.8 years. There were 216 (75%) female patients with an average age of 53 years (SD 17.4 years). Ninety-four patients (32.6%) received preoperative CT scans.

There were no significant differences in demographic characteristics between the two groups (Table 1). Patients with higher energy mechanisms were more likely to receive a CT scan (p=0.047). There was no difference in AO/OTA classifications between the two groups (Table 1).

Those without a CT scan had a significantly lower operative time (Table 2). There was not a significant difference in complication rates, or reoperation rates between those that received a preoperative CT and those who did not (Table 2). There was not a significant difference in rate of posterior malleolar fixation between the two groups (43.8% no CT vs 39.4% CT; p=0.52).

1. Do you usually get preoperative CT scans for trimalleolar ankle fractures?
   - Yes
   - No

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2. Do you usually get preoperative CT scans for trimalleolar ankle fractures?
   - Yes
   - No

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3. When you do get a preoperative CT scan for trimalleolar ankle fractures, what are the common reasons? (choose all that apply)
   - assess for impaction
   - assess for the size of the posterior malleolus
   - protocol
   - decide on approach/positioning
   - other
     - free text response
   - I do not get preoperative CT scans

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4. If there is anything else you would like to share about your use of preoperative CT scans for trimalleolar ankle fracture please comment below

Figure 1. Qualitrics Survey Questions and Responses.

Table 1. Patient Demographic Date and Injury Characteristics

	All (288)	No CT (194)	CT (94)	p value
Age (SD)	53 (17.4)	54 (17.4)	50 (17.1)	0.067
Male Sex	216	144	72	0.76
BMI	30.4 (7.0)	30.4 (7.0)	30.5 (7.0)	0.90
Smoker	35	24	11	1.0
Mechanism:				
High energy	106	64	42	0.047
Low energy	169	122	47	
AO/OTA:				
44B2.3	1	1	0	1.0
44B3.1	3	2	1	1.0
44B3.2	135	96	39	0.2
44B3.3	103	65	38	0.3
44C1.3	9	7	2	0.7
44C2.3	36	23	13	0.7
44C3.3	1	1	0	1.0
Open Fracture	4	3	1	1.0

CT, computed tomography; SD, standard deviation; BMI, body mass index.

Table 2. Patient Surgical Time, Presence of Posterior Malleolar Fixation, and Complications

	All	No CT	CT	p value
Surgical time in minutes (SD)	124 (66)	114 (64)	145 (65)	0.0002
Posterior Malleolar Fixation	122	85	37	0.52
Complications	32	20	12	0.55
Reoperation	21	13	7	0.16
Implant Removal	11	6	5	0.35
Infection	4	2	2	0.60
Revision	3	3	0	0.55
Fusion	4	3	1	1.0
Other	11	7	4	0.75

CT, computed tomography; SD, standard deviation.

Table 3. Positioning for Patients with Posterior Malleolar Fixation

	All (122)	No CT (85)	CT (37)	p value
Supine	26	16	10	0.47
Prone	61	46	15	0.11
Lateral	29	17	12	0.25

CT, computed tomography.

Table 4. Surgeon Response for Reasoning of Obtaining Preoperative CT Scan

Surgeon #	Surgeon response:
2	I get preop CT Scans selectively–it is not a yes or no answer. There are high energy patterns, atypical patterns in which I might want to obtain one.
3	I don't usually get them
4	Assess Fracture Morphology
7	Sometimes when I am using the CT to assess the size of the posterior malleolus fragment, it is to decide if it is worth fixing or fixable. To me the only reason to fix a smaller posterior malleolus fragment is to stabilize the syndesmosis. So if I do not think I can get reliable enough fixation of the fragment based on the CT scan then I might decide to not fix it at all and just place syndesmotic screws if necessary.

For those that had posterior malleolus fixation, 22.4% were positioned supine, 52.6% prone, and 25.0% lateral. There was no difference in patient positioning between those with a preoperative CT scan and those without (Table 3).

Of the 29 surveyed surgeons, 15 responded for a response rate of 52%. 13 (87%) responded “No” to preoperatively obtaining a CT scan for trimalleolar ankle fractures. 3 reported obtaining CT scans due to protocol, 10 would obtain to decide on approach/positioning, 8 would obtain to assess for impaction, 8 would obtain to assess for the size of the posterior malleolus, 2 would obtain for “other” reasons including free responses “teaching, research, location, look for pieces of comminution at the joint…assess for fragmentation”, 2 reported they do not get preoperative CT scans. When asked if there was anything else they would share on CT use in trimalleolar fractures, 4 free response answers were collected and are shown in table 4.

DISCUSSION

This study demonstrated that a preoperative CT translated into increased operative time without improvement in patient outcomes. Additional results demonstrate that there was not an increased rate of posterior malleolar fixation or alteration in patient positioning in those patients that underwent posterior malleolar fixation. This brings into question the utility of obtaining a CT scan for all patients with posterior malleolar involvement.

Previous studies have demonstrated that a CT scan will increase a surgeon's decision to fix the posterior malleolus and change surgeon operative approach or positioning in 16-44% of cases.[2,4] In the survey of OTA members completed by Gibson et al. there was a high rate of changes in operative technique/positioning for ankle fracture fixation after surgeons reviewed a CT scan.[4] Additionally, Kumar et. al studied the use of CT in malleolar ankle fractures and concluded that CT use changed management plan in 23% of cases versus obtaining radiograph alone.[13] This is contradictory to the findings in our study, which demonstrates that obtaining a preoperative CT scan did not increase the rate of posterior malleolar fixation or make a significant difference in patient positioning for patients undergoing fixation of their posterior malleolus.

It has been demonstrated in multiple studies that a preoperative CT scan can aid in fracture identification or help determine an underappreciated fracture morphology.[2,10-11] Despite this, our study demonstrates that even with a greater understanding of the fracture characteristics there was not an increased rate of fracture fixation. This is something surgeons should consider when making the decision to expose a patient to additional radiation and to increase the cost of their care.[1]

Literature has also demonstrated that obtaining a CT scan may aid in preoperative decision making and fracture characterization, however, this does not alter the intraoperative assessment of reduction when using fluoroscopy.[6] With increased understanding of the fracture morphology provided with CT the goal is to obtain better anatomic fixation.[6] This ideal would be difficult to prove without the addition of a postoperative CT to more clearly evaluate the reduction. In this study, the rate of postoperative complications (including revision fixation and conversion to fusion) were not significantly different between the two groups, which suggests that obtaining an adequate reduction was achieved even in those without preoperative CT scans.

Our survey results show that most surgeons (13/15 respondents) do not usually obtain preoperative CT scans for trimalleolar ankle fractures. This is lower than the 70% of surgeons reported in a prior survey study who did not report routine ordering of preoperative CT scans.[4] The most common indications to obtain a CT scan were to decide on approach/positioning, assess for impaction, and assess the size of the posterior malleolus. These reasons are supported by prior studies which demonstrate that a preoperative CT scan can help detect previously undiagnosed/occult fractures and better characterize the morphology and size of the posterior malleolus.[2,10-11,15]

The results of this study must be considered within the limitations of the study design. The retrospective nature of this study prevented a standardized method of determining which patients underwent CT. Due to this, there was likely selection bias as to who did or did not obtain CT scans, this could mean that those with more complex fractures or those with larger posterior malleolar fragments were more likely to undergo CT scans preoperatively. This study did not seek to determine the size of the posterior malleolar fragment preoperatively as the plain radiographs often do not clearly show the extent of the posterior malleolar segment and by design CT scans were not available on all patients. Additionally, we did not comment on the operative approach used for posterior malleolar fixation, only the positioning, which though this provides some insight as to what approach was used does not allow us to comment on this. Strengths of this study were the sample size and the ability to pull patients from a hospital system with many orthopedic surgeons, some which are trauma trained and practice at a level-1 trauma center and other locations which do not have fellowship trained orthopedic traumatologists. This study, unlike prior studies, looked to see whether the preoperative CT scan influenced the patient's postoperative course, which allows some new insight and for future research looking at whether the preoperative CT scan affects fracture reduction or patient reported outcomes.

Ankle fractures with the involvement of the posterior malleolus can be a challenging problem for orthopedic surgeons. Preoperative CT scans have been utilized for preoperative planning for trimalleolar ankle fractures, however, our study indicates that they do not change postoperative outcomes. Though it is known that these can help better characterize fracture morphology, it does not necessarily lead to changes in operative planning. With this in mind, surgeons should use their discretion when selecting patients to undergo preoperative CT scans and select the patient for which they believe a CT will help determine whether posterior malleolar fixation is warranted.

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TEMPORARY STABILIZATION OF TIBIA FRACTURES: DOES EXTERNAL FIXATION OR TEMPORARY PLATE FIXATION RESULT IN BETTER OUTCOMES?

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ABSTRACT

Background: Provisional stabilization of high-energy tibia fractures using temporary plate fixation (TPF) or external fixation (ex-fix) prior to definitive medullary nailing (MN) is a strategy common in damage control orthopaedics. There is a lack of comprehensive data evaluating outcomes between these methods. This study compares outcomes of patients stabilized with either TPF or ex-fix, and with early definitive MN only, assessing complications including nonunion and deep infection.

Methods: A retrospective review was performed on adult patients with tibia fractures treated with MN followed until fracture union (≥3 months) at a single level-1 trauma center from 2014 to 2022. Medical records were evaluated for nonunion and deep infection. Demographics, injury characteristics, and fixation methods were recorded. Significance between patients who underwent TPF and ex-fix was compared with a matched cohort of early MN using Pearson's exact tests, independent t-tests, and one-way ANOVA, depending on the appropriate variable..

Results: 81 patients were included; 27 were temporized with TPF (n = 12) or ex-fix (n = 15). 54 early MN cases defined the matched cohort. All groups had similar patient and fracture characteristics. The difference in rates of nonunion between groups was significant, with TPF, ex-fix, and early MN groups at 17, 40, and 11% respectively (p = 0.027). Early MN had lower rates of nonunion (11% vs. 40%, p = 0.017) and deep infection (13% vs. 40%, p = 0.028) compared to ex-fix.

Conclusion: Temporary ex-fix followed by staged MN was associated with higher rates of nonunion and deep infection. There was no difference in complication rates between TPF and early definitive MN. These data suggest that ex-fix followed by MN of tibia fractures should be avoided in favor of early definitive MN when possible. If temporization is needed, TPF may be a better option than ex-fix.

Level of Evidence: IV

Keywords: tibia fracture, external fixation, temporary plate fixation, open fracture, outcomes

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INTRODUCTION

Provisional stabilization of tibia fractures is sometimes performed for high energy fractures. Often this is performed in the setting of a severe soft tissue injury or open fracture, compartment syndrome, or a vascular injury.[1] In these situations, a two-stage approach beginning with temporary stabilization and ending with definitive medullary nailing (MN) can be employed. This method of temporary fracture stabilization is used in damage control orthopedics and aims to limit infections and expedite conversion to definitive fixation.[1-5]

External fixation (ex-fix) and temporary plate fixation (TPF) are two methods currently used by surgeons to provisionally stabilize and improve axial alignment for open tibia shaft fractures. Historically, external fixation has been the predominant method of temporary fixation for fractures of the tibia, but more recently, TPF has been used to achieve the same goal.[6] Previous work has suggested that both temporizing methods are safe when immediate definitive fixation is not an option, but it remains unclear whether there is a difference in long term clinical outcomes between the two techniques.[7,8]

Some surgeons have suggested that immediate definitive fixation of tibia shaft fractures with MN is safe in most circumstances and that temporary fixation of these injuries is rarely necessary. Recent studies found that tibia fractures definitively or temporarily treated with ex-fix may be associated with increased rates of complication when compared to early definitive MN.[9,10]

The purpose of this study was to compare complication rates among patients who underwent temporization surgery with either TPF or ex-fix for tibia fractures that were later definitively treated with MN, which then included a third group that was established as a matched cohort of similarly classified tibia fractures treated with early definitive MN only. The authors hypothesize that there would be no difference in complications between the TPF or ex-fix groups, but that the early definitive MN would result in fewer complications than ex-fix or TPF, defined by nonunion and deep infections rates.

METHODS

After receiving institutional review board approval, a retrospective review of all patients who underwent medullary nailing for a tibia fracture at a single Level-1 trauma center from 2014 to 2022 was conducted. Operative notes were used to determine whether patients received temporary stabilization with TPF or ex-fix prior to MN, and radiographs were used for confirmation. Patients under the age of 18, who had a pathologic fracture, were followed for less than 3 months (unable to assess fracture union), or that underwent both TPF and ex-fix simultaneously for provisional management were excluded from the study.

Once all temporary fixation cases from the initial search were identified, another cohort from the remaining cases that received early definitive MN was created by splitting cases into two groups: open or closed. These were then randomly arranged and sequentially reviewed to construct a matched cohort that mirrored the proportions of open versus closed fractures seen in the TPF and ex-fix groups. Importantly, these also maintained a comparable distribution of AO/OTA and Gustilo-Anderson fracture characteristics as seen in the TPF and ex-fix groups. The total number of cases in this matched cohort was determined by doubling the number of cases in the TPF and ex-fix groups combined, while using the same exclusion criteria.

Patient demographic and case-specific data including age at operation, sex, substance use history, diabetic status, smoking status, injury mechanism, and duration of temporary fixation and follow-up were recorded. Fracture characteristics including comminution and AO/OTA classification were documented for every fracture, along with Gustilo-Anderson type for open fractures. Recorded complications of interest included tibial nonunion and deep infection.

Statistical Analysis

Descriptive statistics were calculated for all continuous data in the TPF, ex-fix, and early MN groups, including age, follow-up duration, and duration of temporary fixation. These were compared using one-way ANOVA tests and significance was calculated with independent t-tests. All other categorical variables were described with percentages and compared using the Freeman-Halton extension of the Pearson's exact test for significance level. Statistical analysis was completed with commercially available software.

Nonunion

The determination of nonunion relied on clinical and/or radiographic evidence, or the diagnosis of nonunion charted by the attending surgeon following the patient. The criteria for diagnosis of nonunion were as follows: At ≥3 months post definitive fixation, (1) patients experienced motion or pain while stressing or fully weight bearing on the injured extremity; and (2) radiographs demonstrated the presence of fracture lines or absence of bridging callus.

Deep Infection

Deep infections were defined as those occurring anytime during follow-up that related to the inciting tibial injury or subsequent corrective surgery, which resulted in corrective surgery necessitating debridement, removal of hardware, revision, or amputation. At least one of the following criteria had to be met for diagnosis of deep infection: (1) abscess or sinus tract with direct communication to bone; (2) radiographs concerning for osteomyelitis; (3) positive deep tissue culture.

Temporary Fixation

Temporary fixation (stage 1) was the first of a two-stage operation that began with either TPF or ex-fix and ended with definitive MN (stage 2). For open fractures with extensive contamination and soft tissue or vascular damage, initial debridement, vascular repair, and plan for soft tissue coverage were completed by an interdisciplinary team of orthopedic, vascular, and plastic surgeons at stage 1 of the operation. Some tibia shaft fractures with severe comminution or extension into the proximal or distal metaphysis required supplemental fixation with dynamic compression plates (DCP) in addition to MN at stage 2 of the operation.

External Fixation

Ex-fix was performed >24 hours prior to definitive fixation with MN. The reasons for ex-fix included hemodynamic instability, comminuted open fractures, and soft tissue injury. Two patients underwent external fixation at an outside hospital. In all cases, at least one pin was inserted on each side of the fracture, and all fractures underwent definitive MN at the authors' home institution.

Temporary Plate Fixation

TPF was completed >24 hours prior to definitive fixation via MN. The reasons for performing TPF included hemodynamic instability, soft tissue swelling, or need for extensive wound exploration. TPF involved spanning the fracture with either a small or large fragment plate of appropriate length, grossly re-aligning the fracture, and subsequently securing the plate to the tibia in temporary bridge mode. The approach for open fractures utilized existing traumatic wounds whenever possible. All temporary plates were removed prior to definitive MN.

Exhibit 1 depicts a typical example of TPF followed by MN. The patient underwent temporary fixation due to hemodynamic instability and was found to have bilateral segmental pulmonary emboli. For TPF of the right tibia, small percutaneous incisions were made to pass a 4.5 mm 12-hole plate. The tibia was grossly realigned, and the plate was wired in the appropriate position and used as a reduction aid to control coronal translation. The right extremity wounds were closed primarily before transfer back to the ICU. After further resuscitation and stabilization, the provisional plate was removed, and definitive MN was performed.

RESULTS

485 patients were identified based on our criteria. After initial screening, we identified 30 patients who received temporary fixation. Two were treated with both TPF and ex-fix simultaneously and one had inadequate follow-up, so these patients were excluded (Figure 1). Of the remaining 27 patients, 12 were temporized with TPF and 15 with ex-fix. The remaining 455 MN cases consisted of 114 open fractures and 341 closed fractures. Of these, 54 were selected to define the early MN matched cohort.

A total of 81 patients were included for analysis. The mean age was 43±20 years. 78% were male (63/81), 26% were smokers (21/81), 7% were diabetic (6/81), and 27% endorsed substance abuse history (22/81). Mean duration of temporary fixation for the TPF and ex-fix groups were 13.2±10.6 and 10.5±12.6 days (range: 1-53) and there were no statistical differences for baseline characteristics in the three groups. All three groups had statistically comparable patient and injury characteristics (Tables 1 and 2), however, the mean follow-up duration of the TPF, ex-fix, and early MN groups was13.2±12.7, 26.2±23.7, and 12.7±12.3 months (range: 3-66, p=0.01), respectively.

Of all tibia fractures, 84% were comminuted (68/81) and 70% were open (57/81) (Table 2). At 84%, the most common AO/OTA fracture classification encountered was 42C. 19% of the open fractures were classified as

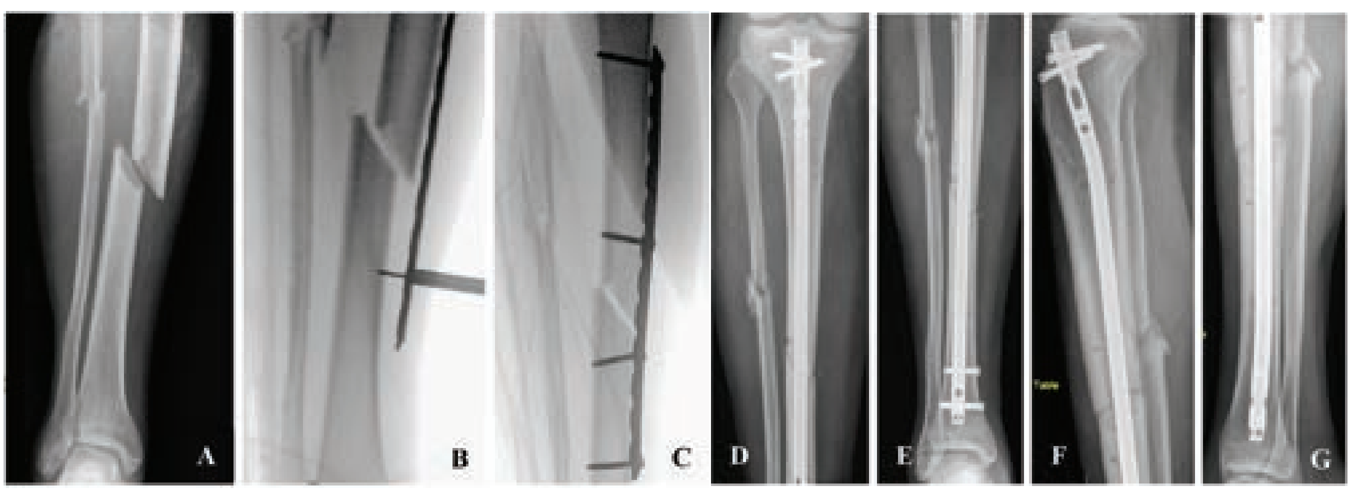

Figure 1A to 1G. Case example. The use of temporary plate fixation for stabilization of tibia fractures. These radiographs were obtained from a 72-year-old male who suffered a polytraumatic event after a high-speed motor vehicle collision. He sustained an aortic injury resulting in retroperitoneal hemorrhage in addition to multiple orthopedic injuries including open left femur, tibia, and fibula fractures as well as closed right tibia and fibula fractures. The preoperative anteroposterior (AP) radiograph (1A) depicts acute comminuted transverse fractures of the tibia and fibula. Intraoperative fluoroscopic images show positioning of the temporary plate (1B) followed by achievement of satisfactory alignment and attachment of plate with four bicortical screws (1C). Twenty-nine days later, the temporary plate was removed, and the tibia fracture was definitively treated with MN. Postoperative AP (1D, 1E) and lateral (1F, 1G) radiographs demonstrate interval healing and improved alignment of the proximal (1D, 1F) and distal (1E, 1G) tibia.

Table 1. Patient Characteristics by Fixation Method

		TPF (n = 12)	Ex-fix (n = 15)	Early MN (n = 54)	p-value
Age		44 ± 20	42 ± 9	43 ± 18	0.951
Male Gender		11 (92%)	10 (67%)	42 (78%)	0.340
Diabetes		1 (8%)	1 (7%)	4 (7%)	0.999
Smoking Status	Never	4 (33%)	5 (33%)	26 (48%)	
	Former	4 (33%)	6 (40%)	10 (19%)	0.074
	Current	2 (17%)	2 (13%)	17 (31%)	
Substance Use		3 (25%)	5 (27%)	14 (26%)	0.871
Temporary Fixation Duration	(days)	13.2 ± 10.6	10.5 ± 12.6	-	0.523
Follow-up Duration	(months)	13.2 ± 12.7	26.2 ± 23.7	12.7 ± 12.3	0.010

TPF = temporary plate fixation, Ex-fix = external fixation, MN = medullary nailing.

Table 2. Injury Characteristics by Fixation Method

		TPF (n = 12)	Ex-fix (n = 15)	Early MN (n = 54)	p-value
Mechanism	Ground level fall	-	1 (7%)	5 (9%)	0.335
	Fall from height	-	1 (7%)	5 (9%)	
	MVC	1 (8%)	5 (33%)	9 (17%)	
	MCC/ATV	1 (8%)	4 (27%)	15 (28%)	
	Auto vs. Peds	7 (58%)	4 (27%)	14 (26%)	
	Ballistic	1 (8%)	-	1 (2%)	
	Other	2 (17%)	-	5 (9%)	
Comminution		12 (100%)	12 (80%)	44 (81%)	0.306
Open Fracture		9 (75%)	10 (67%)	38 (70%)	0.877

TPF = temporary plate fixation, Ex-fix = external fixation, MN = medullary nailing, MVC = motor vehicle collision, MCC = motorcycle crash, ATV = all-terrain vehicle.

Gustilo-Anderson Type I (11/57); 11% were Type II (6/57), and 70% were Type III (40/57). All three groups were statistically similar with respect to fracture characteristics (Table 3).

In total, 17% of patients (14/81) resulted in nonunion. The difference in rates of nonunion between groups was significant, with TPF, ex-fix, and early MN groups at 17, 40, and 11%, respectively ($p = 0.027$, Table 4). A total of 20% of patients developed deep infections including 25% in the TPF group, 40% in the ex-fix group, and 13% in the MN group ($p = 0.053$, Table 4). The early MN group had significantly lower rates of nonunion (11% vs. 40%, $p = 0.017$) and deep infection (13% vs. 40%, $p = 0.028$) compared to the ex-fix group (Table 5). There was no significant difference in nonunion or deep infection between the TPF and ex-fix groups, or in complication rates between the early MN and TPF groups (Table 5).

DISCUSSION

In this single-center retrospective study, the authors compared complication rates between temporary external fixation or temporary plate fixation versus early definitive medullary nailing in the management of high energy tibia fractures. The major findings were that external fixation followed by later medullary nailing was associated with a higher risk of nonunion and deep infection when compared to early definitive medullary nailing. There was no difference in complication rates between temporary plate fixation and early definitive nailing.

Temporary plate fixation has been described more recently in the literature, but information regarding its safety and efficacy is sparse. Some studies suggest TPF may be superior to ex-fix,[7,8] but it remains unclear whether ex-fix or TPF is the better method of temporary stabilization, or if these temporizing methods result in significantly worse outcomes when compared to early definitive MN of tibia fractures.

Table 3. Fracture Classification by Fixation Method

		TPF	Ex-fix	Early MN	p-value
AO/OTA	42A	1 (8%)	1 (7%)	9 (17%)	0.632
	42C	11 (92%)	13 (87%)	44 (81%)	
	43B	-	1 (7%)	1 (2%)	
Gustilo-Anderson	Type I	2 (22%)	1 (10%)	8 (21%)	0.883
	Type II	-	1 (10%)	5 (13%)	
	Type III	7 (78%)	8 (80%)	25 (66%)	
	IIIA	3 (43%)	5 (63%)	20 (80%)	0.118
	IIIB	3 (43%)	1 (13%)	4 (16%)	
	IIIC	1 (14%)	2 (25%)	1 (4%)	

TPF = temporary plate fixation, Ex-fix = external fixation, MN = medullary nailing.

Table 4. Complication Rates Compared to Fixation Method Overall

	Fixation method(s)	Rate	p-value
Non-union	Early MN	6 (11%)	0.027
	Ex-fix	6 (40%)	
	TPF	2 (17%)	
	Overall	14 (17%)	
Deep infection	Early MN	7 (13%)	0.053
	Ex-fix	6 (40%)	
	TPF	3 (25%)	
	Overall	16 (20%)	

TPF = temporary plate fixation, Ex-fix = external fixation, MN = medullary nailing.

Table 5. Complication Rates Compared to Fixation Method by Pairing

	Fixation method(s)	Rate	p-value
Non-union	Early MN vs. ex-fix	12 (17%)	0.017
	Early MN vs. TPF	8 (12%)	0.449
	Ex-fix vs. TPF	8 (30%)	0.186
Deep infection	Early MN vs. ex-fix	13 (19%)	0.028
	Early MN vs. TPF	10 (15%)	0.259
	Ex-fix vs. TPF	9 (33%)	0.343

TPF = temporary plate fixation, Ex-fix = external fixation, MN = medullary nailing.

In a 2017 retrospective study, Whiting et al. compared complication rates between a cohort of patients receiving damage control plating (n = 9) or ex-fix (n = 11) for temporary fixation of open tibia fractures. They found no difference in complication rates and determined that TPF was quicker and less expensive than ex-fix.[7] Another retrospective study conducted by Fowler et al. in 2019 concluded that TPF was at least as safe as ex-fix and may even reduce the long-term rates of deep infection in their cohort of Gustilo-Anderson type IIIB tibia fractures.[8] Similar to present literature, our study demonstrated that TPF had less complications compared to ex-fix for temporary stabilization.

More recently, Bunzel et al. observed an infection rate of 32% for tibia fractures treated with ex-fix prior to MN in a 2023 retrospective study. They recommended avoiding the use of ex-fix for temporary fixation whenever possible and limiting time spent in ex-fix to the shortest duration necessary.[9] Furthermore, a systematic review of 17 studies by Turley et al. found that the rates of tibial nonunion (9.7%) and infection (8.1%) were low in their cohort of 1850 patients receiving early MN for open tibia shaft fractures.[11] These results are agreeable with our study findings. Our study adds supporting data to a growing body of evidence suggesting that TPF may be the better alternative to ex-fix for temporary stabilization of tibia fractures and that early definitive medullary nailing should be considered whenever possible.

This study is limited by the nature of it being retrospective. Some patients did not attend all follow-up visits unless they were symptomatic. However, the authors of this study used adequate follow-up approaches for accurately reporting outcomes, aligning with established standards for orthopedic trauma follow-up protocols.[12,13] Secondly, some cases involving severely comminuted tibia shaft fractures with extension into the metaphysis were treated with MN and supplemental DCP. It was not possible to control for this treatment approach in our study. Finally, the sample sizes for the TPF and ex-fix groups were relatively small; consequently, the study may lack the statistical power to discern differences between the two temporary techniques. This limitation is mitigated by the positive results observed when separately comparing the TPF and ex-fix groups to the matched early MN cohort. Further prospective and larger comparative multi-center studies may be beneficial in providing more robust insights into the superiority of a particular treatment approach.

CONCLUSION

In this present study, temporary external fixation of high energy tibia fractures followed by staged medullary nailing was associated with a higher risk of nonunion and deep infection compared to early definitive medullary nailing. There was no difference in complication rates between temporary plate fixation and early definitive medullary nailing. These data suggest that external fixation followed by medullary nailing of tibia fractures should be avoided when possible. In cases requiring temporization, damage control plating may be a better option than external fixation. Early definitive intramedullary nailing should also be considered as a viable treatment option.

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