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CANCER IN ORTHOPAEDIC SURGEONS: RESULTS OF AN AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS (AAOS) SURVEY

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ABSTRACT

Background: There is a currently limited data regarding cancer risk in Orthopaedic Surgeons. This study summarizes a survey on cancer prevalence in orthopaedic surgeons.

Methods: A cancer prevalence survey was emailed to all 23,370 members of the American Academy of Orthopaedic Surgeons (AAOS).

Results: 1826 (7.8%) AAOS members responded to the survey. 291 respondents (15.9%) have been diagnosed with cancer. The average age of those with cancer was 66 years, while the average age of those without cancer was 56 years ($p<0.001$). The most common cancers were skin cancer (9.58%), prostate cancer (5.11% of men), and breast cancer (2.4% of women). Screening colonoscopy had been performed in 129/203 (63.5%) surgeons between the ages of 50 and 55 years. We were unable to demonstrate an association between specific types of cancer and orthopaedic specialty. 36% of those aged 50-55 years had not undergone screening colonoscopy.

Conclusion: This study highlights the overall 15.9% prevalence of cancer and 9.58% prevalence of skin cancer in all orthopaedic surgeons; the 5.11% prevalence of prostate cancer in male orthopaedic surgeons; and the 2.4% prevalence of breast cancer in female orthopaedic surgeons who responded to the survey. There is room for improvement in routine screening for prostate cancer (men), breast cancer (women) and colon cancer (both).

Level of Evidence: IV

Keywords: cancer, orthopaedic surgeons, occupational hazard

INTRODUCTION

Hospital personnel are exposed to multiple occupational hazards throughout their career, such as radiation exposure,[6] traumatic stress,[1] and infectious disease.[16] The potential health risks associated with these hazards have motivated several research efforts in identifying how specific risks impact the health outcomes of hospital personnel. However, many of these studies have focused on the relationship between occupational hazards and health outcomes for certain healthcare professionals, such as nurses and social workers,[1,12] or specialists who are presumed to have a higher propensity for hazard exposure, such as radiologists.[13] To the best of our knowledge, the associations between occupational hazards and health outcomes for orthopaedic surgeons have not received much attention. In particular, there are relatively few studies that consider associations between occupational hazards and risk of cancer for orthopaedic surgeons.[10,12,13] These associations could be substantial given that orthopaedic surgeons regularly experience radiation exposure and endure long work hours, which may cause a predisposition to specific types of cancer.[4,5,7,8,18] Consequently, the objective of this study is to evaluate the rate and characterize the types of cancer amongst orthopaedic surgeons.

METHODS

Data Collection

We developed a cancer risk survey to identify associations between different types of cancers and the demographics of orthopaedic surgeons. The survey was designed to determine the following: (a) the percentage of respondents who had different types of cancer; (b) the associations between surgeon demographics (years of practice, age, specialty, and gender) and cancer prevalence; (c) the association between cancer occurrence and the subsequent continuation of work as an orthopaedic surgeon; and (d) the association between compliance

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with radiation precautions (such as the use of fluoroscopy and lead use) and cancer incidence. The survey was also designed to assess adherence to routine cancer screening tests. To ensure the quality and clarity of the survey questions, one author developed them initially. Each member of the group then individually reviewed the questions to provide clarification and ensure that the response options would yield useful information.

Once the survey design was finalized, an email invitation to complete the survey was sent to all 23,370 members of the American Academy of Orthopaedic Surgeons (AAOS). This invitation was extended to individuals from every category of membership, including Candidates, Candidates in fellowship, Active Fellows (FAAOS), and Emeritus Fellows. The survey was first emailed on March 21, 2021, and two reminder emails were sent on March 28, 2021 and April 5, 2021. The survey was closed after April 12, 2021. On average, participants required approximately seven minutes to complete the survey.

We note that this cancer risk survey was merged with another survey that included questions regarding non-cancerous occupational hazards of orthopaedic surgeons before it was emailed to AAOS members. This paper will report only the findings related to cancer.

Statistical Analysis

Statistical analyses consisted of t-tests and chi-square tests where applicable, with statistical significance set at $p = 0.05$. The likelihood ratio test for logistic regression between a null model and a model with a parameter of interest was used to determine whether or not the effect of continuous demographic information (such as age) had a statistically significant association on categorical outcomes (such as whether or not the respondent was diagnosed with cancer).

RESULTS

A total of 1,826 individuals completed the survey, which indicates a 7.8% response rate among 23,370 AAOS members (Table 1).

Prevalence and types of cancer

Out of the total 1,826 respondents, 291 individuals (15.9%) reported that they have been diagnosed with cancer. The most common types of cancers reported were skin cancer (9.58%), prostate cancer (5.11% of men), and breast cancer (2.4% of women), as summarized in Table 2.

59 of these respondents reported having genetic cancer syndromes. 24 had BRCA (BReast CAncer gene)1 or BRCA2 mutation, 8 had FAP (familial adenomatous polyposis), 4 had Lynch syndrome, 1 had multiple endocrine neoplasia, 3 had more than one genetic cancer syndromes, and 24 had “other” genetic cancer syndromes.

Table 1. Demographics of Orthopaedic Surgeons With Cancer and Without Cancer

Demographic	Surgeons with Cancer	Surgeons without Cancer	Total
Total Respondents	291 (15.9%)	1,535 (84.1%)	1,826
Average Age (yrs.)	66	56	57.67 (±12.63)
Sex			
Male	264 (18.1%)	1,198	1,462
Female	22 (13.1%)	146	168
Career Stage (years in practice)			
0-5	0 (0%)	22	22
6-10	2 (1.7%)	119	121
11-15	5 (2.9%)	169	174
16-20	12 (7.8%)	141	153
21-25	27 (12.5%)	189	216
25+	245 (25.6%)	711	956
Cases with Fluoroscopy	28.56%	36.1%	N/A
Use of Lead Garments			
Every Time	177 (60.8%)	835 (61.7%)	1012 (61.5%)
Most of the Time	51 (17.5%)	293 (21.6%)	344 (20.9%)
Other	63 (21.6%)	226 (16.7%)	289 (17.6%)
Smoking Status			
Current	1 (0.34%)	8 (0.59%)	9 (0.55%)
Former	44 (15.1%)	91 (6.7%)	135 (8.2%)
Never	246 (84.5%)	1,253 (92.7%)	1,499 (91.2%)

*Total counts differ due to instances of unanswered questions on some surveys.

Relationship of age and cancer diagnosis

The average age of those who completed the survey was 57.67 years (SD 12.63). The average age of those who had been diagnosed with cancer was 66 years while the average age of those without cancer was 56 years ($p<0.001$). The average age at the time that cancer was detected was 54 years (Table 3).

Relationship of career stage to cancer

There was a strong relationship between years in practice and prevalence of cancer. The prevalence of cancer for individuals with 0-5 years of practice was 0% (0/22), with 6-10 years was 1.6% (2/121); with 11-15 years was 2.87% (5/174); with 16-20 years was 7.84% (12/153); with 21-25 years was 12.5% (27/216); and with more than 25 years was 25.63% (245/956) ($p < 0.00001$).

Table 2. Cancer Types and Prevalence in Orthopaedic Surgeons

Cancer Type	Cases	Overall Prevalence (%)
Skin	175	9.58
Basal Cell CA (41%)	71	
squamous cell CA (29%)	51	
melanoma (24%)	43	
other (6%)	10	
Prostate	75	4.11 (5.11 % of men)
Genitourinary	24	1.31
Renal	10	
Urothelial	9	
Testicular	5	
Colorectal	22	1.20
Gastrointestinal	21	1.15
Hematologic	10	0.55
Head/Neck	6	0.33
Breast	4	0.22 (2.4 % of women)
Bone/Soft Tissue	3	0.16
Chronic Leukemia	3	0.16
Lung	3	0.16
Non-Hodgkin's Lymphoma	2	0.11
Neuroendocrine	2	0.11
Gynecologic (both were cervical)	2	0.11

Specialty vs cancer and type

We were unable to demonstrate an association between specific types of cancer and orthopaedic specialties. Skin cancer was the most prevalent type of cancer diagnosis for every orthopaedic specialty. General Orthopaedists displayed a higher prevalence for cancer diagnosis compared to other types of specialties (21.8 % vs 15.9%), but this difference was not statistically significant (p = 0.08) (Table 4). We note that the population of General Orthopaedists who completed this survey was relatively older than populations of other specialists (average age 64.89 years vs 56.32 years for all others; 58.71 for all orthopaedists).

Gender vs cancer type

Of the 1,826 total respondents, 1462 individuals identified as male: 264 of these men (18.1%) had been diagnosed with cancer. Additionally, 168 respondents identified as female, with 22 women (13.1%) reporting a cancer diagnosis. There were 196 individuals who did not disclose their gender, and among them, five individuals (2.6%) reported a cancer diagnosis.

Table 3. Cancer Types and Present Age

Cancer Type	Average Age (years)
Skin Cancer	53
Prostate Cancer	60
Genitourinary	54
Gastrointestinal	55
Colorectal	55
Hematologic	55
Head and Neck Cancer	51
Breast Cancer	51
Bone and Soft-tissue cancer	61
Lung Cancer	56
Neuroendocrine Cancer	38
Gynecologic Cancer	41

Table 4. Orthopaedic Specialty and Cancer Prevalence

Specialty	Cancer	Surgeons	Prevalence
Adult Reconstruction	82	417	17.4%
Spine	22	159	13.8%
General	109	499	21.8%
Pediatric Orthopaedics	28	118	23.7%
Orthopaedic Trauma	37	223	16.6%
Hand	36	261	13.8%
Shoulder and Elbow	35	219	16.0%
Foot and Ankle	14	112	12.5%
Oncology	5	47	10.6%
Sports	69	415	16.6%

Prostate cancer was present in 75/1462 men (5.1% prevalence), while breast cancer was reported by 4 out of 168 women (2.4% prevalence), as shown in Table 2.

Diagnosis of cancer and association with key career decisions

When participants were asked if their cancer diagnosis and/or treatment influenced their decision to retire, 22/268 (8.2%) said yes. The average age of people who replied that it did influence their decision to retire was 69.67 years vs 67.13 years for those who replied that it did not influence their decision (p=0.45).

25/287 participants diagnosed with cancer (8.7%) applied for disability after their diagnosis. Four individuals who had cancer did not respond to this question.

Fluoroscopy use and cancer incidence

Individuals who have been diagnosed with cancer reported that they used fluoroscopy in an average of 28.56% of their surgical cases. Those without cancer reported that they used fluoroscopy in 36.1% of cases. This association was not statistically significant (p=0.077).

Use of protective lead garments vs prevalence of cancer

In surgical cases requiring fluoroscopy, 177/291 surgeons who have been diagnosed with cancer (60.8%) wore lead garments for every surgery, while 51 out of 291 surgeons (17.5%) wore lead garments for most surgeries.

For surgical cases requiring fluoroscopy, 835/1354 (61.7%) people without cancer used lead garments all of the time and 293/1354 (21.6%) wore lead garments most of the time.

Use of protective lead garments vs prevalence of thyroid disease

In surgical cases requiring fluoroscopy, 73/110 (66.4%) surgeons with thyroid disease wore lead garments all of the time and 19/110 (17.3%) wore them most of the time.

Among individuals without thyroid disease, 934/1534 respondents (60.9%) used lead garments all of the time and, 325/1534 (21.9%) wore lead most of the time.

Among the 103 individuals surveyed who provided detail about their thyroid disease, 47 of them have hypothyroidism, 17 of them have Hashimoto's thyroiditis, 8 of them have cyst or polycystic disease, 7 of them have at least one thyroid nodule, 6 of them have Grave's disease, 6 of them have Cancer, 6 of them have benign adenoma, 5 of them have hyperthyroidism, and one individual has autoimmune thyroiditis. One respondent mentioned having papillary carcinoma of the thyroid and noted that thyroid shields were not available during their residency training, but thyroid shields are currently available and used.

Routine Cancer Screening

Screening colonoscopy had been performed in 129/203 (63.5%) surgeons age 50-55 years; 345/391 (88.2%) in those aged 56-65 years, and 317/355 (89.3%) in those aged >65 years.

Further, for different age groups of female surgeons, screening mammography had been performed in 6/34 (17.6%) women aged 30-39 years; 12/29 (41.4%) aged 40-44 years; 9/15 (60%) aged 45-49 years, 38/44 (86.4%) aged 50-59 years, and 28/31 (90.3%) aged 60 years and older (Table 5).

Table 5. Age and Rate of Screening Mammography

Age (years)	Respondents	Underwent Screening
30-39	34	17.6%
40-44	29	41.4%
45-49	15	60%
50-59	44	86.4%
60+	31	90.3%

Smoking and cancer

Of the 291 surgeons who had been diagnosed with cancer, only 1 individual currently smokes tobacco, while 44 are former smokers. The remaining 246 respondents (84.5%) reported that they have never smoked. Of the 1535 surgeons without cancer, 1352 answered questions about smoking: 8 currently smoke tobacco and 91 formerly smoked tobacco; 1253 (92.7%) never smoked tobacco.

Only 3 surgeons reported having been diagnosed with lung cancer. Out of these 3 surgeons, only 2 responded to the numbers of years they had smoked prior to diagnosis, with one individual reporting 40 years of smoking, and another reporting 5 years (Table 6).

Pre-malignant diagnosis prevalence

When asked "have you ever been diagnosed with a premalignant condition," 333 individuals (20.3%) responded yes, and 1306 individuals (79.7%) responded no.

Work disability in surgeons with cancer

When the 291 individuals who were diagnosed with cancer were asked whether they filed for disability, 25 of them responded affirmatively, 252 responded stated that they did not file for disability, and 14 did not provide a response for this question.

DISCUSSION

We performed a cross-section prevalence study of orthopaedic surgeons in the American Academy of Orthopaedic Surgeons. Of the 1,826 surgeons that responded to the survey, 15.9% reported that they had been diagnosed with cancer. Skin cancer is the most common cancer reported by orthopaedic surgeons. The prevalence of cancer showed a significant positive correlation with both the age of the surgeon and their number of years in practice, which indicates that these factors could contribute to an increased likelihood of cancer diagnosis. The impact of cancer on an orthopaedic surgeon was notable in terms of their professional decisions. In particular, approximately 8.2% of orthopaedic surgeons stated that their cancer diagnosis influenced their decision to retire, and 8.7% of surgeons filed for disability as a result of their diagnosis.

We emphasize that we are not the first to study cancer risk in orthopaedic surgeons. Mastrangelo and colleagues found that 9 of 31 orthopaedic surgeons (29%) in their study who practiced at a medical facility with poor radiation safety practices were diagnosed with cancer, and noted that cancer prevalence was significantly lower for workers who were not exposed to radiation.[10] Further, Chou and colleagues performed a survey of female orthopaedic surgeons in the AAOS, and reported that cancer prevalence was 85% higher for female orthopaedic surgeons when compared to the general U.S. female population. These findings also indicate that female orthopaedic surgeons are more likely to have a normal BMI, are less likely to smoke, and are less likely to use menopausal hormone replacement therapy for more than four years relative to the general population.[4] They postulated that the higher breast cancer prevalence could be partly explained by female orthopaedic surgeons being more likely to delay childbearing until after age 38, and being more likely to have fewer children. A subsequent study showed that the higher rate of cancer observed in female orthopedic surgeons was not observed in female Urologists or Plastic Surgeons.[9]

We note that there are some limitations to our study design - in particular, this study had a low response rate (7.8%). As per the AAOS market research committee, this response rate is similar to other surveys routinely performed by the AAOS, many of which are used to inform decision making and act as feedback for the AAOS. The data from this study may be biased by individuals who are more likely to report cancer incidence or are more likely to report healthy outcomes from cancer. However, this study represents the largest number of respondents compared to any other study done prior about cancer prevalence among orthopedic surgeons. This study did not obtain complete demographic data (such as ethnicity and race) to analyze certain subpopulations of surgeons. Despite these limitations, our study appears to be the first to survey the entire AAOS comprehensively on cancer prevalence and occupational hazards.

Comparing the cancer prevalence statistics obtained from this study to national data is a challenging task. For example, national organizations such as the National Cancer Institute (NCI), the National Cancer Comprehensive Network (NCCN), the Surveillance, Epidemiology, and End Results Program (SEER), and the Center for Disease Control (CDC) report data based on cancer incidence rather than prevalence. It must also be emphasized that the statistics reported by these organizations encompass a broader scope that includes pediatric cancers and other young adult cancers that are excluded because we evaluated only cancers that were diagnosed from start of orthopaedic practice.[11] A thorough literature search was unsuccessful in identifying the prevalence of cancer in adults. We were unable to identify any studies on the incidence of cancer in specialties that use little or no radiation, so a comparison withthis population can not be performed.

While this study is unable to provide statistical support for routine radiology safety procedures, the authors are strongly supportive of these precautions. The trend toward utilizing less-invasive and percutaneous techniques in orthopaedic procedures often results in prolonged exposure to higher doses of intraoperative fluoroscopy,[8,18] which underscores the importance of implementing adequate radiation safety measures for orthopaedic surgeons. Mandatory training and assessment of orthopaedic surgeons in radiation principles and safety practices will protect the health and safety of the surgeons, their co-workers, and their patients.[2,4,7,14,15,17,18]

This study also highlights the prevalence of breast cancer in female orthopaedic surgeons and prostate cancer in male orthopaedic surgeons. Due to this, we recommend that all female orthopaedic surgeons follow American College of Obstetricians and Gynecologists (ACOG) guidelines for clinical breast exam every 1-3 years until age 39; women aged 40 years and older who are at average risk for breast cancer should have clinical breast exam every year as well as screening mammography every 1-2 years.[3,5,9,19] Likewise, male surgeons should perform routine screening for prostate cancer. Evidence based guidelines for skin cancer screening do not currently exist. We recommend that any suspicious-looking skin lesions be reported to and evaluated by your primary care physician or a dermatologist.

This study motivates future evaluation of risk factors for cancer within different sub-populations of orthopaedic surgeons as well as the risk factors for cancer within other medical professions that face similar occupational hazards.

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SEARCHING FOR A JOB: A SURVEY OF HAND FELLOWSHIP APPLICANTS AND CURRENT HAND SURGEONS

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ABSTRACT

Background: Core curricula do not include courses on how to find employment after hand fellowships. Little data exists in literature regarding job selection in hand surgery. This study's purpose was to provide information to future hand surgeons on ways of finding a job that meets their expectations and to elucidate factors that should be considered before deciding on a hand practice.

Methods: A web-based survey asked hand fellows and fellowship applicants how they were searching for employment, the kind of practice they sought, expectations about hours, call, salary, possible niches, and importance of location, research, and passive income. A second survey was sent to hand surgeons. Statistical analysis determined how fellow expectations differed from reality.

Results: Prospective hand surgeons completed 96 of 270 (36%) surveys and hand surgeons completed 63/107 (59%). Most prospective hand surgeons utilize word of mouth, mentors/faculty to search for employment, whereas most surgeons received connections through residency, friends/family, or cold calling. The niches that prospective hand surgeons planned to bring to their practice differed from those of practicing surgeons. Expectations of call matched those of practicing hand surgeons, with most expecting to work 50 to 60 hours per week. For prospective surgeons, location and passive income were important but research was less so. Most hand surgeons have passive income and indicated low research participation.

Conclusion: Minimal training in job selection has been cited as a reason for changing jobs. The applicants' and fellows' expectations on call, work hours, passive income, and research were similar to hand surgeons, but the niches they hoped to fill differed, perhaps indicating those may not be possible in actual practice. This study provides perspective on what practice as a hand surgeon is like and things to consider when job searching.

Level of Evidence: IV

Keywords: job search, hand fellows, private practice

INTRODUCTION

Orthopaedic surgery and subspecialty training prepare the trainee to care for a wide variety of pathologies. The core curriculum of residency and fellowship training is in place to ensure that a baseline core competency is met prior to graduation. The focus, rightfully, is on training residents and fellows to be competent surgeons. However, core curricula do not offer training on how to look for a job or what to expect. It is safe to assume that guidance in finding a job varies among residents and could affect their future satisfaction with the jobs they choose. Over the years more attention has been focused on physician burnout, including resilience and wellness training in residency programs.[1,2] In the field of orthopaedic surgery, nearly half of surgeons beginning practice will change jobs within the first few years.[3] One of the main reasons given for leaving a first job was that it was not as advertised,[3] potentially indicating the importance of having an awareness of what is wanted versus what is expected.

Little data exists regarding job selection in orthopaedics and, more specifically, in hand surgery. Many resources are available to find employment, including job boards, professional society websites or conferences, personal connections, and faculty recommendations, but there is no set standard on how to look for a job or where to gather information about job expectations.

A recent study surveyed hand-fellowship applicants about what they thought were the most important components of a fellowship.[4] The results indicated that exposure to "bread-and-butter" hand surgery was most desired along with complex cases, including soft-tissue coverage, nerve surgery, and wrist reconstruction.[4] Although this was noted as a desire in fellowship, it is not known if this is what was wanted in future practice.

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This study surveyed current hand-fellowship applicants and hand fellows to gain an understanding of what they are looking for in their first job and what resources they are utilizing to find future employment. In addition, hand surgeons who had completed a hand-surgery fellowship were surveyed to determine how expectations of prospective hand surgeons differ from the reality of a practice. The purpose of this study was to provide information to future hand surgeons on ways of finding a job that meets their expectations and to elucidate factors that should be considered before deciding on a hand practice.

METHODS

Two anonymous, web-based surveys were created through SurveyMonkey, one for hand fellows or applicants and one for hand surgeons in practice. The first, a 17-question survey, was created to collect data from prospective hand-fellowship applicants who had applied to one of two hand-fellowship programs during the 2021-2022 academic year. Additionally, this survey was sent to hand fellowship coordinators for dissemination to current hand fellows throughout the United States. The survey included questions regarding if and how residents/fellows were looking for a job, what kind (academic, private, hospital, or hybrid) and the size of practice (number of partners in practice) they were hoping to join, and how important research, location, and opportunity for passive income were in their future job. They also were queried about whether they planned to take call and, if so, what kind (hand, replant, or general), as well as anticipated work hours and salary (Figure 1).

A separate 12-question anonymous survey was sent through SurveyMonkey to hand-fellowship graduates of the Indiana Hand to Shoulder Center from 2005 to 2021, currently working as hand surgeons (Figure 1). Questions similar to those of the hand-fellowship cohort were asked, including how long they had been practicing, how they found their current job, the number of partners in their practice, their participation in research, if they have an opportunity for passive income, if they have a specialty niche, what type of call they take (general, hand, both, and/or replant), the type of complex cases they perform, and the average hours worked per week. Other questions included whether they had changed jobs since their fellowship and how beneficial their fellowship had been to their current practice in hand surgery.

This study was determined to be exempt from approval by the Institutional Review Board of the University of Tennessee Health Science Center. (#21-08529-XM) Willingness of the subject to participate constituted adequate documentation of consent.

Prospective Fellow/Fellow Cohort

1. What is your current position PGY 4, PGY 5, Fellow
2. How are you searching for a job? AAOS job board/ASSH job board/Recruiter/Word of mouth/Mentor/ faculty/Not currently searching/other(free response)
3. Have you had any job interviews yet? Yes/No If yes, # of interviews_________
4. If yes to the previous question, what year was your first interview? (Select 1 for 4th year, 2 for 5th year, or 3 for fellowship year).
5. Do you have a signed contract for a position at the current time? Yes/No
6. What kind of practice are you hoping to join? Academic__ Private__ Hospital __ Hybrid__
7. Would you be comfortable taking general call? Yes/No
8. Is there a certain number of senior partners you would want to have in your future practice? 1/2/3/4/other (free response)/Does not matter
9. How important is research in your future practice? 1-10 (1 not at all, 10 a lot)
10. How important is location when searching for a job? 1-10 (1 not at all, 10 a lot)
11. How important are passive income opportunities to your future job? (MRI, ASC, PT, etc…..) 1-10 (1 not at all, 10 a lot)
12. Do you plan to bring a niche to your future practice? Yes/No If yes, what is your prospective niche________
13. Do you plan on taking Hand call/General call/Both Hand and General call/No call
14. Will you take replant call? Yes/No
15. What is your expected call frequency? Every _____ days
16. How many hours do you expect to work? 30-40/40-50/50-60/60-80/80+
17. What do you expect your future salary to be? 200-400k/400-600k/600-800k/800k-1mil/1 mil+

Graduated Fellow Cohort

1. How many years have you been in practice? __________
2. How did you find your current job? Recruiter/Hired by home residency/Connections made from fellowship/AAOS job board/ASSH job board/other__________
3. Have you changed job position since fellowship? Yes/No If yes, how many times? _____
4. Do you take Hand call/ General call/both Hand and General call/No call?
5. What is your current employment status? Hospital/Partner/Partnership track/Nonhospital/other (free response)
6. How involved in research are you in your current practice? 1-10 (1 not at all, 10 a lot)
7. Do you participate in passive income options (ASC, MRI, PT etc…)? Yes/No
8. How beneficial do you feel your year of fellowship has been to your practice of hand surgery?
   - Not helpful, I would not do fellowship in retrospect
   - Somewhat helpful, but could have done as well without it
   - Useful, I would not change my decision in retrospect
   - Vital, I would not do hand surgery without a fellowship
9. Number of hand partners in your practice? ___________________
10. How many hours a week do you work on average? 30-40/40-50/50-60/60-80/80+
11. Do you practice complex hand surgery i.e. local flaps/soft tissue coverage, hand/ wrist /elbow recon, nerve injuries? Yes/No. If yes, what do you do?________
12. Do you take replant call? Yes/No

Figure 1. Surveys sent to prospective hand surgeons and hand surgeons.

Statistical Analysis

Descriptive analysis of the survey results was performed. The two groups, prospective hand surgeons and practicing hand surgeons, were analyzed using descriptive statistics. Comparative statistics also were performed between graduating fellows and current residents. Fisher's exact test was used to compare qualitative statistics. A t-test was performed to compare expected call for the prospective cohort.

RESULTS

Ninety-six of 270 (36%) surveys were completed by prospective hand surgeons (65 postgraduate year [PGY]-4, eight PGY-5 residents, 23 current fellows; response rate: residents 73%, current hand fellows 13%. Sixty-three of 107 hand surgeons (59%) completed the survey.

Prospective Hand Surgeons

Most PGY-4 applicants, 65% (42/65), were not searching for a job; half of PGY-5 residents (4/8) and all (23) hand fellows were searching for a job. Table 1 lists resources being used to find jobs and the number of interviews. Of those, one PGY-5 resident and one fellow began the process as a PGY-4, nine began as a PGY-5, and 12 started during fellowship. In this cohort 1.5% (1/65), 12.5% (1/8), and 69.5% (16/23) in the PGY4, PGY5, and current fellow groups, respectively, had signed contracts. Practice type preference varied, with most wanting to join a private-academic hybrid practice. Preferences on practice size varied, with 49% (47/96) having no preference (Table 2). On a scale of 1 (not important) to 10 (very important), the response to how important research is for future practice averaged 3.84; 25 responded with 1 and 11 replied with 8 or higher. Practice location was very important (7.98 on the same scale); most (n = 75) rated location an 8 or higher. Respondents rated passive income opportunities as 5.44 in importance. Forty-six percent (44/96) planned to bring a niche to their practices.

Regarding future call, 30% (29/96) expected to take hand call only, 68% (65/96) anticipated both hand and general call, with 57% (55/96, including all 8 PGY-5 respondents) planning to take replant call, and 2.08% (2/96), both current fellows, not anticipating call. On average PGY-4s expected to take call every 6.18 days (standard deviation [SD] = 2.51), PGY-5s every 4.63 days (SD = 1.31), and current fellows every 6.30 days (SD = 5.66), with no significant differences between groups. A majority (n = 49; 51%) expected to work 50-60 hours per week, and most (n = 57, 59%) expected to earn $400,000 to $600,000 per year.

Current Hand Surgeons

Of the practicing surgeons (n = 63), 21 had been in practice for 1 to 5 years, 17 for 6 to 10 years, 21 for 11 to 15 years, and four for 16 to 20 years. A job change since graduation was noted by 32% (20/63; 18 surgeons changed jobs once). The resources that practicing hand surgeons used to find jobs are shown in Table 3.

Most hand surgeons are in practice with fewer than four partners (Table 4). Seventy-three percent (46/63) rated their participation in research as a 1 on a scale of 1 to 10 (with 1 being not involved and 10 being very involved). Sixty-eight percent (43/63) reported passive income (i.e., ambulatory surgery centers, MRI, physical therapy, or durable medical equipment). Hand surgeons reported practice niches, but those differed significantly

Table 1. Sources That Prospective Hand Fellows and Current Fellows are Using to Search for a Job and the Number of Interviews Completed

	PGY4	PGY5	Fellow
Source	(65)	(8)	(23)
AAOS[a]	5	0	8
ASSH[b]	11	1	14
Recruiter	3	0	6
Word of mouth	18	3	10
Mentor	17	3	13
Faculty	16	2	10
Interviewing	3	1	23
Average interviews (range)	2.33 (1-4)	2 (2)	3.19 (1-10)

[a]American Academy of Orthopaedic Surgeons; [b]American Society for Surgery of the Hand; PGY, post-graduate year.

Table 2. Types and Size of Practice Prospective Hand Surgeons Expected to Join

Type of practice	
Private practice	28/96 (29.1%)
Hospital-based practice	4/96 (4.2%)
Academic practice	25/96 (26.0%)
Private-academic practice	38/96 (39.5%)
Size of practice	
One partner	11/96 (11.4%)
Two partners	20/96 (20.8%)
Three partners	13/96 (13.5%)
Four partners	5/96 (5.2%)
No preference	47/96 (48.9%)

Table 3. Resources that Current Hand Surgeons Used to Find Their Jobs

Answer choices	Responses (n = 63)	
Recruiter	11.11%	7
Hired by home residency	3.17%	2
Connections made from fellowship	14.29%	9
AAOS[a] Job Board	6.35%	4
ASSH[b] Job Board	14.29%	9
Other (free response)		
Personal connection of friends or family	19.05%	12
Connection in residency	19.05%	12
Cold called	6.35%	4
Other	6.35%	4

[a]American Academy of Orthopaedic Surgeons; [b]American Society for Surgery of the Hand.

Table 5. Type of Call and Duty Hours of Current Hand Surgeons

Type of call	Number (n = 63)
General call	21/63 (33.3%)
Hand call	22/63 (34.9%)
Replant call	15/63 (23.8%)
General and hand call	16/63 (25.39%)
No call	4/63 (6.3%)
Duty hours	
30-40	3/63 (4.76%)
40-50	17/63 (26.98%)
50-60	30/63 (47.62%)
60-80	10 (15.87%)
80+	3 (4.76%)

Table 4. Comparison of Specialty Niches Between Prospective Hand Surgeons and Hand Surgeons Using Fisher's Exact Test

	Shoulder	Peripheral nerve/ microsurgery	Brachial plexus	Elbow	Arthroscopy	Trauma	Pediatrics
PGY-4	1	4	3	4	2	2	3
PGY-5	0	2	1	0	0	0	0
Fellow	1	2	4	0	2	1	0
Prospective hand surgeons	2	8	8	4	4	3	3
Current hand surgeons	1	18	2	7	0	0	2
Fisher's Exact Test ($P < 0.05$)	0.61	0.04*	0.04*	0.52	0.05*	0.10	0.67

*Denotes statistical significance; PGY, post-graduate year.

from what prospective hand surgeons expected (Table 5). Most surgeons perform complex hand surgery (92%; 58/63), including local flaps/soft-tissue rearrangement; hand, wrist, or elbow reconstruction; and nerve injuries. Most surgeons take call, with 24% (15/63) taking replant call (Table 5). Duty hours varied, but most surgeons work between 40-60 hours per week (Table 5).

DISCUSSION

This study was conducted to determine how expectations of future hand surgeons may differ from the reality of a hand-surgery practice and to provide information on how to find a practice that aligns with their needs and expectations. Hand surgeons are in demand in the United States. A study by Chan et al.[5] found that there were 2.4 fellows per job posting in hand surgery, which is lower than for foot and ankle, adult reconstruction, and trauma but higher than all other subspecialties. General orthopaedic positions had the highest number of job offerings.[5]

No set curriculum prepares orthopaedic residents to find jobs after training, which may be part of the reason why up to half of orthopaedic surgeons change jobs within their first 5 years of practice.[3] Laratta et al. found that the two major reasons for leaving a first job were financial and that the practice was not as advertised.[3] Twenty of 63 (32%) hand surgeons in our study changed jobs since fellowship: 19 surgeons changed once and one changed jobs twice, although this may not be representative of all hand surgeons since the survey was confined to one cohort that graduated from the same fellowship. Laratta et al.[3] also found that over half of orthopaedic surgeons thought they had minimal training in selecting their first job, and 88% felt inadequately prepared for the business side of orthopaedics. According to our results, of the 96 prospective hand surgeons, 13 were utilizing the American Academy of Orthopaedic Surgeons (AAOS) job board, 26 were using the American Society for Surgery of the Hand (ASSH) job board, 31 were guided by word of mouth, and 61 used a mentor/faculty to find a job. Most hand surgeons had used other means, including family or friend connections, or relationships made during their surgical training. Most PGY4 applicants were not looking for a job, but those who were primarily used mentors, faculty, and word of mouth compared to fellows who primarily used faculty, mentors, word of mouth, and the ASSH job board.

Preferences on practice type (private, academic, and hospital) and size (number of partners in practice) varied among the prospective hand-surgeon respondents, but most were seeking to join private-academic practices. Sixty percent of the hand surgeons surveyed were in practices with fewer than four partners.

Expectations of prospective hand surgeons on research, passive income, and location were similar to actual practice, with interest in research being low and location being the most important followed by the opportunity for passive income. The majority of hand surgeons noted passive income opportunities.

In a study by Harper et al.[4] the main reason for residents pursuing a career in hand surgery was exposure to a variety of complex procedures, including complex wrist reconstruction, peripheral nerve surgery, and soft-tissue coverage. The current study revealed a difference in niches between practicing surgeons and the prospective hand surgeons. Brachial plexus surgery and arthroscopy skills were more highly sought in the prospective hand surgeon cohort, while peripheral nerve/microsurgery was a more common response in the practicing group. However, the hand-fellow group may anticipate peripheral nerve/microsurgery to be embedded in their fellowships and thus are searching for even more niche fields.

Most applicants and current fellows intended taking both hand and general call, whereas only 16 of 63 (25%) hand surgeons actually take hand and general call. In a study of hand call practices by Douleh et al.,[6] 72% of hand surgeons take hand-specific call, with nearly half of them taking replant and microvascular call. They also found that most hand surgeons take call six or fewer times per month.[6] This aligns with our study which showed that PGY-4, PGY-5, and current fellows expected to take call approximately every 6 days; there was no difference between these groups. This study showed that most hand surgeons take some form of hand call, with 24% taking replantation call. Fifty-seven percent of the hand-fellow applicants and current hand fellows note that they would take replantation call.

Over the years, both the percentage of residents completing fellowship training and jobs requiring fellowship training have increased.[7,8] From 1984 to 2014, the percentage of jobs requiring a fellowship increased from 5% to 64%.[7] Almost all hand surgeons in this study thought that their fellowship was vital to their career and stated that they would not perform hand surgery without a fellowship.

Limitations

This study has some limitations. The study population included only those applicants applying to a hand-surgery fellowship at two institutions, which did not capture all current applicants, introducing possible selection bias. We also did not have direct access to the current fellows and had to use the fellowship coordinators as intermediaries for dispersing the survey, possibly explaining the low response rate in that category. Regarding the hand-surgeon cohort, these were only surgeons who completed a fellowship at one institution, which may affect generalizability and introduce selection bias.

Overall, hand surgeons have many opportunities to find work. Further work needs to be done to assess the best way to prepare orthopaedic residents and fellows in choosing their future jobs.

CONCLUSION

Minimal training in job selection has been cited as a reason for changing jobs. The applicants' and fellows' expectations on call, work hours, passive income, and research were similar to hand surgeons, but the niches they hoped to fill differed, perhaps indicating those may not be possible in actual practice.

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THE INFLUENCE OF PATIENT PROVIDER EDUCATIONAL INTERACTIONS AND ASSOCIATED PREOPERATIVE VARIABLES ON OUTCOMES IN THE HIP DYSPLASIA POPULATION

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ABSTRACT

Background: Patient provider interactions influence patient treatment adherence, clinical outcomes, patient satisfaction, and an overall patient's engagement in healthcare decisions. The purpose of this study was to examine the effectiveness of patient provider educational interactions and associated variables on patient reported outcomes in the hip dysplasia population.

Methods: A secondary data analysis was completed with 6-month postoperative survey data from participants, who had undergone periacetabular osteotomy. Data analysis including demographic variables, patient reported outcome results, and pre-operative knowledge retention.

Results: A significant difference was found between participants' expectations of crutch use and physical therapy care with actual performance ($p<0.001$ and $p=0.01$) and with engagement in pre-operative support based on mental health history ($p=0.02$).

Conclusion: Pre-operative interactions with a provider team and prior patients (pre-operative support) can influence a patient's educational experience. Providers should review educational interventions and offer pre-operative support to patients.

Level of Evidence: VI

Keywords: patient education, congenital hip dysplasia, patient outcomes, orthopedics

INTRODUCTION

Patient-provider relationships have become a growing focus in healthcare, as researchers attempt to find the most effective patient provider intervention or training to improve satisfaction, adherence, and outcomes.[1-3] Patients who have positive relationships with their providers are more active in decisions involving their treatment plan or general health, which in turn improves adherence with the treatment plan. In orthopedics, there is a desire to facilitate shared decision making between the patient and the provider, however the current patient reported outcome surveys (PROs) employed are poor at predicting if shared decision making (SDM) was met or if the patient was satisfied.[4]

Outcomes must be measured through validated instruments and providers should utilize the data for future recommendations or changes to survey data collection methodologies.[4] Orthopedic surgeons rely on patient reported outcomes to determine overall success of surgical or conservative treatment.[5] The behavior of interpreting patient reported outcome measures and revising provider education or treatment protocols is inconsistent.[5] When providers are unaware of their patients' education or communication preferences prior to treatment, information delivered during a consult can be perceived erroneously and negatively impact satisfaction scores.[6]

Periacetabular osteotomy is the gold standard treatment for pre-arthritic hip dysplasia in adolescents and young adults. Good outcomes can be achieved greater than 10 years after surgery.[7-11] In depth pre-operative education includes discussion of surgical technique, expected post-operative recovery, long-term outcomes, and risks of surgery must be clear to both the patient and potentially their accompanying family. Higher pre-operative expectations have been found to correlate with patients attaining acceptable post-operative symptoms and detectable change.[12]

Investigation is warranted to understand how knowledge is retained from pre-operative education.[13-15] Furthermore, we need to determine if changes in provider service or educational delivery are clinically relevant at reducing potential postoperative complications and improve patient understanding of post-operative expectations. Currently, patient outcome measurements do not identify the key risk factors that may change post-treatment clinical outcomes, therefore future studies need to clearly explain relevant factors.[14] The purpose of this mixed methods study was to examine the effec-

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tiveness of patient provider educational interactions and associated pre-operative variables on patient reported outcomes in the hip dysplasia population.

The following are the associated research questions:

Quantitative Research Questions

1. What are the background characteristics of the participants?

2. To what extent is there a statistically significant difference between pre-operative education and post-operative performance based on a) crutch use, b) physical therapy initiation, and c) opioid use?

3. To what extent is there a statistically significant difference in patient reported outcomes (PRO) defined by 1) ihot-12, 2) Modified Harris Hip, 3) PROMIS-Pain Interference, 4) PROMIS-Physical Function, and 5) HOOS-15 based on pre-operative support?

4. To what extent is there a statistically significant difference between patient reported outcomes (PRO) defined by 1) ihot-12, 2) Modified Harris Hip, 3) PROMIS-Pain Interference, 4) PROMIS-Physical Function, and 5) HOOS-15 based on pre-surgical education as defined by a) pre-operative instructions, b) physical therapy expectations, c) hospital stay, d) post-operative plan, and e) pain control?

5. To what extent is there a difference in pre-operative support based on a) gender, b) mental health, c) comorbidities, and d) age?

Qualitative Research Question

6. How do participants describe their experiences with pre- and post-surgical education?

METHODS

This study was informed by an initial quantitative analysis of a secondary data set, followed by a qualitative analysis of an open-ended questionnaire.

Quantitative Methods

For this sequential mixed methods study, quantitative data was collected through patient reported outcome surveys administered to participants at baseline, 6 week, 3 months and 6 monthssthroughout the six months post-operative period (Appendix A).

Qualitative Methods

The qualitative data assessment focused on patient experiences with educational interventions used during the preoperative consent process. (Appendix B).

Research Setting

The secondary data quantitative analysis was conducted utilizing a 2020-21 periacetabular osteotomy surgical data set from a Midwest hospital. The survey was offered to all participants who planned to undergo a PAO procedure and had signed the informed consent.

Sample and Participants

Convenience sampling was the method of recruitment for the quantitative portion of this study. Participants were recruited at their pre-operative PAO appointment. The quantitative survey contained responses from 32 participants (Table 2.1) and the qualitative portion contained responses from 18 participants.

Participants were recruited based on purposeful sampling for the qualitative portion of the study. All participants, regardless of time frame after surgery, were sent the open-ended questionnaire through Qualtrics.

Table 2.1. Participant Frequency Distribution

Demographic		n	% of sample
Gender			
	Male	5	15.6
	Female	27	84.4
Race			
	Non-Caucasian	1	3.1
	Caucasian	31	96.9
Age			
	13-17	16	50
	18-25	11	34.4
	26-45	5	15.6
Comorbidities			
	0	19	59.4
	1	8	25
	2	2	6.3
	4	1	3.1
	6	1	3.1
	7	1	3.1
BMI			
	18-21	14	43.8
	22-24	8	25
	25-37	10	31.2
Mental Health Diagnoses			
	0	26	81.3
	1	4	12.5
	2	1	3.1
	3	1	3.1

n = 32.

Quantitative Data Collection

The Redcap survey collected data on patient demographics, patient reported outcomes, pre-surgical education variables, post-surgical education variables, use of peer support, complications, and discharge procedures (Appendix A). Self-reported outcome data was collected using five different survey instruments: modified Harris-hip survey (mHHS) ($\alpha = 0.74$), ihot-12 ($\alpha = 0.95$), PROMIS-pain interference, PROMIS-physical function, and the Hip disability and Osteoarthritis Outcome Score (HOOS-15) ($\alpha = 0.96$). Medical history and timeline to surgery was gathered from the electronic medical record, and information was de-identified. Data was collected on the day of surgery, and at postoperatively at six weeks, three months, and six months.

Qualitative Data Collection

A Qualtrics anonymous link was electronically sent to all participants by the research team.

Data Analyses

For the quantitative assessment, data was analyzed using descriptive statistics, paired samples t-tests, independent samples t-tests, and chi square analysis. IBM SPSS v 27 was used to conduct the descriptive and inferential data analyses. Qualitative findings from 18 participant surveys were collected and due to limited responses, qualitative data did not undergo inductive coding.

Table 3.1. Assessment of Normality for Ordinal and Scale Variables

Variables	Skew	SE of Skew	Kurtosis	SE of Kurtosis
Mental Health	1.68	0.41	0.88	0.81
Crutch Use Projected Time	-1.42	0.41	1.41	0.81
Crutch Use Actual Time	-0.17	0.41	0.12	0.81
Physical Therapy Projected Start	1.08	0.41	3.26	0.81
Physical Therapy Actual Start	2.97	0.41	10.70*	0.81
Opioid Projected Use	0.79	0.41	0.65	0.81
Opioid Actual Use	0.90	0.41	-0.01	0.81
PROMIS-PI	-0.54	0.41	-0.98	0.81
PROMIS-PF	1.05	0.41	1.99	0.81
ihot-12	-0.97	0.41	0.37	0.81
mHHS	-1.23	0.41	1.47	0.81
HOOS-15	-2.51	0.41	8.33*	0.81
Comorbidities	0.40	0.41	-1.97	0.81
Age	0.27	0.41	-2.06	0.81
Pre-Operative Support	-0.40	0.41	-1.97	0.81

*Notes values > 8.0 indicating additional non-parametric tests completed. n = 14.

RESULTS

Data and Assumptions of Normality

Quantitative data were initially screened for missing values prior to conducting statistical analysis. Missing values were removed or replaced with the mean value. Table 3.1 summarizes the assessment of normality for independent and dependent variables. As indicated by the (*) in Table 3.1, two variables had kurtosis values > 8.0 in this study. When data are not normally distributed, the main statistical analysis to complete are nonparametric methods.[16]

Descriptive Analysis

A descriptive statistical analysis was completed for the following variables outlined in Table 3.2.

Inferential Statistical Analysis

Results revealed actual crutch use was significantly greater compared to projected use ($p<0.001$) (Table 3.3). Furthermore, crutch use had a very large effect size with Cohen's d = 1.08. There were no significant differences between projected and actual opioid use after surgery ($p= 1.00$)

Table 3.2. Descriptive Statistics for Demographic Data, Independent and Dependent Variables

Variables	Min	Max	Mean	SD
Gender (1 = Male)	0	1	0.84	0.37
Physical Therapy Projected Use	1	6	3.00	1.05
Physical Therapy Actual Use	3	8	3.60	1.04
Opioid Actual Use	1	4	1.83	0.92
Opioid Projected Use	1	4	1.83	0.77
Crutch Actual Use[a]	2	6	2.87	0.91
Crutch Projected Use[a]	1	3	2.66	0.53
Mental Health (1 = Yes)	0	1	0.19	0.40
PROMIS-PI	39	57	48.24	6.01
PROMIS-PF	40	73	51.18	6.98
Ihot-12	19	100	69.62	20.92
HOOS-15	30	100	88.03	14.21
mHHS	41	91	77.36	11.95
Pre-Operative Support (1 = Yes)	0	1	0.59	0.50
Physical Therapy Expectations (1 = Yes)	0	1	0.06	0.25
Post Operative Plan (1 = Yes)	0	1	0.03	0.18
Pain Control (1 = Yes)	0	1	0.06	0.25
Age[b]	1	2	1.43	0.50
Comorbidities (1 = Yes)	0	1	0.41	0.50

Scale[a]: 1 = 4-6 weeks, 2 = 6-8 weeks, 3 = 8-10 weeks, 4 = 10-12 weeks, 5 = 13-16 weeks, 6 = 17-21 weeks. Scale[b]: 1: 13-18 years old, 2 = 19-45 years old. n = 32.

Table 3.3. Paired Samples t-tests – Summary of Results

	Projected		Actual			Effect size	Confidence Intervals	
	M	SD	M	SD	p	d	LL	UL
Crutch Use[a]	2.66	0.53	3.88	0.91	<0.001*	1.08	0.64	1.51
Opioid Use[b]	1.84	0.77	1.84	0.92	1.00	0.00	-0.35	0.35

Scale[a] = 4-6 weeks, 2 = 6-8 weeks, 3 = 8-10 weeks, 4 = 10-12 weeks, 5 = 13-16 weeks, and 6 = 17-21 weeks. Scale[b] 1 = 1 week, 2 = 2 weeks, 3 = 3 weeks, 4 = 4 weeks, 5 = 5 weeks, 6 = 6 weeks, 7 = 7 weeks. *p < 0.001. n = 32.

Table 3.4. Results of the Independent Samples t-tests for Pre-Operative Support

	No		Yes		
	M	SD	M	SD	p
ihot-12	75.16	16.70	65.82	23.03	0.22
Modified Harris Hip	80.46	10.44	75.23	12.71	0.23
PROMIS-PI	47.00	7.33	49.08	4.95	0.38
PROMIS-PF	51.76	7.80	50.76	6.56	0.68

n = 32.

Table 3.5. Results of the Independent Samples t-tests for Pre-Operative PT Expectations

	PT Expectations				
	No		Yes		
	M	SD	M	SD	p
ihot-12	69.14	21.46	76.77	10.11	0.63
Modified Harris Hip	77.05	12.22	82.00	7.07	0.58
PROMIS-PI	48.39	6.16	45.95	2.90	0.59
PROMIS-PF	50.88	7.01	55.75	6.44	0.35

n = 32.

Wilcoxon Sign Rank test was performed to compare differences between pre-operative education and post-operative performance based on physical therapy use. Results indicated longer postoperative actual physical therapy use was common (n=15 %). Differences in anticipated and actual physical therapy use were statistically significant, (z = 2.77, p = 0.006, r = 0.49).

Independent samples t-test the two independent groups were used to compare patient reported outcomes for subjects indicating having no preoperative support and those who did and each dependent variables of ihot-12, modified Harris Hip, PROMIS-PI, and PROMIS-PF responses. Patient reported outcomes were not significantly different based on preoperative support (Table 3.4).

Since the HOOS-15 variable was not normally distributed, a Mann-Whitney U test was performed to determine whether there was a difference in HOOS-15 scores based on pre-operative support. Results demonstrated that there was a not a statistically significant difference in the mean rank (19.92) for the participants who did not utilize pre-operative support compared with the mean rank (14.16) for the participants who did use pre-operative support. (U = 79, p = 0.086, r = 0.30).

Comparisons on four of the five patient reported outcomes as grouped by pre-operative instructions, physical therapy expectations, hospital stay, post-operative plan, and pain control are outlined below. Participants in the "Yes" group indicated that they did have unanswered questions after the provider interaction and those in the "No" group did not. Results revealed that for pre-operative instructions and post-operative plans, there was only (1) participant in the "Yes' group, which created a skewed result with no standard deviation. As a result, the independent sample t-tests for pre-operative support and post-operative plan were removed from the analysis.

Furthermore, participant responses for hospital stay were all reported in the "Yes" group and therefore no independent sample t-tests could be run for the 4 outcome variables based on hospital stay. The results from the remaining independent samples t-tests for pre-operative PT expectations and pain control based on the four outcome measures are reported in Table 3.5 and 3.6. There were no significant findings for either independent variable on any of the four outcome variables.

Due to the HOOS-15 variable violating assumptions of normality, Mann-Whitney U tests were performed to compare the extent to which there was a difference in HOOS-15 scores based on pre-surgical education. Participants in the "Yes" group indicated that they did have unanswered questions after the provider interaction and those in the "No" group did not. Mann-Whitney U tests were not run for pre-operative instructions and post-operative plan due to group differences with only (1) participant in the "Yes" group, and for hospital stay all reported "Yes." Results indicate there was no statistically significant difference between mean ranks for HOOS-15 scores based on physical therapy expectations and pain control. (Table 3.7).

Table 3.6. Results of the Independent Samples t-tests for Pre-Operative Instructions for Pain Control

	Pain Control				
	No		Yes		
	M	SD	M	SD	p
Ihot-12	69.43	21.47	72.41	13.70	0.85
Modified Harris Hip	77.51	12.11	75.00	12.73	0.78
PROMIS-PI	47.96	6.09	52.35	3.18	0.33
PROMIS-PF	51.12	6.94	52.10	10.61	0.85

n = 32.

Chi Square Analysis

Pre-Operative Support

There was a statistically significant difference in whether pre-operative support was used based on mental health history, Pearson $\chi 2$ (1, n = 32) = 5.58, p = 0.02, Cramer's V = 0.42. The proportion of subjects not utilizing pre-operative support was significantly different based on concurrent mental health diagnosis (61% Nono mental health diagnosis & no vs 0.39% with a mental health diagnosis. The proportion of participants who did use pre-operative support with no mental health history was .95 or 95%, vs those with a mental health history was .05 (5%) respectively.

There were no significant differences between age or comorbid conditions, and the use of preoperative support.

Qualitative Findings

Qualitative data was gathered from the open-ended survey questions with free text, however due to limited responses (18 participants), data did not undergo inductive coding for thematic analysis. All qualitative responses are shown in Appendix C.

DISCUSSION

The purpose of this quantitative study was to examine the effectiveness of patient provider educational interactions and associated variables on patient reported outcomes in the hip dysplasia population. Research has indicated that the delivery of patient education has a strong impact on improving overall patient adherence, enhancing patient provider relationships, and improving patients' treatment adherence.[17-18] Literature has also noted that although patient education has the potential to assist patient adherence, the overall correlation between patient provider interactions and patient adherence to their treatment protocol has still not been validated.[5,17]

Table 3.7. Mann Whitney-U Test for HOOS-15

	Mean Rank		
	No	Yes	p
Physical Therapy Expectations	16.12	22.25	0.37
Pain Control	17.02	8.75	0.23

n = 32.

Key Findings

The present study determined how pre-operative instructions impacted the participant's overall surgical experience and patient reported outcomes. Pre-operative support (e.g., contacting another patient prior to surgery) was utilized by 59% of the participants, however, demonstrating non-significant effects on the overall patient reported outcomes for pain and function. Pre-operative support was actively pursued by those participants who did not suffer from a mental health diagnosis. This significant finding extends current literature on the significance of human interaction prior to a medical procedure and the potential to affect patient clinical outcomes.[19] Also, this finding supports the work of others that communication about the medical procedure has the potential to correlate with overall self-confidence, which lends to less future decisional regret.[20-21]

Although not statistically significant, it was found that participants who were 19-45 years old engaged in pre-operative support more than the 13–18-year-old group. These results align with findings by Coburn et al. (2017) who reported as patients develop and grow from adolescents to adults, they desire and become more actively involved in their health care and have higher expectations.[22] The analysis of comorbidities and pre-operative support was found to be non-significant. Studies have identified specific risk factors like pre-opioid use, tobacco use, hypertension, BMI, and diabetes as negative predictors for surgical outcomes.[23-24] However, the findings from this study add to current literature that comorbidities do not influence patients' engagement in pre-operative support.

Halpert (2018) noted that patients are demanding for provider empathy and validation of their condition, in addition to medical treatment. Participants in the study who engaged in pre-operative support may have received their desired empathetic moment or validation of the surgical process.[25] There is a strong potential that preoperative support in a multitude of healthcare settings could enhance human interaction and education to improve post-operative self-efficacy.

The aim of determining the effect of pre-surgical education on patient reported outcomes stemmed from the existing research gap of what pre-operative factors, including knowledge retention, affect patient outcomes.[23,15] In this study, pre-surgical education was evaluated quantitatively and qualitatively, however the limited qualitative data did not undergo a formal inductive coding process. Pre-surgical education was measured by reviewing knowledge retained from the pre-surgical provider interaction and post-operative actual performance. Crutch use and physical therapy utilization were both significant with comparison of the projected and post-performance mean timeframes. There is a potential that the pre-operative education on assistive device use and physical therapy length was unclear to participants. As Boden et al. (2018) reported, pre-operative education in physical therapy has been studied to determine a patient's overall perception and retention. Pre-operative physical therapy education is retained by patients only if it is delivered personally, contains practical information, and the patients find the information interesting.[13]

With a high demand and low control environment, providers' distribution of information or ability to answer questions is limited.[26] However, determining the cause of why patients do not retain information or identifying the most effective educational tools is a source of unclarity.[26,27] There exists the potential that the education on the post-operative plan was unclear with in-office conversation or handouts. This quantitative finding is supported by a few open-ended questionnaire responses, for which participants felt the provider visit was “brief” or “quick.” With a mean participant age of 19.8 years old, it supports a notion that the young adult population has higher expectations of providers and often request to be an active participant in their healthcare.[22]

Patient provider relationships can impact patient satisfaction and outcomes, yet there exists ambiguity in the literature on the specific indicators that assist with providing these positive relationship changes.[27,22,18] Although the quantitative analysis in this study did not reveal statistical significance of the effect of specific independent variables (e.g. pre-operative support) on clinical patient outcomes, there was a significant difference in retention of pre-surgical education following surgery and utilization of pre-operative support based on a history of mental health. Furthermore, there was also a significant difference in knowledge retention regarding specific protocol instructions (e.g., crutch use).

Clinical Implications

Results suggest that future healthcare entities should consider adding pre-operative support to preoperative patient. Furthermore, it is recommended providers inquire about patients' educational preferences prior to their in-office visit to potentially improve patient satisfaction and treatment adherence, in addition to alleviating the burnout of delivery of unretainable information. Healthcare entities should examine the results of this study to review their own protocol for delivering education to their patients, including written, web-based, and verbal instructions.

With the reported results, recommendations for future practice focus on the ability to influence outcomes and the provider patient relationship with appropriate support, clarity, and communication. The following are recommendations for future healthcare practices.

Creating an Opportunity for Pre-Operative Support

Based on the significant findings with respect to mental health and the utilization of pre-operative support in connecting with other patients who have experienced the same procedures it is recommended that healthcare providers offer patients the opportunity to engage with other patients, who have undergone the same medical procedure. If providers are aware of a patient's mental health history, it is encouraged that this opportunity for support before a procedure is also offered to this specific population. This opportunity has a strong potential to promote self-esteem, mitigate fear, and increase overall confidence for patients' post-treatment. With providing the possibility to communicate with another patient, the exchange could lead to a discussion of expectations, validation of provider instructions, and improved post-procedure self-efficacy.

Enhance Pre-Surgery Provider Communication

Based on the quantitative findings regarding knowledge retention gap of pre-surgical information (e.g., crutch use and physical therapy protocol), it is recommended that nurses (or other providers) follow up immediately after a pre-surgical consult. Nurse and other provider communication immediately following a pre-surgical or medical consult has the potential to provide another means for providing clarity, support regarding the provider expectations. Nurses may be able to answer follow-up questions, improve protocol adherence, and improve knowledge retention. This type of communication may be delivered through a phone call or a message on the patient portal. This recommendation has the potential to enhance patient's knowledge retention and expectation for post-procedure outcomes, which may potentially correlate with improvement in the overall patient provider relationship and treatment adherence.

In addition, the following are future recommendations for hip dysplasia patients based on the quantitative findings from this study:

Engage in Pre-Operative Support

Based on the significant finding of engagement in pre-operative support in this study, it is recommended that patients participate in this service if offered by their healthcare provider. With the dynamic myriad of needs changing for patients throughout their lifetime, it is recommended that patients engage in conversation with other patients before a major surgery, treatment, or procedure. As results demonstrated in this study, pre-operative support was used the most in patients who were 19-45 years old with no mental health diagnosis. It is recommended that when presented with the opportunity to communicate with a prior surgical patient, patients should actively pursue. Confirmation of provider expectations, protocols, or offering of reassurance can all assist patients with moving successfully through medical procedure.

Review Pre-educational Materials and Ask Provider Team Clarifying Questions

Provider healthcare teams will present patients with an assortment of educational materials (written protocols, instructions, discharge information). It is recommended that patients thoroughly review all materials prior to their pre-surgical or pre-procedural consult. With an overall understanding or engagement with the instructions prior to the consult, this will prepare patients to come to their office visit with additional questions to clarify any misunderstood information.

Establish Support and Strong Communication with Provider Team

Patient communication requests vary in the form of written, verbal, or electronic (portal). Based on a patient's self-assessment of their own communication needs, patients should adapt and request a specific type of communication to potentially improve their self-esteem or self-actualization through the surgical process, in addition to clinical outcomes. If patients can establish a preferred communication pathway with their provider team, then the effects of provider educational interactions may be more effective on their overall confidence and fear levels, in addition to post-procedure outcomes.

Limitations

First, per the demographic descriptive statistics, the outpatient orthopedic sample dataset had limited diversity amongst the participants with a predominance of participants identifying as female and Caucasian. This sample may not represent the entire hip dysplasia population; therefore, the generalizability of the study was limited with the current selected convenience sample. This selected sample led to a limitation of a small effect size with a smaller sample size (32 participants), however it was sufficient for clinical research.[28] A sample size of 30 was the minimum level to meet an effect size of 1.0 and power of 0.8, which is based on the alpha level of 0.05.[29]

Furthermore, it is postulated that participants who responded to all surveys and questionnaires for this study, were also the participants who felt very satisfied with the overall provider interaction. Finally, there was a limitation in the outcome of the paired samples t-test with opioid projected use and actual use. A p value of 1.0 was due to extracting the same mean for opioid projected and actual use, which means there was no difference between the groups, except by chance.[30]

Conclusions

This quantitative study found that the pre-operative hip dysplastic surgical population had knowledge retention gaps between pre-surgical education and post-surgical retention, and the overall utilization of pre-operative support was based on mental health diagnosis. With the demands of healthcare providers changing to focus on the patient experience, the quantitative findings support the impact of pre-operative support, positive provider interactions, support, and communication on the patient experience. Participants had a positive experience with their care team, which was indicated by majority of the participants not having unanswered pre-surgical questions. If participants did have unanswered questions, it did not significantly impact their patient reported outcomes.

Patient provider interactions could have a profound impact on patient outcomes, biopsychosocial health, and overall patient satisfaction. The focus of the research questions was based on the existing problem statement that healthcare is dynamically moving into a primary focus on patient experience, patient provider relationships and overall patient satisfaction.[31] It is recommended that future research use a methodological design that includes random sampling of the hip dysplastic population from multiple global institutions.

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APPENDIX A. Survey Instruments

PAO Patient Education Survey

Day of Surgery Education Survey

When do you plan to start physical therapy?
____
- o Not Applicable
- o 1 week
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks
- o 7 weeks
- o 8 weeks
- o 9 weeks
- o 10 weeks

When do you plan to remove your dressing?
____
- o Not Applicable
- o 1 weeks
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks

After surgery, when can you start weightbearing on your surgical leg? _____________
- o Not applicable
- o 1 week
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks
- o 7 weeks
- o 8 weeks
- o 9 weeks
- o 10 weeks

How long after surgery do you plan to stop using crutches? __________________
- o Not applicable
- o 1 week
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks
- o 7 weeks
- o 8 weeks
- o 9 weeks
- o 10 weeks

When do you plan to return to work?
____________________________ (Free Text Box)

Date: ___________________________

When do you plan to return to sport/athletics?
____
- o Not applicable
- o 1 week
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks
- o 7 weeks
- o 8 weeks
- o 9 weeks
- o 10 weeks

When do you expect to be off opioids?
____
- o Not applicable
- o 1 week
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks
- o 7 weeks
- o 8 weeks
- o 9 weeks
- o 10 weeks

Do you currently use opioids? (Select appropriate box)
1. Yes
2. No

Did you quit smoking? (Select Appropriate box)
1. Yes
2. No

APPENDIX A. Survey Instruments (Continued)

At this time, are you taking any Vitamin D, Calcium or protein supplements? (Select Appropriate Box)
1. Yes
2. No

What percent of patients undergo hip replacement within 20 years after PAO?

____

Do you feel that all of your pre-operative questions were answered by the hip preservation team? If not, please expand.
1. Yes
2. No

If no, why? ___________________________________

Six Week Post-Surgery Education Survey

Was your post-surgical discharge process informative?
1. Yes
2. No

What components of your discharge and initial phase of treatment (6 weeks) did you not anticipate? (Text box)

____

What materials, given to you by the hip preservation team, were the most helpful? (Text Box)

____

Are you continuing to use all prescribed medication?
1. Yes
2. No

6-Month Post-Surgery Education Survey (Text box)

When did you stop using opioid pain medications?
o Not applicable
o 1 week
o 2 weeks
o 3 weeks
o 4 weeks
o 5 weeks
o 6 weeks
o 7 weeks
o 8 weeks
o 9 weeks
o 10 weeks

When did you start physical therapy (how many weeks after surgery)?
o Not applicable
o 1 week
o 2 weeks
o 3 weeks
o 4 weeks
o 5 weeks
o 6 weeks
o 7 weeks
o 8 weeks
o 9 weeks
o 10 weeks

When did you complete or were discharged from physical therapy? (Date)

____

Did you continue a home exercise program after being discharged from physical therapy (Select appropriate box)?
1. Yes
2. No

When did you return to work?
o Not applicable
o 1 week
o 2 weeks
o 3 weeks
o 4 weeks
o 5 weeks
o 6 weeks
o 7 weeks
o 8 weeks
o 9 weeks
o 10 weeks

What questions/concerns did you feel were not answered pre-operatively? (Check appropriate box(s))
o Pre-Operative Instructions
o Physical Therapy Expectations
o Hospital Stay
o Post-Operative Plan
o Pain Control
o Other
o NA

APPENDIX A. Survey Instruments (Continued)

When did you stop using crutches?
- o Not applicable
- o 1 week
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks
- o 7 weeks
- o 8 weeks
- o 9 weeks
- o 10 weeks
- o 11 weeks
- o 12 weeks
- o 13 weeks
- o 14 weeks
- o 15 weeks
- o 16 weeks

After your surgery, what did you use to help with your pain? Check all that apply
- o Ice
- o Heat
- o Electrical Stimulation
- o Dry Needling
- o Other Pain Medications
- o Ultrasound

When did you return to sports or general fitness?
- o Not applicable
- o 1 week
- o 2 weeks
- o 3 weeks
- o 4 weeks
- o 5 weeks
- o 6 weeks
- o 7 weeks
- o 8 weeks
- o 9 weeks
- o 10 weeks

Did you consult with another individual that had undergone a PAO for hip dysplasia?
1. Yes
2. No

Was it beneficial to your recovery?
1. Yes
2. No

How did you connect with the other individual?
- a. In person meeting
- b. Social media
- c. Phone Call
- d. Any combination of the above?

Did you use a toilet seat lift?
1. Yes
2. No

Did you use any other adaptive equipment (e.g. reacher) at home? (Text box)

____

Is there anything you wish you would've known prior to surgery?

____

Were your recovery expectations met by the hip preservation team? If not, which aspects were not met?
1. Yes
2. No

If not, why? ____

Did you feel that your care team listen to your concerns and answer all of your questions during your recovery?
1. Yes
2. No

Did you take any supplements after surgery including iron, calcium, vitamin D?
1. Yes
2. No

Any issues with your dressing or incision after surgery?
1. Yes
2. No

APPENDIX B. Qualitative Open-Ended Questionnaire

As a participant in the Periacetebular Osteotomy (PAO) research study at University of Iowa, this short questionnaire is intended to gather information regarding your experience (pre-surgical and post-surgical) with the Young Adult Hip Team. The purpose of this portion of the study is to deepen our understanding of your experience with provider education and communication during the surgical process. Thank you for your participation and willingness to complete the survey. Also, for your knowledge, all information will be de-identified.

How did the Young Adult Hip team support you during your pre and post-operative recovery?

Describe the impact that the written, verbal, or other educational tools had on your experience.

How did your level of confidence (regarding the surgical process) change following the provider educational handouts and in-office consult?

How would you describe the overall communication from the Young Adult Team?

How would you change the method or type of delivery of the pre-surgical education?

Appendix C. Examples of Survey Responses to Open-Ended Questions

Question	Survey Responses
How did the young adult hip team support you during your pre and post-operative recovery?	"I was provided all the information that I needed to understand be comfortable with the procedure." "They made sure I was prepared. They walked me through step-by-step asking if I had any questions along the way." "Post op visits were a little brief, prefer a little more time for questions." "Provide information on recovery." "Provided instruction and counseling about what the procedure is, what recovery would be like, and what to expect in general."
Describe the impact that the written, verbal, or other educational tools had on your experience	"The verbal education and explanations of every step of this surgery and recovery was very helpful and had a huge impact on my experience." "It helped having these tools to feel less overwhelmed and know what to expect." "Decreased anxiety 10/10." "It was very well written out for me to understand what was expected."
How did your level of confidence (regarding the surgical process) change following the provider educational handouts and in-office consult?	"I had all the confidence in the world that this hip team would take care of me and they absolutely did that. The office handouts were a bit overwhelming but when they went over them with me, I felt a lot more at ease." "I became more confident. Obviously, I had many fears, but some were eased." "Confidence in my team has always been expectional. They have been phenomenal at each stage." "The educational handouts weren't much different than any medical handout, but still helped me feel confident when I would go to in-office consults."
How would you describe the overall communication from the Young Adult Team?	"Very good and easy to contact." "Excellent. Nurses answer questions on myChart or phone quickly. I feel like if I needed to talk to the surgeon or PA, I could do so." "The communication is exceptional; they provide plenty of resources but are also available for questions/follow up."
How would you change the method or type of delivery of the pre-surgical education?	"An online resource to view the pre-surgical education." "Add more time speaking with nursing and going over any questions or concerns patients may have." "The pre-surgical education seemed standard and provided necessary information. Perhaps a before/after diagram of what the hip would look like could be helpful to some. Maybe a highlight of what muscles will be affected."

TRENDS IN RESEARCH PRODUCTIVITY AMONG RESIDENTS APPLYING FOR UNITED STATES ORTHOPEDIC FOOT AND ANKLE FELLOWSHIPS

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ABSTRACT

Background: Little empirical research has been done on factors evaluated in the fellowship matching process, this study intends to evaluate the impact of research productivity.

Objective: The purpose of this study is to identify research trends and characterize the academic profiles of recent Foot and Ankle (F&A) fellows in the United States when they applied for fellowship.

Methods: The American Orthopedic F&A Society website was used to identify accepted fellows between the years 2017-2023. A retrospective bibliometric analysis was performed using the total number of publications up to December 31st of the year prior to the start of fellowship, collected from each fellow's Scopus profiles. Recorded data included total number of publications, citations, authorship position, and publications with a F&A focus. Data was compared between academic versus community fellowship programs, and by years, fellowship and residency program region, medical degree, and sex.

Results: A total of 444 F&A fellows from 2017 to 2023 were identified, and 404 (90.99%) were verified. Fellows averaged 5.288±10.075 publications and 60.646±232.297 citations. Fellows were listed as first author in 31.35% publications and middle author in 65.08% publications, while 93.81% of fellows had at least 1 publication, and 54.95% percent had at least 1 first author publication (Table 1). A statistically significant increase in average number of publications was identified between the years 2017 and 2018 and the years 2020-2023 (Table 2).

Conclusion: There exists a statistically significant, increasing trend in research productivity of F&A fellows across the years 2017-2023. Over half of fellows published at least one first authorship article, and just under half had a publication focused on F&A.

Level of Evidence: II

Keywords: foot and ankle, fellowship, research

INTRODUCTION

Among all surgical specialties, orthopedic surgery has the highest rate (87.4%) of trainees who plan on pursuing a fellowship following residency.[1] This trend is becoming universal, and fellowship-trained orthopedic surgeons have increased employment opportunities,[2] academic leadership appointments,[3] and higher financial returns.[4] Foot and Ankle (F&A) fellowships are attractive due to a very high level of career satisfaction.[5] However, little empirical research has been done on quantifiable factors of successful F&A fellowship applicants. The purpose of this study is to identify research trends and characterize the academic profiles of recent F&A fellows in the United States (U.S.) when they applied for fellowship.

METHODS

The American Orthopedic F&A Society website was used to identify accepted F&A fellows beginning their training between the years 2018-2022. Fellows who applied but did not match into F&A could not be identified. Each fellow's name was manually searched in Scopus, a publicly available abstract and indexing database, to obtain their academic and bibliometric profiles. Fellow profiles were confirmed by cross-referencing their name, residency program, medical school, and geographic region with publicly available information from departmental websites, LinkedIn, and Doximity profiles. Geographic region was determined using the National Geographic United States Regions map. Additional information collected for each fellow included type of medical degree and sex. Fellowship program type was classified as either academic or community programs based on their affiliation with a medical school. Fellows were excluded if their fellowship information could not be confirmed. After confirmation, the total number of publications published or accepted up to December 31st of the year prior to the applicant's match year were included in the analysis to reflect the resident's research profile during their fellowship application cycle. Research

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experiences such as abstracts, presentations, letters, and posters were excluded from the analysis. Each publication was examined to determine authorship position and focus of the publication. Recorded data included total number of publications, citations, and authorship position, and averages per fellow were calculated. This data was then compared between years, fellowship program and residency program region using one-way ANOVA on ranks with Dunn's post-hoc comparisons between groups. Data was compared by fellowship program type, medical degree, and fellow sex using unpaired Mann-Whitney u-tests. P values < 0.05 were considered significant.

RESULTS

A total of 444 F&A fellows from 2017 to 2023 were identified, and 404 (90.99%) could be verified. These fellows produced a total of 2279 publications and 24,501 citations. All fellows averaged 5.288 ±10.075 publications and 60.646±232.297 citations. Fellows were listed as first author in 720 (31.35%) publications and middle author in 1495 (65.08%) publications, while 93.81% of fellows had at least 1 publication, and 54.95% percent had at least 1 first author publication. Of the total publications, 668 (43.07%) were focused on F&A, with 43.07% of fellows having 1 or more publication with a F&A focus (Table 1). The majority of articles (64.52%) were published while fellows were in residency.

A statistically significant increase in average number of total publications was identified between the years 2017 and 2018 and the years 2020-2023. Additionally, there was a statistically insignificant increase in first author publications between 2023 and 2017 ($p < 0.1$). There was also a statistically insignificant difference in average number of publications based on type of medical degree, with MD's having higher average publications per fellow compared to DO's (Table 2). There were no statistically significant differences based on sex, but with regard to fellowship program region, fellows from the Southeast produced statistically significantly more total publications compared to fellows from the Southwest, and the difference between first author publications was statistically insignificant ($p=0.0508$). Additionally, there were statistically significant differences based on residency program region, with fellows who did their residency in the Northeast and International Medical Graduates producing more total publications and first author publications compared to graduates from Southwestern residency programs (Table 3). When evaluated by fellowship program type, there was a statistically insignificant difference in total publications with fellows at academic programs averaging 6.018±9.501 and fellows at community programs averaging 3.819±5.418 ($p=0.080$); however, there was a statistically significant difference in first author publications, with fellows at academic programs averaging 1.945±3.905 and fellows at community programs averaging 0.869±1.511 ($p=0.034$) (Table 3).

DISCUSSION

F&A fellowships are attractive due to a very high level of career satisfaction,[5] though little empirical research has been done on factors that can improve an applicant's competitiveness for matching into a fellowship. Although academic achievement and research are important criteria fellowship directors consider when interviewing applicants,[5,6] quantified standards for research productivity remain unknown. Our study analyzed research trends of recent orthopedic F&A fellows during their residency training.

The vast majority of fellows had a minimum of one publication at the time they applied to fellowship, with over half of fellows having published at least one first authorship article, and just under half with a publication focused on F&A orthopedics. Moreover, there exists a statistically significant, increasing trend in research productivity of orthopedic F&A fellows across the years 2017-2023, largely driven by increases in middle authorship publications. Unsurprisingly, the 2020-2021 year featured the greatest average number of publications, likely due to the impact of COVID-19. Additionally, there

Table 1. Research Productivity Among All Foot and Ankle Fellows*

	n(%)
Total of All Fellows (n=404)	
Number of Publications	2297
1 or more Publications	334 (82.67%)
Number of First Authorship Articles	720 (31.35%)
1 or more First Authorship Articles	222 (54.95%)
Number of Middle Authorship Articles	1495 (65.08%)
Number of Articles with Foot and Ankle Focus	668 (29.08%)
1 or more Articles with Foot and Ankle Focus	174 (43.07%)
Number of Citations	24501
Average Per Fellow	
Number of Publications	5.288±10.075
Number of First Authorship Articles	1.718±3 .770
Number of Middle Authorship Articles	3.700±7.154
Number of Articles with Foot and Ankle Focus	1.653±4.755
Number of Citations	60.646±232.297

*Number of publications and citations represents a fellow's research output prior to the start of their fellowship. Research Trends Among All Foot and Ankle Fellows 2017-2023.

Table 2. Association of Research Productivity with Fellowship Year, Fellow Sex, and Fellow Degree

	Number of Fellows [n(%)]	Number of Publications [n(%)]	Average Publications per Fellow	Average First Author Publications per Fellow	Number of Citations [n(%)]	Average Citations per Publication
Fellowship Year						
2023-2024	53 (13.12%)	411 (17.89%)	8.321±10.029*	2.208±2.86†‡	6195 (25.28%)	6.857±10.024
2022-2023	63 (15.59%)	398 (17.15%)	6.317±9.137⁑	2.476±6.050	2696 (11.00%)	5.744±9.127
2021-2022	51 (12.62%)	382 (16.66%)	7.490±11.490⁂	2.039±3.731	5001 (20.41%)	10.680±15.990
2020-2021	56 (13.86%)	474 (20.64%)	8.618±13.062※	2.655±5.562	4729 (19.30%)	6.589±8.016
2019-2020	64 (15.84%)	286 (12.45%)	4.469±5.960	1.563±2.115	3579 (14.61%)	5.857±9.698
2018-2019	59 (14.60%)	169 (7.36%)	2.864±5.431*⁑⁂※	0.814±1.548†‡	1768 (7.22%)	7.909±13.790
2017-2018	59 (14.60%)	126 (5.49%)	2.492±3.319*⁑⁂※	0.926±1.681†‡	533 (2.18%)	2.379±4.241
Fellow Sex						
Male	316 (78.22%)	1873 (81.15%)	5.927±10.953	1.813±3.931	19294 (78.75%)	6.556±10.212
Female	88 (21.78%)	424 (18.46%)	4.818±5.899	1.670±2.495	5207 (21.25%)	6.109±12.508
Fellow Degree						
MD	369 (91.33%)	2206 (96.04%)	5.978±10.376†	1.864±3.761	23775 (97.04%)	6.698±10.651
DO	35 (8.66%)	91 (3.96%)	2.600±5.197†	0.914±2.280	726 (2.96%)	3.932±11.481

*, ⁑, ⁂, ※ = $p < 0.05$
†, ‡ = $p < 0.1$

Table 3. Association of Research Productivity with Fellowship Program Region, Residency Program Region, and Fellowship Program Type

	Number of Fellows [n(%)]	Number of Publications [n(%)]	Average Publications per Fellow	Average First Author Publications per Fellow	Number of Citations [n(%)]	Average Citations per Publication
Fellowship Program Region						
Midwest	67 (16.58%)	268 (11.67%)	4.00±6.137	1.07±1.803	2766 (11.29%)	6.867±10.052
Northeast	91 (22.52%)	600 (26.12%)	6.593±9.585	1.879±2.855	5309 (21.67%)	6.256±9.809
Southeast	137 (33.91%)	1056 (45.97%)	7.708±14.049*	2.533±5.293†	12264 (45.97%)	5.450±9.903
Southwest	34 (8.42%)	88 (3.83%)	2.588±2.476*	0.735±1.024†	879 (3.59%)	6.286±9.825
West	75 (18.56%)	285 (12.41%)	3.800±4.773	1.400±2.488	3283 (13.40%)	8.260±13.865
Residency Program Region						
Midwest	96 (23.76%)	386 (16.80%)	4.021±5.380	1.229±2.364	4407 (17.99%)	7.522±14.071
Northeast	87 (21.53%)	744 (32.39%)	8.551±14.713⁑	2.356±3.554⁑	10249 (41.83%)	7.045±9.730
Southeast	97 (24.01%)	394 (17.15%)	4.062±5.701	1.351±1.985	2820 (11.51%)	4.839±8.223
Southwest	38 (9.41%)	102 (4.44%)	2.684±4.281*⁑	0.684±1.817*⁑	560 (2.29%)	5.386±12.97
West	41 (10.15%)	189 (8.23%)	4.610±5.540	1.390±1.973	2162 (8.82%)	8.531±10.682
International	45 (11.14%)	482 (20.98%)	10.711±16.341*	4.067±7.941*	4303 (17.56%)	5.563±6.012
Fellowship Program Type						
Academic	343 (84.90%)	2064 (89.86%)	6.018±9.501†	1.945±3.905*	22413 (91.48%)	6.487±10.576
Community	61 (15.10%)	233 (10.14%)	3.819±5.418†	0.869±1.511*	2088 (8.52%)	6.298±11.704

*, ⁑ = $p < 0.05$
† = $p < 0.1$

was also a statistically insignificant ($p < 0.1$) increase in first authorship publications between 2017 and 2023. Thus, research output appears to be an increasingly influential factor considered in fellowship applications. With the average F&A fellowship director having strong achievements in research,[6] these findings regarding the research productivity of F&A fellows are not surprising. Surprisingly, however, 17.33% of fellows did not produce any publications prior to the start of fellowship – these fellows were confirmed to have completed a F&A fellowship, while those who were not verified to have completed a F&A fellowship were not included in this statistic.

There does exist a statistically significant regional difference with regard to total research output for fellowship programs between the Southeast and Southwest. Moreover, fellows who completed their residency in the Northeast and internationally produced the most total and first author publications, on average, though it was only statistically significant compared to fellows who completed their residency in the Southwest. The authors hypothesized there would be multiple significant regional differences with regard to residency program region within the United States, though the data only supports this claim when comparing the Northeast to the Southwest.

In addition to research productivity, letters of recommendation (LORs) are considered the most important criterion in obtaining an interview for orthopedic fellowship.[7,8,9] While these letters include subjective metrics about an applicant's skillsets, qualifications, and characteristics, they also contain objective metrics such as exam scores and research publications.[10] Given the increasing difficulty in matching into the most competitive fellowship programs with a heavy emphasis on research, residents may be engaging in more academic research to strengthen their LOR, accounting for the increasing number of publications per fellow over the last 5 years. Additionally, elective research years and implementation of research curricula during orthopedic residency may also be contributing to this trend.[11,12] Additionally, the rising number of research fellowships and medical students pursuing research gap years may explain why publication output is the highest in recent years, as students are engaging in research earlier in their academic careers.[13-15] Further research is needed to assess whether increased research productivity is a consequence of the growing competitiveness in matching into orthopedic fellowship programs, or if increasing research productivity is driving the increased competition.

Our study is subject to limitations characteristic of all retrospective bibliometric analyses. The data collected in this study is restricted to the information publicly available on F&A fellowship websites and the AOFAS website – which publishes a yearly list of incoming fellows. However, not all fellows listed could be confirmed and included in the study. Second, although the data was collected in accordance with specific date parameters to best reflect the research profile of a F&A fellow at the time they applied for fellowship, discrepancies in time to publication between journals may misclassify publications as those being completed during fellowship rather than residency. Additionally, this study did not account for differences in length of training or time spent during research years. Finally, the Scopus database only lists research published within their registry of indexed journals, potentiating the risk of uncaptured publications. Numerous studies, however, have utilized the Scopus database to provide complete bibliometric profiles for analysis of research trends within orthopedic surgery.[16-18] Despite these limitations, this study is valuable in that it is the first to quantify and characterize research output trends among residents applying for orthopedic F&A fellowships in the United States.

CONCLUSION

The overall number of publications per fellow applying into orthopedic F&A fellowships has been increasing in recent years. The only statistically significant difference in total research output with regard to fellowship program region exists between the Southeast and Southwest, though fellows from programs in the Southeast and Northeast United States produced the highest average publications per fellow. With regard to residency program region, fellows who completed their residency in New England and international medical graduates produced the highest number of total publications and first author publications per fellow, though only statistically different from those who attended residency programs in the Southwest United States. Although research output is one of the many factors evaluated in fellowship applications, it represents a quantifiable measurement of productivity with trends suggesting it may become more valuable for prospective fellows in years to come.

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TARSAL TUNNEL SYNDROME - A COMPREHENSIVE REVIEW

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ABSTRACT

Tarsal tunnel syndrome (TTS) refers to compression of the posterior tibial nerve as it traverses the tarsal tunnel in the ankle. First described by Keck and Lam in 1962, TTS is an underdiagnosed cause of heel pain and foot dysfunction.[1,2] The tarsal tunnel contains the tibial nerve, posterior tibial artery, and tendons of the tibialis posterior, flexor digitorum longus, and flexor hallucis longus muscles. Compression of the tibial nerve within this tunnel leads to pain, numbness, tingling, and weakness along its distribution.

The clinical presentation of TTS can vary due to the numerous etiologies and range of structures involved. Symptoms may develop insidiously over months to years or have a traumatic onset. Lack of definitive clinical tests or imaging often delays diagnosis, which contributes to poor patient outcomes and treatment success. In severe or long-standing cases, permanent nerve damage may occur if left untreated.

TTS deserves increased recognition given its potential to significantly impact mobility and quality of life. This review provides a comprehensive overview of the anatomy, etiology, diagnosis, and management of TTS. Optimal strategies to diagnose and treat this condition based on available evidence are discussed to improve patient outcomes and limit disability. Early diagnosis and intervention are key to avoiding permanent nerve injury and maximizing the benefits of treatment, whether conservative or surgical.

Keywords: tarsal tunnel syndrome (TTS), etiology, diagnosis, management

Anatomy

The tarsal tunnel is a firm osteofibrous canal in the ankle formed by the flexor retinaculum and talus, navicular, and calcaneus bones. The flexor retinaculum spans between the medial malleolus and the calcaneus, forming the roof of the tunnel. It contains tendons of the tibialis posterior, flexor digitorum longus, and flexor hallucis longus muscles, as well as the posterior tibial artery, vein, and nerve.[1]

The tibial nerve originates from the sciatic nerve in the popliteal fossa. It descends deep into the calf, providing motor branches to the soleus, tibialis posterior, flexor digitorum longus, and flexor hallucis longus muscles. Near the ankle, the tibial nerve bifurcates into the medial and lateral plantar nerves, which provide sensory innervation to the plantar surface of the foot and toes.[2] These nerves and their branches are susceptible to compression within the tarsal tunnel.

The medial plantar nerve provides sensory branches to the medial arch, the plantar aspect of the first through third toes, and the medial two lumbricals. The lateral plantar nerve supplies the lateral arch, the plantar aspect of the fourth and fifth toes, all interossei, and the remaining lumbricals. Terminal branches of these nerves form the common plantar digital nerves, which supply sensory innervation between the toes.[3]

Vascular supply to the tarsal tunnel contents arises from branches of the posterior tibial artery. It provides the medial and lateral plantar arteries at the bifurcation of the tibial nerve, as well as branches that vascularize the flexor retinaculum, nerve, and tendons within the tunnel.[4] Impaired blood flow contributes to nerve compression and dysfunction in TTS.

In summary, the tibial nerve and its branches, along with the posterior tibial artery and tendons within the tarsal tunnel, are at risk of compression due to changes in tunnel size, volume, or dynamics. A detailed understanding of tarsal tunnel anatomy is essential to diagnosing and treating TTS. The next section will review the etiologies underlying nerve compression and the resulting clinical manifestations.

Etiology

The etiology of TTS includes a range of intrinsic and extrinsic factors that compress the tibial nerve within the tarsal tunnel. Intrinsic causes originate within the tunnel itself, such as varicosities of the posterior tibial vein or tenosynovitis of the tendons. Extrinsic causes exert pres-

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sure from outside the tunnel, including trauma, ankle instability, space-occupying lesions, systemic conditions, and idiopathic factors.[5]

Varicosities of the posterior tibial vein are found in 20% of patients with TTS.[6] Valve insufficiency leads to venous dilation and congestion, which compresses the tibial nerve. Tenosynovitis refers to inflammation of the flexor tendon sheaths, which occupy a substantial portion of the tunnel and can distort its shape. Trauma such as fractures, sprains, or direct crush injuries fracture bones, rupture tendons, or damage nerves within the tarsal tunnel.

Ankle instability caused by conditions like posterior tibial tendon dysfunction alters the dynamics and loading through the tarsal tunnel. This leads to stretching or irritation of the tibial nerve with excessive motion. Space-occupying lesions include ganglia, neuromas, lipomas, or other masses that physically compress the tibial nerve.[7] Systemic conditions associated with TTS include diabetes, hypothyroidism, rheumatoid arthritis, and obesity due to fluid retention or biochemical changes.[8]

In many cases, no underlying cause can be identified, which is referred to as idiopathic TTS. Contrary to common belief, a flat or pronated foot is not directly linked to the development of TTS.[9] However, foot deformities may contribute to altered gait, biomechanics, and load transmission through the ankle, which could predispose to this condition through other mechanisms.

Clinical Manifestations

The clinical presentation of TTS varies depending on the underlying etiology and severity of tibial nerve compression. Symptoms include pain, numbness, tingling, weakness, and a sensation of walking on pebbles or sand. Pain is typically worse at night and with activity, located in the sole of the foot and radiating to the toes.[10] Paresthesias tend to follow the distribution of the medial and lateral plantar nerves. Weakness is usually secondary to intrinsic muscle atrophy, leading to clawing of toes and loss of arch.[11]

Patients frequently report a gradual onset of symptoms that have persisted for months or years. However, traumatic TTS presents more acutely in association with an inciting event. Pain is often described as aching, burning, or stabbing in nature. Numbness and tingling are initially intermittent but become constant in severe, longstanding cases as nerves degenerate. Motor deficits occur late, and their presence indicates advanced disease.

On a physical exam, Tinel's sign over the tarsal tunnel elicits pain and paresthesia into the plantar foot, which is considered a positive finding. Swelling or a palpable mass may be noted within the tunnel. The flexor retinaculum and tendons feel tense or thickened. Atrophy of intrinsic foot musculature results in claw toe deformities, a loss of arch, and a "bag of worms" feel upon plantar palpation.[9] Pain and paresthesia can be elicited through passive stretch and resistance testing of toe flexors and abductors. A vascular exam reveals decreased or absent pedal pulses in severe cases. Neurological testing confirms decreased sensation to light touch, pinprick, temperature, and vibration modalities.

Diagnosis remains challenging without definitive clinical tests and is made through a combination of symptoms, physical findings, and ruling out other potential causes of heel pain or nerve compression. A diagnostic workup may include imaging, nerve conduction studies, and diagnostic injections, which are useful to support a diagnosis of TTS when findings are inconclusive.

Diagnostic Modalities

Diagnosing TTS begins with a thorough history and physical exam to determine symptoms, identify potential etiological factors, and rule out other causes of heel pain or nerve compression. Diagnostic studies provide objective evidence to support a clinical diagnosis of TTS when findings are inconclusive.

These include:

Imaging: Radiographs evaluate the bony anatomy and alignment of the ankle and hindfoot. Ultrasound allows dynamic visualization of the tibial nerve, flexor tendons, and other structures within the tarsal tunnel. MRI defines soft tissue morphology and can detect space-occupying lesions, tendonitis, or a Baker's cyst.[12] These modalities exclude other pathologies but have limited sensitivity and specificity for TTS.

Nerve conduction studies: Electromyography (EMG) assesses the integrity and conduction velocity of the tibial nerve and its branches. A reduced amplitude of sensory responses in the medial and lateral plantar nerves or delayed distal motor latency of the abductor hallucis muscle suggest chronic nerve compression.[13] However, findings are often normal, especially in mild cases or when symptoms have a gradual onset over years. Serial studies may be required to detect abnormalities.

Diagnostic injections: A local anesthetic injection into the tarsal tunnel provides temporary relief of symptoms, which helps confirm the diagnosis. Cortisone reduces local inflammation that may be contributing to nerve compression, with longer-term relief indicating a role in symptoms. These injections also help determine if surgical intervention may be beneficial when symptoms return after the injected drugs lose effect.[14]

Pressure provocation tests: The pressure probe and Fowler's test manually apply focal pressure over the tarsal tunnel to reproduce patient symptoms.[15] These in-office tests lack standardization, sensitivity, and specificity, but their use is described for diagnosis when supported by clinical findings.

No single diagnostic modality can confirm or exclude TTS. Diagnosis relies on clinical presentation supported by findings across imaging, electrophysiology, and diagnostic injections. When uncertain, a trial of conservative treatment may also be useful to determine the potential benefit of surgical management.

Differential Diagnosis

Conditions that cause heel pain or nerve compression and mimic the symptoms of TTS include:

Plantar fasciitis: Dull ache in the sole, heel, and arch, worse in the morning or with initial steps. Tenderness at the medial calcaneal tubercle. 50% of patients have flat feet or high arches.[16] X-rays are normal; US or MRI may show plantar fascia thickening. Symptoms improve with stretching, orthotics, or steroid injections.

Stress or bony fractures: localized tenderness over the fracture site. History of increased activity or trauma. Radiographs detect fractures, and MRI is confirmative. Immobilization and avoiding weight-bearing relieve symptoms.

Morton's neuroma: sharp pain and paresthesias in the 3rd web space, worse with walking, jumping, or toe squeeze. Palpable mass between metatarsals on exam. Diagnosis is clinical; US, MRI, or diagnostic injections may be used. Conservative treatment focuses on shoe modifications, orthotics, and steroid injections.

Nerve entrapment: Compression at a single site elicits symptoms. Common locations include the medial malleolus (Baxter's nerve), the deep peroneal nerve at the foot dorsum, or the intermetatarsal nerves at the toes. The diagnosis is clinical; electrophysiology studies confirm nerve dysfunction. Treatment focuses on padding, orthotics, steroid injections, or surgery to release the entrapped nerve.

Vascular claudication: Aching pain in the arch, heel, or calf muscles with walking that subsides with rest. Absent or diminished pedal pulses on examination The ankle-brachial index detects arterial insufficiency. Treatment includes lifestyle changes, medication, and, in severe cases, surgical revascularization.

The diagnosis of TTS requires a thorough clinical workup to rule out conditions that could mimic or contribute to symptoms. The distribution of pain and paresthesias, findings on imaging, and response to diagnostic injections help distinguish TTS as the primary diagnosis and underlying cause of disability. The key to differentiation is identifying or excluding pathologies at sites other than the tarsal tunnel that may be contributing to or primarily responsible for the patient's symptoms.

Management

Treatment of TTS aims to reduce tibial nerve compression through conservative or surgical means, depending on symptom severity and the underlying etiology. Conservative options are trialed first, with surgery reserved for those failing medical management or with acute trauma, space-occupying lesions, or fixed deformities.

Conservative treatment includes:

Rest and immobilization: Reduces mechanical compression from activity. Especially beneficial in traumatic or acute cases. Prescribe limited weight-bearing and ankle bracing for up to 6 weeks.[17]

Physical therapy: Focuses on stretching and strengthening intrinsic foot and ankle muscles. Ultrasound, massage, and iontophoresis with dexamethasone provide anti-inflammatory effects.[18] In a study of 46 TTS patients, PT reduced symptoms in 70% of cases, with benefits maintained at 6 months.[19]

Orthotics and bracing: Arch support, padded shoe inserts, and ankle braces or strapping redistribute pressure and provide stability. Benefits over 75% of patients in studies with significant pain and function improvement.[20,21]

Medications: NSAIDs reduce inflammation and pain. Gabapentin, or pregabalin, for neuropathic pain has some benefits. Steroid injections may be useful when symptoms are refractory to other treatments.[22] Injections of hydrocortisone showed over 90% efficacy in multiple studies.[23,24]

Activity modification: Avoid walking long distances, climbing stairs or hills, driving, and prolonged standing or sitting. Lifestyle changes are very effective at controlling symptoms in mild to moderate cases.[25]

For severe or refractory cases, surgery aims to release the flexor retinaculum and decompression the tibial nerve. Open procedures were first described in 1962 and popularized in the 1970s. Recent minimally invasive options include endoscopic and percutaneous techniques with similar efficacy but lower morbidity:[26]

Open decompression: Gold standard, with up to 90% success rate. Requires a 3-5 cm incision along the posteromedial ankle.[27] Risks include damage to vascular and tendon structures, as well as wound complications.

Endoscopic decompression: Two small incisions through which surgical instruments are inserted. Magnification and illumination allow clear visualization of the tibial nerve. Similar patient outcomes to open surgery with a lower risk of complications.[28]

Percutaneous decompression: Needle is inserted under US guidance to cut the flexor retinaculum. Least invasive option but technically difficult, and the risk of neurovascular damage is higher. There is limited available evidence on efficacy.[29]

In summary, a graduated approach, starting with conservative modalities followed by surgical options if needed, provides the best opportunity for symptom relief and functional restoration in patients with TTS. Monitoring response to treatment guides escalation to more aggressive interventions to gain control of symptoms and avoid long-term disability from this condition.

CONCLUSION

Tarsal tunnel syndrome requires a multidisciplinary approach for diagnosis and management due to its complex anatomy and variable etiology. Conservative treatment provides relief for most patients, but minimally invasive surgery may be required for refractory or severe diseases. Close follow-up and patient education are essential to maximizing and maintaining improvements from interventions. No single diagnostic test can conclusively diagnose TTS, so a high level of clinical suspicion and a combination of modalities to rule out other causes are needed. With a focused treatment plan addressing all underlying factors, a significant reduction or resolution of pain, paresthesia, and weakness can be achieved, allowing a return to high-level function.

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CANAL FILL RATIO IN HEMIARTHROPLASTY COMPARED TO TOTAL HIP ARTHROPLASTY: A CASE CONTROL STUDY

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ABSTRACT

Background: Cementless stems are commonly used in hemiarthroplasty (HA) for femoral neck fractures. Recent studies have reported increased risk of periprosthetic fracture with cementless stems compared to cemented HA. In elective total hip arthroplasty (THA), lower proximal canal fill ratios (CFR) of cementless stems have been associated with worse outcomes. The purpose of this study was to compare CFRs and complications following HA for femoral neck fracture compared to THA for arthritis. We hypothesized that HA would have lower CFRs.

Methods: 130 patients undergoing cementless hemiarthroplasty for femoral neck fracture were identified and matched by age, sex, and BMI to 328 patients undergoing elective cementless THA. Postoperative radiographs were independently evaluated by two investigators to determine Dorr femur type and CFR at four points. Interrater agreement was calculated for CFR and Dorr type. Complication rates were compared between HA and THA groups.

Results: Dorr type and CFR measurements showed strong agreement between investigators. Dorr type was similar between groups. Hemiarthroplasties had significantly lower CFR at each level, with the greatest difference at the lesser trochanter. Dorr C femurs had worse CFR, specifically in the HA group. Complications rates were similar between HA and THA.

Conclusion: Worse CFR in HA compared to THA further suggests that cemented stems should be considered in HA. Suboptimal CFR represents a potential cause of complications including periprosthetic fracture following HA.

Level of Evidence: III

Keywords: hemiarthroplasty, canal fill ratio, periprosthetic fractur

INTRODUCTION

Hip fracture is a serious medical condition in the elderly population with high morbidity and mortality which often leads to compromised mobility and significant associated healthcare expenses. In the US, it is estimated that the rate of hip fractures in recent years has increased due to a large aging population with increased risk factors for hip fractures such as osteoporosis.[1,2] Displaced unstable femoral neck fractures are of the greatest concern due to their delicate blood supply and typically require early surgical intervention to prevent further complications.[3] However, there is debate within the orthopedic community about the optimum surgical intervention for treating hip fractures in order to produce the best outcomes and minimize complications.

Common methods to treat femoral neck fractures include cannulated screw fixation and either cemented or cementless hemiarthroplasty (HA) or total hip arthroplasty (THA). Cannulated screws might seem preferable due to shorter operative times, but a growing body of evidence has shown that HA is associated with lower rates of reoperation and mortality, while leading to higher functional outcomes compared to screw fixation for intracapsular hip fractures.[4-7] Areas of controversy remain regarding choice of HA compared with THA[8-10] as well as choice of cemented implants versus cementless. Advantages of uncemented HA include shorter operative time, less blood loss, preservation of bone stock, potential for osseointegration, and theoretical lower rates of intraoperative cardiovascular collapse.[11] However, multiple recent studies have reported increased risk of periprosthetic fracture with cementless stems compared

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to cemented HA.[12-14] Patients thinner femoral cortices, as described by the Dorr classification, have been shown to be at increased risk for intraoperative fracture.[15,16]

There is little to no published data regarding the fit of the femoral prosthesis within the femoral canal in cementless HA and how fit confers to risk for periprosthetic fractures. A technique measuring canal fill described for elective THA has shown a relationship with radiographic complications, including subsidence.[17] The purpose of this study was to determine if canal fill after hemiarthroplasty for femoral neck fractures is suboptimal. The comparison group chosen was patients undergoing routine THA for osteoarthritis with cementless fixation. Although some authors have suggested that THA patients with severe osteoporosis should have cemented fixation, implant placement without cement is still in common usage.[18-20] We hypothesized that cementless HA for femoral neck fracture would be associated with lower CFRs compared to elective primary THA and that worse CFR could be an explanation for increased complication rates.

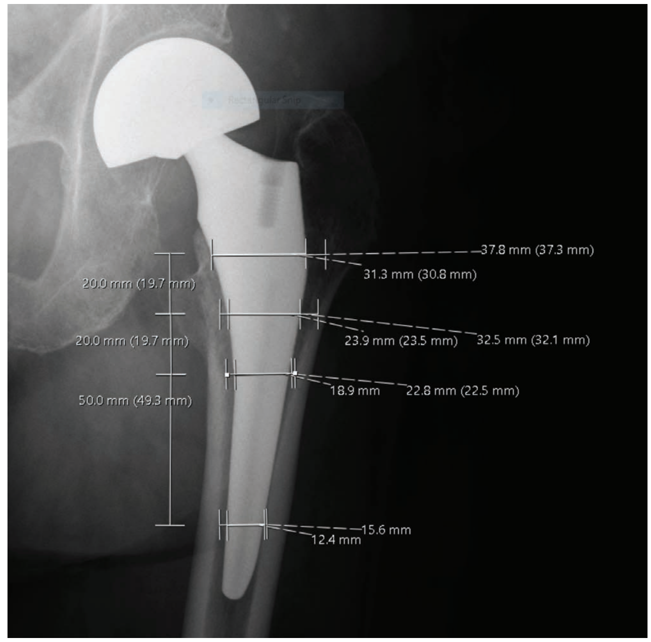

Figure 1. CFR calculated at the lesser trochanter (LT) as 23.9/32.5 = 73.5%; the LT +2 cm as 31.3/37.8 = 82.8%; the LT -2 cm as 18.9/22.5 = 84.0%; and the LT -7 cm as 12.4/15.6 = 79.5.

METHODS

Population and Data

Following institutional review board approval, 130 patients undergoing cementless HA for femoral neck fracture between January 2010 and November 2020 were identified. A power analysis was conducted, determining that this cohort size would allow for at least 90% power to detect differences in canal fill ratio. Procedures were performed by one of 27 surgeons in a large orthopaedic practice with multiple locations throughout a metropolitan region. Patients were propensity matched by age, sex, and body mass index (BMI) to 328 patients undergoing cementless primary elective THA for osteoarthritis. Revisions and primaries using revision-type implants were excluded. Stem type was recorded based on the classification system described by Khanuja et al.[21]

Postoperative radiographs were independently evaluated by two investigators (SK and JH) to determine Dorr femur type and canal fill ratio (CFR). CFR was calculated by dividing the diameter of the femoral stem by the intramedullary canal diameter at four points as described by D'Ambrosio: the level of the lesser trochanter (LT), the LT + 2 cm, LT -2 cm, and LT -7 cm.[22] An example CFR calculation is shown in Figure 1. Charlson Comorbidity Index (CCI) was recorded for each patient. The electronic medical record was queried to identify 90-day complications, 90-day readmissions, and reoperations on the same hip for any reason.

Table 1. Demographics of Hemiarthroplasty and Total Hip Arthroplasty Groups

	Hemiarthroplasty (n=130)	THA (n=328)	P value
Age	79.8 +/- 10.7	79.1 +/- 10.1	0.344
Sex			0.06
Male	29.2%	36.0%	
Female	70.8%	64.0%	
Race			0.626
White (Non-Hispanic)	86.2%	84.1%	
Black	6.1%	8.8%	
Other	7.7%	7.1%	
BMI	25.2 +/- 5.6	25.5 +/- 4.4	0.160
Charlson Comorbidity Index	1.76 +/- 3.0	0.7 +/- 1.1	0.711
Stem			<0.001
Type 1	76.2%	96.4%	
Type 2	16.9%	2.7%	
Type 3	6.9%	0.9%	

Reported as mean +/- standard deviation or percentage. P values from Mann Whitney, Chi square, or Fisher exact tests.

Statistical Methods

Interrater reliability was calculated for CFR using intraclass correlation coefficients (ICC) and for Dorr classification using Fleiss's Kappa. Continuous variables were compared between groups using Mann-Whitney tests. Nonparametric data was reported as median and interquartile range (IQR). Categorical variables were analyzed with chi square or Fisher exact tests and reported as percentages. For Dorr classification, THA and HA femur types were compared using a pairwise comparison or proportions using the average proportion of classification by each reviewer. For CFR, average measurement values between reviewers were used to compare HA to THA. Multiple comparison testing was used to compare CFR between different Dorr types in patients where reviewers agreed on Dorr type. Logistic regression was used to investigate association of the CFR with complications. An alpha of 0.05 was used for all statistical tests. All statistical analyses and calculations were performed using R software (Foundation for Statistical computing, Vienna, Austria).

RESULTS

Demographics

Mean age of patients undergoing hemiarthroplasty for femoral neck fracture was 79.8 +/- 10.7 years compared to 79.1 +/- 10.1 years in matched patients undergoing elective primary THA (p=0.461). The majority of patients undergoing HA were female (70.8%) and white (86.2%). Age, sex, BMI, and race were statistically similar between groups (Table 1). Median CCI was also similar between groups. Type 1 stems (single wedge) were used for the majority of cases in both groups; however, the frequency of type 2 (double wedge, metaphyseal filling) and type 3 stems (tapered) was higher for HA than for THA (Table 1).[21]

Dorr Classification and Canal Fill Ratio

Classification of femur Dorr type showed strong agreement between reviewers (Table 2). Based on pairwise comparisons with Bonferroni correction, Dorr types showed no significant differences between THA and HA (Table 3). Type B femurs were more common in both groups, followed by type A then type C.

There was strong agreement between reviewers of the measured canal fill ratios (ICC >0.7) at the level of the lesser trochanter, 2 cm above the lesser trochanter, and 2 cm below the lesser trochanter. There was moderate to strong agreement (ICC 0.674) between reviewers 7 cm below the lesser trochanter. Using mean CFR between reviewers, the canal fill was significantly greater for THA compared to HA at each level (Table 3). This difference was greatest at the level of the lesser trochanter, with a median CFR of 0.86 compared to 0.71 (p<0.001). The difference was smallest 7 cm below the greater trochanter, although the difference was still significant (median 0.85 versus 0.79, p<0.001). Effect size was moderate to large at all levels.

Dorr classification A versus C was also significantly associated with CFR (tables 4 and 5) at the level of LT -2 cm (0.89 vs 0.86, p=0.049) (Figure 2). While statistically significant, the slight difference for THA was likely

Table 2. Agreement Between Reviewers for Dorr Classification and CFR

	Agreement Index	P value or 95% Confidence Interval	Agreement Strength
Dorr Femur Type			
Type A	0.804	p<0.001	Strong
Type B	0.852	p<0.001	Strong
Type C	0.775	p<0.001	Strong
Canal Fill Ratio			
LT + 2 cm	0.720	95% CI: 0.586 – 0.803	Strong
Lesser trochanter	0.826	95% CI: 0.731 – 0.869	Strong
LT – 2 cm	0.778	95% CI: 0.725 – 0.820	Strong
LT – 7 cm	0.674	95% CI: 0.674 – 0.721	Moderate/ Strong

Agreement indices were Fleiss' Kappa for Dorr type and Intraclass Correlation Coefficients for CFR.

Table 3. Dorr Type and CFR in Hemiarthroplasty and THA

	Hemiarthroplasty	THA	Effect Size	P value
Dorr Femur Type				
Type A	28.1%	22.9%		0.399
Type B	49.6	62.3%		0.070
Type C	22.3%	14.2%		0.173
Canal Fill Ratio				
LT + 2 cm	0.66 +/- 0.10	0.74 +/- 0.06	0.98	<0.001
Lesser trochanter	0.71 +/- 0.16	0.86 +/- 0.07	1.12	<0.001
LT – 2 cm	0.76 +/- 0.13	0.87 +/- 0.07	1.06	<0.001
LT – 7 cm	0.79 +/- 0.13	0.85 +/- 0.10	0.53	<0.001

Reported as percentage or mean +/- standard deviation. P values from proportions test (Dorr type) and t tests (CFR).

Table 4. CFR by Dorr Type for THA

	Dorr A	Dorr B	Dorr C	P value
LT + 2 cm	0.73 [0.69, 0.77]	0.74 [0.70;0.77]	0.75 [0.68;0.80]	0.559
Lesser trochanter	0.86 [0.82, 0.90]	0.88 [0.84;0.91]	0.88 [0.81;0.92]	0.219
LT – 2 cm	0.89 [0.86, 0.92]	0.88 [0.84;0.93]	0.86 [0.81;0.92]	0.192
LT – 7 cm	0.88 [0.82, 0.92]	0.87 [0.81;0.92]	0.84 [0.80;0.91]	0.284

Reported as median [25th percentile; 75th percentile].

Table 5. CFR by Dorr Type for HA

	Dorr A	Dorr B	Dorr C	P value
LT + 2 cm	0.67 (0.09)	0.66 (0.09)	0.67 (0.09)	0.793
Lesser trochanter	0.85 [0.68;0.90]	0.73 [0.58;0.85]	0.67 [0.60;0.81]	0.018
LT – 2 cm	0.87 [0.77;0.91]	0.79 [0.71;0.84]	0.75 [0.58;0.79]	<0.001
LT – 7 cm	0.89 [0.82;0.95]	0.80 [0.72;0.89]	0.74 [0.62;0.80]	<0.001

Reported as mean +/- standard deviation or median [25th percentile; 75th percentile].

clinically insignificant. HA showed decreasing CFR from Dorr A to Dorr B to Dorr C at the lesser trochanter and below (table 5). The greatest differences were found between Dorr A and Dorr C femurs, with lower CFRs at the levels of the LT (0.85 vs 0.67, p=0.022), the LT -2 cm (0.87 vs 0.75, p=0.001), and the LT -7 cm (0.89 vs 0.74, p<0.001) (Figure 3).

Complications

At least 90-day follow-up was obtained for 89.3% of the THA group and 76.9% of the HA group. Ninety-day total complication and readmission rates were similar between groups, as shown in Table 6. Complications occurred in 4.6% of patients undergoing THA, and 3.5% of patients were readmitted. 8.5% of patients undergoing HA experienced a complication, and 1.5% were readmitted. Complications in the THA group included periprosthetic fracture, instability, prosthetic joint infection, persistent wound drainage, seroma, venous thromboembolism, syncope, and urinary tract infection (UTI), and two mortalities. Complications in the HA group included periprosthetic fracture, prosthetic joint infection, instability, pneumonia requiring intensive care, and UTI, and six mortalities. The combined fracture/dislocation rates were similar between groups (THA 0.9% versus HA 1.5%, p=0.625). There was a significantly higher 90-day mortality rate in the HA group (4.6% versus 0.6%, p=0.008). Logistic regression did not demonstrate increased complication rates based on worse CFR.

Six patients (1.8%) in the THA group underwent reoperation. Reasons included periprosthetic fracture, revision for dislocation, revision for prosthetic joint infection, and irrigation and debridement for wound infection. Two patients (1.5%) in the HA group required additional surgery for prosthetic joint infection and periprosthetic fracture.

DISCUSSION

The most significant finding of this study was that canal fill ratio was significantly lower for patients undergoing cementless hemiarthroplasty compared to THA in a matched cohort, and this was demonstrated with strong interrater agreement. This finding occurred despite similar percentages of Dorr A, B, and C type femurs that were also classified with strong interrater agreement. Additionally, we found that Dorr type was associated with CFR to a greater extent in HA than THA. We did not demonstrate significant differences in complication

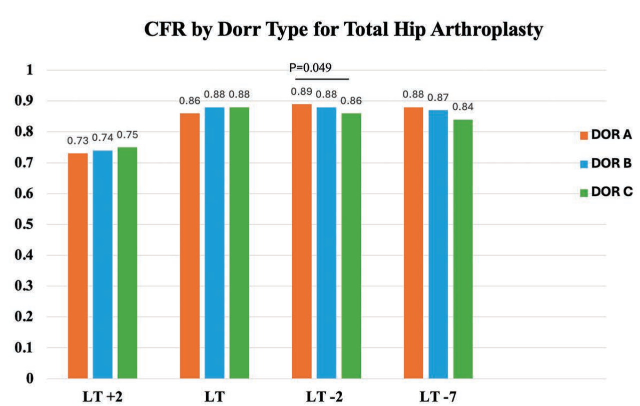

Figure 2. CFR by Dorr Type for Total Hip Arthroplasty.

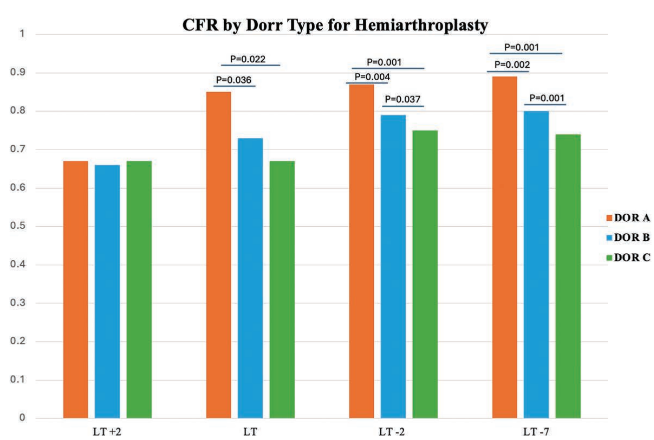

Figure 3. CFR by Dorr Type for Total Hemiarthroplasty.

Table 6. Complications and Readmissions

	Hemiarthroplasty	THA	P value
Total Complications	8.5%	4.6%	0.162
Fracture or Dislocation	1.5%	0.9%	0.625
Readmission	1.5%	3.4%	0.367
Reoperation	1.5%	1.8%	0.999
90-day mortality	4.6%	0.6%	0.008

P value from Fisher exact tests.

or readmission rates between the groups. Periprosthetic fractures, dislocations, and reoperations all occurred at similar rates, although mortality was higher in patients undergoing hemiarthroplasty.

Urgent surgical intervention within 48 hours has been shown to reduce morbidity and mortality following femoral neck fractures.[23] Hemiarthroplasty is often preferred for displaced fractures, especially in elderly patients, and has a lower perceived difficulty compared to THA.[24] Cementless hemiarthroplasty specifically has the advantage of shorter operative times and blood loss, which can be critical when dealing with elderly patients often presenting with multiple medical comorbidities.[25] A recent meta-analysis by Fenelon et al. showed higher mortality within two days of cemented HA compared to uncemented HA, but no difference at seven days, thirty days, or one year following surgery.[26] In a randomized trial, Taylor et al. described a higher rate of implant related complications following cementless hemiarthroplasties.[27] They noted significantly increased rates of subsidence, intraoperative fracture, and postoperative periprosthetic fracture. They found cementless HA operative times to be slightly shorter but observed no differences in blood loss, length of stay, or postoperative pain. Langslet et al. similarly described a higher rate of postoperative periprosthetic fractures following cementless HA, but also found significantly higher Harris hip scores at 5 years postoperatively.[13] Our data may provide an anatomical basis for this finding and supports the recommendation that cemented fixation should be considered for HA.

As HA is generally performed on a more urgent basis compared to THA, surgeon experience may contribute to the ability to achieve optimal implant fit. While it has been shown that hemiarthroplasty can be safely performed regardless of surgeon volume,[28] our theory is that less experienced arthroplasty surgeons may provide at least a partial explanation for lower canal fill rations in these patients.[29] However, our study was not designed to evaluate this, since all patients were operated on by specialized arthroplasty surgeons with extensive experience in placing implants. In fact, our group of 27 arthroplasty surgeons still demonstrated inferior CFR's as compared to the matched cohort of total joint patients.

Analysis of implant type between the two groups demonstrated some important differences. Interestingly, in spite of a higher rate of type 2 metaphyseal filling stems used in the hemiarthroplasty group, canal fill was still lower at all levels. Rattanaprichavej et al. recently found that Dorr B and C femurs had a higher rate of subsidence following THA, noting that a higher CFR at 2 cm below the lesser trochanter was protective against subsidence.[30] When looking at patients with periprosthetic fracture following THA, Bigard et. found that Dorr C femurs conferred a greater risk, although canal fill was not significantly associated with fracture.[31] Our study found that Dorr C femurs in hemiarthroplasty had significantly worse canal fill at multiple levels compared to Dorr A. These findings suggest that Dorr C femurs along with poor CFR may contribute to periprosthetic fracture risk. Surgeons might be tempted in these cases to use a larger stem, but this must be balanced with the risk for intraoperative fracture when trying to place a larger stem in a Dorr C femur. This study was not powered to determine whether a more canal filling stem type would be advantageous.

CFR is a topic that remains relatively unstudied in the current literature, especially relating to hemiarthroplasty. Only a single study by Lo et al. has reported on CFR in HA, finding that lower CFR was associated with increase rates of subsidence in bipolar HAs at 12 weeks follow-up.[32] They acknowledged this subsidence as an important risk factor for complications, although excluded patients with early periprosthetic fracture from analysis. To our knowledge, our study is the first to compare CFR of HA to THA. These findings demonstrated that although the fit of femoral prosthesis in cementless HA was less than THA, it did not correlate with an increased risk of periprosthetic fracture or any other type of complication. While our study demonstrated differences in CFR between HA and THA and the association of Dorr type on CFR, it was likely underpowered to detect statistically significant differences in complications such as dislocation or periprosthetic fracture.

Limitations of our study include the retrospective nature and limited follow up of our patients. As hemiarthroplasties are generally performed urgently, it is possible that postoperative complications may have arisen that presented to an outside hospital limiting accurate tracking of complications. We found a lower rate of complications in this cohort than commonly described in the literature, which suggests that complications likely occurred in patients lost to follow-up.[33-35] As discussed, our cohort was powered to detect differences in CFR but not events such as periprosthetic fracture and dislocation. Utilization of data only from arthroplasty surgeons also limited our ability to interpret results for surgeons in general practice. Our a priori decision to propensity matches the patients for age also biased the results since the average THA patient is younger than that for HA. However, the fact that a matched group of osteoarthritic THA patients showed improved canal fill, indicates that there is something clearly different about patients undergoing HA for fracture.

CONCLUSION

Patients who undergo cementless HA for femoral neck fractures have inferior canal fill ratios compared to routine THA patients. This suggests that the mechanism for increased periprosthetic fractures in these patients may be suboptimal canal fill. Given that CFR rates are concerningly low post cementless HA, when interpreted in the context of previously published data, our findings further strengthen the rationale for utilizing cemented fixation in the setting of HA post hip fracture. Future research is necessary to determine whether these trends can be reversed utilizing alternative stem designs that are able to achieve improved canal fill and large studies will be necessary for adequate power to show direct relationship to periprosthetic fracture.

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CORONAL MALALIGNMENT IS INFREQUENTLY PRESENT IN PATIENTS WITH ASEPTIC TIBIAL LOOSENING

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ABSTRACT

Background: Coronal lower extremity malalignment and improper implant position have been described as risk factors for aseptic tibial loosening following primary total knee arthroplasty (TKA). However, several prior studies have shown no association between alignment and implant loosening. Meanwhile, there is increasing interest in kinematic alignment. Therefore, we sought to determine the incidence of coronal malalignment of the limb and tibial component in patients that were revised secondary to aseptic tibial loosening.

Methods: A cohort of 73 patients that were revised for aseptic tibial loosening was identified. Patient demographics were recorded. Radiographs from the primary procedure (preoperative and postoperative) were reviewed to determine the index coronal alignment of the knee and tibial component. Adequate alignment was noted if limb alignment was in neutral or appropriate valgus alignment and tibial implant position was within 3° of the neutral mechanical axis.

Results: Four (5.5%) patients had varus alignment of the tibial component >3°. Therefore, 69/73 (94.5%) patients had well-aligned tibial implants. The average coronal alignment of the limb was 3° of valgus and six (8.2%) patients had coronal varus limb alignment (all >0° anatomic varus).

Conclusion: Limb and tibial implant malalignment were infrequently seen in patients revised secondary to aseptic tibial loosening. Most patients fell within previously described "safe" alignment parameters (<3° varus for the tibial component and neutral or valgus limb alignment). Specifically, malalignment was only present in approximately six to eight percent of patients. Therefore, factors other than alignment appear to contribute most to the development of aseptic tibial loosening.

Level of Evidence: III

Keywords: total knee, alignment, aseptic loosening, malalignment, arthroplasty, revision

INTRODUCTION

Total knee arthroplasty (TKA) is an effective procedure for improving pain and function in patients with knee osteoarthritis.[1-6] Despite favorable long term survivorship results, a subset of patients will unfortunately require revision surgery for a variety of reasons.[7-9] One of the most common reasons for failure following TKA remains aseptic loosening.[10-13] In fact, as other modes of failure become less common, including polyethylene wear and osteolysis, the relative burden of aseptic loosening failures has increased.[14,15] As such, numerous contemporary studies have demonstrated aseptic loosening to be one of the top three causes of failure following TKA.

Previous authors have attempted to define risk factors for aseptic loosening. There have been a variety of risk factors associated with aseptic loosening including obesity, preoperative varus deformity, cement viscosity, and cementation technique including lipid contamination and motion during cementation.[16-22] However, the role of limb and tibial alignment as a risk factor for loosening remains controversial. Berend et al. noted tibial alignment of >3° varus and a varus limb alignment of ≥0° were significantly associated with tibial varus collapse.[23] However, several recent studies have failed to demonstrate an association between implant loosening and coronal implant malalignment.[25]

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Abdel et al. performed a twenty-year retrospective review of 398 TKAs[26] and found there was no significant difference in aseptic loosening between patients that were mechanically aligned (0° ± 3° relative to the mechanical axis) and those that were not (19.5% vs. 15.1% (p=0.97), respectively). Most studies that have reviewed this topic are small retrospective cohort studies. Unfortunately, large databases do not capture radiographic parameters such as limb and implant alignment, and consequently are not able to offer any further insight on this topic. Therefore, there is still debate as to whether coronal malalignment contributes to implant loosening. To further study this concept, we asked the following research question: how frequent is limb and tibial coronal malalignment identified in patients with aseptic tibial loosening? We hypothesized that even among a cohort of patients revised for aseptic tibial loosening, component and limb malalignment would be uncommon.

METHODS

This is an institutional review board approved, retrospective cohort study of patients from a single institution. Inclusion criteria included those who underwent primary TKA and who were subsequently revised for aseptic tibial loosening, those who had cemented primary TKAs, and those who had radiographs demonstrating tibial implant loosening confirmed intraoperatively. Exclusion criteria included femoral component loosening, failure due to infection, and no radiographs prior to failure. The institutional joint registry was queried from 2010-2021 to identify all such patients. Prior to revision, all patients had radiographs demonstrating tibial implant loosening and this finding was confirmed intraoperatively. With this criteria, 73 patients were identified for inclusion.

A retrospective chart review and database query were utilized to collect patient demographic information including age, gender, body mass index, as well as date of primary and revision surgery.

A radiographic analysis was performed on this patient population's preoperative and postoperative (primary TKA) radiographs. The preoperative evaluation included assessing the following radiographic parameters on the anteroposterior (AP) knee standing radiograph: 1) the anatomic lateral distal femoral angle (alDFA), 2) the anatomic medial proximal tibial angle (amPTA), and 3) the anatomic femoral tibial angle (aFTA).[27,28] Similarly, the following radiographic parameters were recorded on the three-month postoperative (primary TKA) AP knee radiograph: 1) the alDFA, 2) the amPTA, and 3) the aFTA.

We categorized the tibial implant position (amPTA) into two categories: 1) well-aligned (0° ± 3° of varus or valgus) and 2) mal-aligned >3° of varus or valgus. Similarly, given precedence in the literature, we classified the anatomic coronal limb alignment (aFTA) as 1) well-aligned neutral or valgus anatomic alignment and 2) mal-aligned for anything >0° varus. No included patients had postoperative alignment ≥10° of anatomic valgus.

Stats

Study data were collected and managed using REDCap electronic data capture tools hosted at our institution. All data underwent descriptive statistical analysis using SAS version 9.4 (SAS Institute, Cary, NC; http://www.sas.com/software/sas9). Standard descriptive statistics were reported including measures of central tendency, variance, as well as frequencies and proportions.

RESULTS

Patient Demographics

The cohort consisted of 73 patients that were revised secondary to aseptic tibial loosening. The mean age was 60.0 years and mean BMI was 34.2 kg/m^2. There were 50 females and 23 males included (Table 1).

Outliers

Only four (5.5%) patients had varus alignment of the tibial component >3°. Therefore, 69/73 (94.5%) patients had well-aligned tibial implants. Only six (8.2%) patients had overall varus limb alignment (amPTA) (>0° varus). (Table 2).

Preoperative Radiographic Assessment

Preoperative radiograph assessment demonstrated the overall mean aFTA was 0.2° varus (range: 15° varus to 11° valgus). Preoperative amPTA was 3.8° varus (range: 11° varus to 2° valgus). Preoperative alDFA was 6.3° valgus (range: 2° valgus – 10° valgus) (Table 3). 27 patients had valgus alignment, three had neutral alignment, and 43 had varus alignment.

Postoperative Radiographic Assessment

Postoperative radiographic assessment demonstrated the overall aFTA alignment was 2.7° valgus (range: 5° varus to 9° valgus). The postoperative amPTA was 1° varus (6° varus to 3° valgus) The postoperative alDFA was 4.5° valgus (range: 1° valgus – 8° valgus) (Table 4).

Table 1. Patient Demographics

Age (years) (Range)	60 ± 8.2 (46—79)
Gender (%female)	68.4
BMI (kg/m2) (Range)	34.2 ± 6.3 (21.4—50.0)
BMI > 40 kg/m2, n (%)	14 (19%)

Table 2. Outliers

Varus amPTA outlier, n (%)	6 (8.2%)
Varus tibial component >3°, n (%)	4 (5.5%)

Table 3. Preoperative Radiographs

aFTA (mean, range)	0.2° varus (15° varus – 11° valgus)
amPTA (mean, range)	3.8° varus (11° varus – 2° valgus)
alDFA (mean, range)	6.3° valgus (2° valgus – 10° valgus)

Table 4. Postoperative Radiographs

aFTA (mean, range)	2.7° valgus (5° varus – 9° valgus)
amPTA (mean, range)	1° varus (6° varus – 3° valgus)
alDFA (mean, range)	4.5° valgus (1° valgus – 8° valgus)

DISCUSSION

The role that coronal malalignment plays in determining risk of tibial aseptic loosening following primary TKA remains disputed.[24,26,29] Initial studies with older implants suggested that anatomic coronal alignment is associated with a significant decrease in aseptic loosening.[24,29] These earlier studies have explored both anatomic limb and tibial component coronal alignment. Contrarily, more recent studies have failed to demonstrate any association between coronal alignment and implant loosening.[25,26]

Berend et al. initially showed varus alignment of the tibial component >3° and/or varus limb alignment were statistically associated with varus collapse of the tibial component.[29] In a similar study from the same institution, Ritter et al. evaluated risk factors for implant loosening in 6,070 knee replacements.[24] They concluded that tibial implant varus alignment was a significant risk factor for implant loosening. To the contrary, Abdel et al. assessed mechanical alignment using full length hip-to-ankle films and found that the long-term incidence of revision for "well-aligned" and "mal-aligned" TKA was similar (19.5% vs. 15.1% (p=0.97)), respectively.[26]

The impact of alignment on outcomes following TKA is of perhaps increasing importance given the recent interest in kinematic alignment principles. When using kinematic principles, the limb and tibial component alignment are often positioned outside of the previously defined "safe zones." A recent randomized controlled trial comparing kinematic and mechanical alignment failed to demonstrate any significant difference in tibial component migration or loosening.[30] In fact, to our knowledge, no study evaluating kinematically aligned knees has demonstrated a significantly increased risk of aseptic tibial loosening when compared to mechanical alignment.

Most patients in our study had knee replacements that fall within previously described "safe zones." These "safe zones" include an aFTA in neutral or valgus and an amPTA within 3° of varus or valgus from the mechanical axis. In our study, ~92% of patients had neutral or valgus coronal limb alignment. Additionally, only four patients were noted to have excessive (>3° varus) tibial component varus. Therefore, in this series, over 90% of patients revised for aseptic tibial loosening had adequate limb and tibial component coronal alignment.

Numerous factors are known to be associated with aseptic tibial loosening. These factors include, but are not limited to, patient BMI, implant size, preoperative alignment, and cementation technique.[21,22,24,31,32] Recent evidence suggests that the implant-cement interface is the "weak link" in tibial component fixation.[33] However, the exact mechanism for implant failure is still undetermined. While a long-held adage of TKA has stressed the importance of neutral coronal alignment in preventing tibial aseptic loosening, limb and tibial coronal alignment were within acceptable limits for the vast majority of patients in this study. Taken in conjunction with contemporary work demonstrating no difference in long-term revision in well- and mal-aligned TKAs, it appears factors other than alignment are likely driving aseptic loosening.

While this study represents the first evaluation of limb and tibial implant coronal alignment in a large cohort of patients with aseptic tibial loosening, there are several notable limitations. First, this study was retrospectively performed, and therefore has limitations related to the study design. Second, the denominator for mal-positioned TKA patients for this study is unknown. Therefore, we are unable to comment on incidence of aseptic loosening in "well-aligned" vs. "mal-aligned" knees. However, we can conclude that "well-aligned" knee replacements are still at risk for aseptic loosening and represent the majority of patients being revised for this indication. Third, the alignment method chosen by the surgeon was unknown. In other words, we were unable to determine if the surgeon's intent was to position the patient in mechanical or kinematic alignment. Fourth and finally, antero-posterior knee radiographs were utilized to determine coronal implant and limb alignment.

While it is known that this is not the ideal method to assess coronal alignment, the previously published alignment "safe zones" that were utilized in this study were based off AP knee radiographs.[24,29]

Most patients with aseptic tibial loosening have both coronal limb and tibial implant alignment within previously defined "safe zones." While extreme implant malpositioning could contribute to implant failure and is to be avoided, in this study only six to eight percent of patients with aseptic loosening had mal-aligned tibia or overall varus limb alignment, respectively. Therefore, efforts for potentially decreasing the incidence of aseptic loosening should primarily focus on design or technique factors aimed at improving implant fixation.

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HIP DYSPLASIA DIAGNOSED AFTER SKELETAL MATURITY: FACTORS ASSOCIATED WITH PROGRESSION TO OSTEOARTHRITIS

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ABSTRACT

Background: Hip dysplasia diagnosed after skeletal maturity is distinct from developmental dysplasia of the hip (DDH) in infants and young children. While the natural history of DDH in infants and young children is well-established, the association between hip dysplasia diagnosed after skeletal maturity and osteoarthritis is less clear. This narrative review summarizes existing literature assessing characteristics of hip dysplasia diagnosed after skeletal maturity associated with progression to osteoarthritis.

Methods: Publications were identified from a PubMed search. Three reviewers screened articles for studies that longitudinally assessed progression to osteoarthritis, disability, or arthroplasty for individuals with untreated hip dysplasia identified after skeletal maturity. In total, 13 articles met screening criteria, including 7 prospective cohorts, 2 case-control studies, 1 retrospective case series, 1 cross-sectional analysis, and 2 retrospective cohort studies.

Results: Most studies reported an association between radiographic hip dysplasia and development of osteoarthritis over time,[1-10] though some studies questioned the association between simple radiographic measures of dysplasia and joint degeneration.[11] Joint subluxation and incongruity, history of hip pain, and any evidence of radiographic osteoarthritis at the initial time-point were all reliably associated with future joint degeneration. Though many studies confirmed at least an association between the center edge angle of Wiberg and future osteoarthritis development, there was evidence proposed that clinical factors (age, sex, body mass), novel radiographic markers, and pathologic joint mechanics are significant contributors to joint failure.

Conclusion: Hip dysplasia diagnosed after skeletal maturity is associated with development of osteoarthritis beyond 10 years in the majority of published literature, though some studies question the reliability of simple radiographic measures as predictors of osteoarthritis development. Previous literature is limited by small sample size, follow up duration, low diversity in the population, and variable methods characterize severity of hip dysplasia and hip joint failure. Overall, evidence of hip subluxation and incongruity, female sex, more severe dysplasia, and low and high body mass are associated with development of osteoarthritis. Future studies should focus on large, diverse populations with follow up of at least 20 years and consider advanced metrics to quantify pathologic joint mechanics to predict hip joint failure.

Level of Evidence: IV

Keywords: hip dysplasia, osteoarthritis, hip dislocation, developmental dysplasia of the hip, hip osteoarthritis, progression of osteoarthritis

INTRODUCTION

Hip dysplasia encompasses a spectrum of hip disorders ranging from congenital hip dislocations in infants to radiographic undercoverage of the femoral head by the acetabulum in adolescents and adults.[12] In infants and young children, hip dysplasia is characterized by hip instability or dislocation. The natural history of hip dysplasia in infants and children (prior to skeletal maturity) is well-established for treated and untreated hips including the association with osteoarthritis and early end-point arthroplasty in the long term.[13-16] Radiographic hip dysplasia in adolescents or young adults (after skeletal maturity) can be a distinct pathology that is identified either incidentally or associated with

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pain and dysfunction.[14,17,18] The natural progression of hip dysplasia to osteoarthritis in adolescents and young adults is less clear. The aim of this narrative review is to summarize existing longitudinal studies reporting progression of hip dysplasia after skeletal maturity to osteoarthritis.

Hip dysplasia in adolescents and adults is primarily a radiographic diagnosis. In 1939, Gunnar Wiberg defined hip dysplasia with the center-edge angle measurement on an anterior posterior pelvis radiograph.[17] Even today the center-edge angle is widely established as the gold standard for radiographic evaluation of dysplasia.[19] However, recent studies indicate that the center-edge angle is likely an over-simplification of the three-dimensional acetabular deficiency in hip dysplasia.[20,21] Other radiographic measures are also employed to diagnose and quantify hip dysplasia, including Tönnis angle,[12] extrusion index, anterior and posterior wall indices,[22] Shenton's line to assess subluxation,[11,14] and others.[23]

Wiberg found that a center-edge angle of ≤ 20° predicted eventual osteoarthritis development.[17,19] Inadequate coverage of the femoral head by the dysplastic acetabulum results in a mechanical overload of the acetabular rim, cartilage, and labrum during weight-bearing activities.[24] Thus, over time, in adult populations, this damage leads to osteoarthritis.[12,17,19,25] However, not all studies support the conclusion that dysplasia is directly associated with osteoarthritis. Because of uncertainty surrounding the causative relationship between hip dysplasia and osteoarthritis, there is a need to examine the body of evidence reporting the natural progression of an untreated dysplastic hip to osteoarthritis. This narrative review summarizes the natural progression of untreated hip dysplasia identified after skeletal maturity to osteoarthritis.

METHODS

Publications were selected by searching the PubMed database through October 2023. The literature search was performed by a University of Iowa Carver College of Medicine librarian with assistance of the authors for key words. The following key words and related MESH terms were used: hip dislocation, developmental dysplasia of the hip, congenital hip dislocation, hip OA. The authors searched the reference lists of selected review literature for additional articles.

To be included, the study had to 1) report longitudinal outcomes of untreated dysplasia of the hip in skeletally mature individuals, 2) be available in English. No letter, editorial, or comment publications were included. Articles were excluded if 1) the primary purpose did not involve the natural progression of untreated hip dysplasia, 2) the subjects were only assessed at one timepoint, 3) the primary hip followed had previously undergone surgical treatment or intervention for dysplasia, 4) subjects were skeletally immature, or 5) animal models were the primary subjects. Articles reporting incidence of hip dysplasia in hips with osteoarthritis were not included in this review.

The search resulted in 690 articles from PubMed. After removing duplicates and screening titles and abstracts, 35 primary articles and 8 review articles were found. Full text papers were screened, and articles were excluded for not meeting the criteria outlined above. The reference lists of the selected review papers were screened for additional inclusion. For this focused review, 13 articles were included.

RESULTS

This review reports study findings that investigated the natural history of hip dysplasia after skeletal maturity. Joint failure in these studies was defined as progression to osteoarthritis, development of pain and dysfunction, and conversion to total hip arthroplasty. Tables 1-3 provide the characteristics for each of the primary studies assessed for this review. Our search resulted in 7 prospective cohorts, 2 case-control, 1 retrospective case series, 1 cross-sectional analysis, and 2 retrospective cohort studies.

Incidence and Timing of Osteoarthritis Progression

Progression of osteoarthritis secondary to untreated dysplasia has been described individually by Hasegawa, Iidaka, and Morita in their respective cohorts.[1,2,10] These findings provide a timeline of progression, progression rate of osteoarthritis, and the probability of symptomology aligning with progression itself. The specific findings are broken down below (Table 1).

In Hasegawa et al.'s longitudinal study, the authors examined a cohort of skeletally mature individuals with radiographic acetabular dysplasia and found a progression rate of 33% from pre-arthritis to early-arthritis in an average time course of 9.2 years.[1] This group was severely dysplastic with an initial mean center-edge angle of 3.7°. Radiographic markers of more severe dysplasia (lower center-edge angle and greater slope of the acetabular roof) were predictors of osteoarthritis progression. Those with more advanced osteoarthritis at baseline had a progression rate of 66% from early-arthritis to advanced-arthritis in an average time course of 7.8 years. This group had a mean initial center-edge angle of 1.1°, and broken Shenton's line predicted osteoarthritis progression. In both groups, joint incongruence, femoral head deformity, and broken Shenton's line predicted osteoarthritis progression. The authors suggested that surgical treatment should be considered given the high risk of osteoarthritis progression in these severely dysplastic hips.

Table 1. Longitudinal Studies That Assess Incidence and Timing of Progression to Osteoarthritis in Dysplastic Hips

Author	Study Design	Timepoint	Subjects	Identification	Definition of dysplasia	Outcomes	Conclusions
Hasegawa et al. 1992	Prospective cohort	Mean 12.8 years follow up (range, 10-25 years)	59 patients (86 hips) with mean age of 29.9 years (range, 13-61 years) 54 female & 5 male patients	Early osteoarthritis	Various indices were evaluated, including Shenton's line, center-edge angle, Sharp angle, acetabular head index, slope of acetabular roof, acetabular depth ration, and femoral head lateralization. No values specified.	33% of the joints developed early osteoarthritis from pre-osteoarthritis within an average of 9.2 years. 66% developed advanced-stage osteoarthritis from early osteoarthritis within an average of 7.8 years.	Patients with center-edge angle <0 ° without subluxation, or a broken Shenton's line of >10 mm, or a center-edge angle <10° with subluxation, should be operated on to prevent osteoarthritis. If acetabular head index is <60 or if acetabular roof angle is <-5 °, or the acetabular depth ratio is <200, surgical treatment should be performed.
Hisatome et al. 2005	Prospective cohort	Mean 10.1 years (range, 7.0-15.6 years)	61 patients with mean age of 38.2 (range, 20-58 years)	Minimally symptomatic osteoarthritis of bilateral dysplasia	Center-edge angle <20°	1/35 pre-osteoarthritis progressed to early osteoarthritis. 6/26 early osteoarthritis hips progressed to advanced osteoarthritis. Kaplan-Meier survivorship predicted 10-year survival rate of 83.7% (95% CI 70-98%)	If the contralateral nonoperated hip has good joint congruity, minimal symptoms, and no or little radiographic change in patients with pre- or early osteoarthritis and bilateral acetabular dysplasia, the probability of radiographic progression is low.
Iidaka et al. 2020	Prospective cohort	3, 7, 10 years (mean follow- up, 7.1 years)	1,043 males & 1,932 females with mean age of 70.2 years (range, 23-95 years)	Asymptomatic nation-wide cohort	Center-edge angle <20°	15/607 hips experienced OA progression; of these 15, 46.7% had acetabular dysplasia at baseline. 592/607 did not progress to OA, and 8.6% of these hips were found to have acetabular dysplasia at baseline.	Authors reinforced the association of symptomatic hip dysplasia in women more commonly than men.
Morita et al. 2018	Retrospective case series	Mean 20 years (range, 10-27 years)	88 hips (11 males & 77 females) with mean age of 39 years (range, 17–53 years)	Asymptomatic contralateral hip, Tönnis Grade 0, no previous surgical interventions	Center gap, lateral center-edge angle, femoral head extrusion index, acetabular depth- to-width index, femoral head lateralization. Center-edge angle started at ≤25°	Probability of osteoarthritis progression was 13% after 20 years (95% CI, 7.1–22.1). Probability of symptom development was 34% (95% CI, 24.7–46.1).	Probability of osteoarthritis progression was less compared to previous reports, but may be due to subjects not having degenerative changes or pain in contralateral hips at first evaluation.

The Japanese ROAD study reported incidence of hip osteoarthritis in an observational cohort with follow up at 10 years.[10] They found that hip dysplasia, defined as center-edge angle <20 degrees, inferred a hazard ratio of 14.78 (95% confidence interval 3.66-56.06) for progression to osteoarthritis. Overall, women were at a greater risk of osteoarthritis progression. The findings reinforce the association of symptomatic hip dysplasia in women more commonly than men.

Morita et al. followed the contralateral hips of 88 patients undergoing unilateral rotational acetabular osteotomy for 10-27 years (mean, 20 years).[2] They only included contralateral hips that had a baseline Tönnis grade of 0 and were asymptomatic at the time of the osteotomy. At 20 years post-op, the probability of osteoarthritis progression was 13%, and the probability of symptom development was 34%. The mean time to symptom development was 15 years (range, 8-22 years). The mean center edge angle for the entire cohort was 15° (range, -6 to 25°). They found that extrusion index and a novel center gap measurement were predictors of osteoarthritis.

In contrast, Hisatome et al. followed the asymptomatic or minimally symptomatic contralateral hips of patients undergoing rotational acetabular osteotomy in their symptomatic hip for 7.0-15.6 years (mean, 10.1 years).[26] 1 of 35 hips without osteoarthritis progressed to early osteoarthritis. 6 of 26 early osteoarthritis hips progressed to advanced osteoarthritis. The authors also used Kaplan-Meier survivorship analysis to determine that the 10-year survival rate of non-operated hips (endpoint: radiographic progression to osteoarthritis) was 83.7%. Therefore, the authors concluded that patients with radiographic acetabular dysplasia who had good joint congruity, minimal symptoms, and pre- or early osteoarthritis had a low probability of developing radiographic progression to OA. Mean follow-up was less (10 years) in this study compared to 20 years in the study by Morita et al.[2]

Radiographic Markers Associated with Osteoarthritis Progression

The advanced deterioration of a dysplastic hip may carry with it marked radiographic changes and indices that correspond to progression. The measures used to track radiographic changes over time were reported by Murphy et al., Lane et al., Mavcic et al., Aoki et al., and Cooperman.[3-6,11] Meanwhile, Morita et al. introduced a new radiographic parameter used to predict osteoarthritis progression (Table 2).

Murphy et al. assessed for progression of osteoarthritis in contralateral hips of patients undergoing total hip arthroplasty.[3] All patients who met the following criteria for radiographic hip dysplasia develop osteoarthritis before the age of 65 years: 1) center-edge angle of at least 16°, 2) acetabular index of depth-to-width of <38%, 3) acetabular index of <15°, 4) uncovering of femoral head of ≤31%, and 5) 0 peak-to-edge distance. The mean center edge angle was 7° in patients that developed osteoarthritis and 34° in patients that did not develop osteoarthritis. The authors note that applying these radiographic measures will aid in the assessment and management of hip dysfunction secondary to dysplasia.

As previously established, the center-edge angle has been implicated as highly indicative for the diagnosis of dysplasia and continues to be an indicator of progression as further highlighted by Lane et al.[4] Their study obtained baseline and follow-up pelvic radiographs (mean, 8 years) assessing acetabular depth and center-edge angle. The study concluded that a decrease in the center-edge angle is associated with an increase in risk for incident hip osteoarthritis in this population. The findings insist on the paradigm that incongruity and progressive instability will result in incident hip osteoarthritis over time. A limitation of this study was that only patients over 65 years old were included.

However, center-edge angle has been challenged as a predictor for hip osteoarthritis by some studies such as Mavcic et al. who posit that elevated cumulative joint contact stress predicts hip osteoarthritis better than the center-edge angle.[5] Aoki et al. compared the lateral instability index to other radiographic measurements in 22 unilateral hips with pre-arthrosis for at least 15 years.[6] Despite the age at examination, center-edge angle, acetabular head index, and Sharp angle all being important radiographic parameters in the diagnosis of dysplasia, the study found that only the lateral instability index was associated with progression of osteoarthritis in this cohort. Lateral instability index was defined as the sum of the lateral opening angle of the acetabulum and the femoral neck-shaft angle. Specifically, the authors discovered that a lateral instability index of 196 was the threshold value for the progression to osteoarthritis to be more likely.

The center-edge angle was also critically evaluated by Cooperman et al. in 1983.[11] The authors reanalyzed the Wiberg data[17] and determined that when subluxed hips were removed from analysis, the center-edge angle was not an accurate predictive marker of osteoarthritis development. The authors then followed 20 adults (32 stable, dysplastic hips) without arthritis for 22 years. Although all patients eventually developed osteoarthritis, the authors found that measurement of center-edge angle (or other markers such as Sharp's acetabular angle, percentage of the femoral head covered by the acetabulum, acetabular depth, and inclination of the lateral lip of the acetabulum) were not reliable markers to predict the timeline of osteoarthritis progression. They suggested that factors that lead to hip osteoarthritis development are more complex than simple radiographic measures given that some with severe dysplasia do not develop degeneration while some with mild dysplasia develop severe end-stage osteoarthritis.

To further address the controversy regarding the center-edge angle and other standard radiographic features of dysplasia, Morita et al.[2] examined the potential of new radiographic predictor of osteoarthritis progression called the center gap measurement through a retrospective analysis on the contralateral hips of patients undergoing eccentric rotational acetabular osteotomy. The horizontal plane of the acetabulum for the center gap measurement was found to be an independent risk factor for osteoarthritis progression with an individual sensitivity of 62% and a 71% positive predictive value when combined with the femoral head extrusion index. Thus, when combined with the femoral head extrusion index, the center gap in the horizontal plane was proposed to be an effective, objective parameter to predict the natural course of asymptomatic hips in patients with hip dysplasia.

Other Risk Factors for Osteoarthritis Progression

The progression and natural history of the dysplastic hip is not exclusive to dysplasia alone as there are associated risk factors that may aid in predicting the course of osteoarthritis. More specifically, additional joint morphologic deformities, comorbid conditions, gender, and lifestyle factors compound the degenerative effect of dysplasia on the hip. The following studies addressed these factors (Table 3).

The pattern of progression and degeneration appears to be accelerated by additional morphological factors such as femoroacetabular impingement from cam deformities as highlighted by Wyles et al. in 2017.[7] In their longitudinal, follow-up study (mean, 20 years), Wyles and his colleagues reviewed the radiographs of the contralateral hips of patients who received unilateral primary total hip arthroplasty and diagnosed them with hip dysplasia, femoroacetabular impingement, or normal morphology. Radiographs were reviewed to determine progression from Tönnis grade 0 to 3 until the final follow up or operative intervention with total hip arthroplasty. Degenerative changes occurred earlier in patients with hip dysplasia, followed by femoroacetabular impingement and normal morphology. Femoroacetabular impingement followed a similar progression to normal hips. The group with both cam deformity and concomitant acetabular dysplasia developed osteoarthritis the most rapidly.

Alternatively, Jacobsen et al. assessed osteoarthritis progression in the observational Third Copenhagen City Heart Study but did not find an association between radiographic dysplasia and osteoarthritis developed over 10 years.[27] This study did not include hips with subluxation. They found a trend toward greater joint space loss over time in dysplastic hips that was non-significant. The authors postulated that labrum tear or detachment was associated with accelerated joint degeneration though this was not assessed in their study.

Hip dysplasia was a strong independent determinant of radiographic osteoarthritis in men and women over the age of 55 as found by Reijman et al.[8] in the Rotterdam Study. A center edge angle <25° inferred an adjusted odd ratio of 4.3 (95% confidence interval 2.2 – 8.7) for joint space narrowing and 2.4 (1.2-4.7) for radiographic osteoarthritis progression. They also found that this independent association is enhanced by mechanical workload, female sex, and low body mass. Similarly, as found by Ohfuji et al., we can expand the factors that can predict a faster decline of the hip.[9] Their study found that weight gain since age 20 or persistent heavier weight in Japanese female subjects revealed an increased odds for more severe osteoarthritis stage at diagnosis. Other characteristics were age, lower education, lower acetabular head index, and longer duration since symptom onset. Weight control may be an important, modifiable risk factor in slowing the progression of osteoarthritis in a dysplastic hip.

Iidaka et al. assessed risk factors for incident and progressive hip osteoarthritis.[10] The risk factors found to be significantly associated with incident hip osteoarthritis were age, obesity, and acetabular dysplasia at baseline with a hazard risk of 1.05. As for progressive hip osteoarthritis, the significant risk factors included baseline hip pain and acetabular dysplasia with a hazard ratio of 5.68. With that, the authors emphasized the importance of assessing patient-reported pain and dysfunction.

DISCUSSION

To our knowledge, the earliest evidence of the relationship between hip dysplasia and osteoarthritis comes from a report by Le Scolan in 1924 where she described various patterns of dysplasia in a large group of patients who seemed to have abnormal connections between the acetabulum and head of the femur.[28] She noted that patients tended not to experience symptoms until they exerted themselves or had pronounced subluxation. Among the patients, there was a group of 13 subjects, 16 to 46 years of age, and 6 of them were found to have osteoarthritis. For 5 of these 6 cases, the patients were asymptomatic before their osteoarthritis developed.

Wiberg's research further evaluated the connection between dysplasia and osteoarthritis by completing the first longitudinal study that followed 17 patients with center-edge angles under 20° for 28 years. All developed osteoarthritis, and all but one had developed the condition by 65 years of age. The study concluded that lower the center-edge angle was associated with a more rapid onset of osteoarthritis.[17]

However, Cooperman et al. later examined Wiberg's data and found that the center-edge angle was potentially confounded by hip subluxation; when subluxed hips were removed from analysis, the center-edge angle no longer was an effective predictor of osteoarthritis progression.[11] This has led to variability amongst studies in defining and measuring dysplasia and its progression. Studies by Mavcic et al. and Aoki et al. demonstrated that other radiographic markers, such as high cumulative contact stress and the lateral instability index, were better predictors of progression.[5,6] Ultimately, more recent investigations have assessed the potential of new radiographic parameters, as seen with Morita et al.[2] But with this study, there is no direct comparison in parameter sensitivity against the current gold standard, Wiberg's center-edge angle, further contributing to the uncertainty of dysplasia in how it should be identified and observed in its natural course.

Table 2. Longitudinal Studies That Assessed Radiographic Markers of Hip Dysplasia Associated With Osteoarthritis Progression

Author	Study Design	Timepoint	Subjects	Identification	Definition of dysplasia	Outcomes	Conclusions
Aoki et al. 2010	Prospective cohort	Mean of 16.2 years (range, 15.08 - 18.6 years)	22 women with mean age of 35.5 years (range, 22-50 years)	Prearthrosis or early osteoarthritis secondary to hip dysplasia	Anterior & lateral opening angle, Sharp angle, center-edge angle & acetabular head index No values specified.	Disease progression in 12 (2 to early osteoarthritis, 6 to advanced-stage, 4 to terminal-stage total hip arthroplasty). Mean interval for progression 8.8 years (range, 7 – 10 years). Lateral instability index > 196 predicted likely progression of disease.	Associated with progression: lateral instability index. Not associated with progression: age at initial examination, center-edge angle, acetabular head index, Sharp angle nor acetabular head index.
Cooperman et al. 1983	Prospective cohort	Radiographs at baseline & at follow-up of an average of 22 years after initial presentation.	20 adults (32 hips) with mean age of 43 years (range, 27-57 years) when first presenting. Mean age at the time of follow up was 65 years (range, 36-70 years).	Asymptomatic	CE angle ≤20° & intact Shenton's line.	7 patients in whom severe osteoarthritis developed during the 4th, 5th, & 6th decades had acetabular indices that were essentially indistinguishable from those of 9 patients who presented arthritis-free in the 6th decade.	Hip subluxation leads to early osteoarthritis. Acetabular dysplasia in adults in the absence of subluxation is a deformity that leads to osteoarthritis, but the process may take decades to manifest. Factors of hip development other than those used to measure acetabular dysplasia may be important in determining the natural course of acetabular dysplasia in the absence of hip subluxation.
Lane et al. 2000	Case-control analysis	Mean of 8.34 years (range, 7.42-10.37 years)	9704 white women aged 65 years and older with a mean of 70.3±4.7 years	Asymptomatic multi-center cohort	Acetabular depth <9 mm or center-edge angle <30°	Subjects who developed incident hip OA: center-edge angle 36.4±6.6° & mean acetabular depth: 12.8 mm ±3.0. Subjects who did not develop hip OA: 39.0 ± 6.8 & mean acetabular depth: 13.0 mm ±2.8. CE angle OR of incident hip OA: 3.3 (95% CI 1.1–10.1). Acetabular dysplasia OR of incident hip OA: 2.8 (95% CI 1.0–7.9).	Decrease in the center-edge angle is associated with a small increase in risk for incident hip osteoarthritis in this population.
Mavcic et al. 2008	Prospective cohort	Mean of 29 years (range, 20-41 years)	Mean age of 51 years at follow-up (range, 38-80 years)	Asymptomatic	None stated.	Dysplastic hips at 51 yeras of age with higher pcml experienced same prevalence of osteoarthritis as normal hips at 68 years Dysplastic hips had higher peak and cumulative contact stress, and lower center-edge angle WOMAC score predicted in dysplastic hips by cumulative contact stress, Wiberg center-edge angle, and BMI	High cumulative contact stress predicts early hip osteoarthritis better than center-edge angle

Table 2. Longitudinal Studies That Assessed Radiographic Markers of Hip Dysplasia Associated With Osteoarthritis Progression (continued)

Morita et al. 2018	Retrospective case series	Mean 20 years (range, 10-27 years)	88 hips (11 males & 77 females) with mean age of 39 years (range, 17–53 years)	Asymptomatic contralateral hip, Tönnis Grade 0, no previous surgical interventions	Center gap, lateral center-edge angle, femoral head extrusion index, acetabular depth-to-width index, femoral head lateralization. Center-edge angle started at ≤25°.	Center gap measurements were more lateral in patients with osteoarthritis progression. Osteoarthritis progression: femoral head extrusion index (HR 1.11; 95% CI, 1.01–1.22), center gap X (HR, 1.52; 95% CI, 1.07–2.16).	Center gap in horizontal plane had a modest association with osteoarthritis progression. Future studies needed to determine normal value of center gap for patients without developmental dysplasia of the hip and to assess the center gap in lateral radiographic views
Murphy et al. 1995	Prospective cohort	Reaching age 65 years of age after initial total hip replacement in contralateral hip	43 patients who reach 65 yeras of age without developing severe osteoarthritis compared to 74 patients who developed severe osteoarthritis	Contralateral early and severe osteoarthritis groups	Center-edge angle, acetabular index of depth to width, femoral-head extrusion index, acetabular index of the weight-bearing zone, & lateral and superior subluxation. No specific values specified.	Patients without severe osteoarthritis: center-edge angle 34 ± 9°, vertical distance 1 ± 2 mm, mean lateral distance 6 ± 2 mm, peak-to-edge distance 16 ± 4 mm, femoral-head extrusion index 12 ± 8%, acetabular index of depth to width 48 ± 6%, acetabular index weight- bearing zone 6 ± 6°. Patients with severe osteoarthritis: center-edge angle 7 ± 12°, vertical distance 10 ± 8 mm, mean lateral distance 13 ± 4 mm, peak-to-edge distance 3 ± 5 mm, femoral-head extrusion index 36 ± 12%, acetabular index of depth to width: 31 ± 7%, acetabular index weight-bearing zone 25 ± 10°	Groups who did and did not develop severe osteoarthritis had significantly different radiographic parameters. Patients who reached 65 years of age without severe osteoarthritis had center-edge angle of at least 16°, acetabular index of depth at least 38%, acetabular index ≤15°, uncovering of femoral head ≤31%. None had zero peak-to- edge distance.

Table 3. Additional Risk Factors for Osteoarthritis Progression in Dysplastic Hips

Author	Study Design	Timepoint	Subjects	Identification	Definition of dysplasia	Outcomes	Conclusions
Iidaka et al. 2020	Prospective cohort	3, 7, 10 years (mean follow- up, 7.1 years)	1,043 males & 1,932 females with mean age of 70.2 years (range, 23-95 years)	Asymptomatic nation-wide cohort	Center-edge angle <20°	Significant risk factors for incident hip osteoarthritis: age HR 1.05 (1.03-1.08 95% CI), obesity HR 1.78 (1.10-2.75), acetabular dysplasia at baseline HR 2.06 (1.30-3.17). Significant risk factors for progressive hip osteoarthritis: baseline hip pain HR 5.68 (1.07-22.61) and acetabular dysplasia 14.78 (3.66-56.06).	Age, obesity, & acetabular dysplasia at baseline were risk factors for incident hip OA, while hip pain & acetabular dysplasia at baseline were risk factors for progressive hip OA.
Jacobsen et al. 2005	Case-control analysis	Mean 10.2 years (range, 9.1-11.9 years)	81 subjects - 54 female, mean age 53.1 years (range, 25-70 years); 27 male, mean age 48.6 years (range, 24-79 years)	Symptomatic dysplastic patients and controls, self- reported	CE angle ≤20°	No difference between dysplasia and control group in self-reported pain. Women reported more frequent pain than men. Minimum joint space width decreased for both dysplasia & control subjects. No significant differences in degeneration in subjects with dysplasia & controls were found.	Suggests that labral tears or detachments are critical to development of degeneration, and dysplastic hips are more likely to experience labral tear.
Ohfuji et al. 2016	Cross-sectional analysis	Comparison of body weight at age 20 and later at osteoarthritis diagnosis	336 Japanese women with mean age of 57.7 years (23.2-84.5).	Newly diagnosed with hip osteoarthritis secondary to acetabular dysplasia	Various indices chosen for examination: Sharp angle, center-edge angle, acetabular roof obliquity angle, acetabular head index, & approximate acetabular quotient. No specific values specified.	Patients with weight gain since age 20 had a 2-fold increased OR for more severe stage of osteoarthritis at diagnosis. Other significant characteristics were higher age, lower education, parity, lower acetabular index, & longer duration since symptom onset.	Weight gain or lasting heavier weight since age 20 in Japanese female subjects with acetabular dysplasia is associated with more severe stages of osteoarthritis at diagnosis. Weight control may play an important role in preventing the development of hip osteoarthritis.
Reijman et al. 2005	Retrospective cohort	Radiographs of the hip at baseline and at follow up (mean time of 6.6 years)	835 subjects ≥55 years of age (mean 65.6 years).	Symptomatic and radiographic osteoarthritis (pre-OA, initial stage, advanced stage or terminal stage)	CE angle <25° & acetabular depth <9 mm	Mean center-edge angle was 35.1 ± 5.6° & mean acetabular depth was 12.2 ± 2.8 mm. 9.3% of subjects developed incident radiographic hip osteoarthritis (joint space narrowing ≥1.0 mm) during the follow up period. Subjects with acetabular dysplasia had a 4.3-fold increased risk for incident radiographic osteoarthritis of the hip compared with subjects without dysplasia.	Acetabular dysplasia is a strong independent determinant of incident radiographic hip osteoarthritis in men and women ≥55 years of age. This association was found to be enhanced by mechanical workload, female sex, and low BMI.

Table 3. Additional Risk Factors for Osteoarthritis Progression in Dysplastic Hips (continued)

Wyles et al. 2017	Retrospective cohort	Mean follow up was 20 years (range, 10–35 years)	162 patients with a mean age at the time of inclusion was 47 years (range, 18–55 years), and 56% (91 of 162) of the patients in this study were female.	Contralateral asymptomatic. All had Tönnis Grade 0 degenerative change in their hip at the time of contralateral total hip arthroplasty.	Lateral center-edge angle (<25° = dysplasia), Tönnis angle (>10° = dysplasia), femoral head lateralization (>10 mm = dysplasia), femoral head extrusion index (>0.25 = dysplasia), acetabular depth-to- width index (>0.38 = dysplasia)	35 of 162 patients eventually underwent total hip arthroplasty: 33% had dysplasia. Degenerative change was most rapid in patients with dysplasia followed by FAI and normal morphology. Likelihood of degeneration was increased with femoral head lateralization >8 mm, femoral head extrusion index >0.20, acetabular depth-to-width index <0.30, lateral center-edge angle <25°, and Tönnis angle <8°.	After mild degenerative change develops in the hip, patients with dysplasia have a higher probability of progressing to end-stage osteoarthritis or total hip arthroplasty at 10- and 20- year follow up compared with FAI and normal morphology. Incremental changes in radiographic parameters that are more representative of dysplastic morphology indicate a worse prognosis.

Additionally, prevalence studies have also challenged Wiberg's findings of dysplasia progressing into osteoarthritis. Croft et al. concluded that only a small proportion of all hip osteoarthritis was due to dysplasia (although the authors acknowledge that for some people, it is the predisposing factor for osteoarthritis).[29] In several studies of Japanese, Turkish, Chinese, and Nigerian subjects, it was found that although the subjects demonstrated a higher prevalence of dysplasia than their European counterparts, they experienced relatively lower rates of osteoarthritis.[30-34] Though, it is also clear that pre-arthritic hip dysplasia can cause pain and dysfunction.[35]

The progression of dysplasia to osteoarthritis was also questioned by Hisatome et al.[26] Ultimately, the authors concluded that patients with dysplasia had a low probability of progressing to osteoarthritis if the patient was asymptomatic and had sufficient joint congruity. A limitation of this study was that the mean follow up was 10 years. A study with mean 20 years follow up had contrasting outcomes in a similar population (Japanese patients undergoing rotational osteotomy). Radiographic measures of dysplasia were associated with osteoarthritis, and they also noted that symptoms developed at an average of 15 years. Follow up greater than 10 years is necessary to assess natural history of osteoarthritis development in dysplastic hips.

The investigation by Clohisy et al. in 2011 expands the support for this interconnection. The authors analyzed a large cohort of 604 patients (710 hips), 50 years of age or younger, who underwent primary total hip arthroplasty secondary to premature, end-stage hip disease.[36] Of the 710 hips, 337 (47.5%) had osteoarthritis. Within this group of 337, 163 (48.4%) were found to have dysplasia on radiographic imaging.[36] Ultimately, dysplasia of the hip was considered a predominant structural abnormality associated with osteoarthritis.

Furthermore, the concept of poor joint congruity leading to osteoarthritis progression was previously described by Mavcic et al.[15] and is further corroborated by a study completed by Aitken et al. in 2022.[24] The authors analyzed a cohort of patients with concurrent, symptomatic acetabular dysplasia and femoroacetabular impingement. The team created patient-specific models to assess joint contact stress throughout the gait cycle with pre-operative CT scans. Regional cartilage degeneration observed arthroscopically correlated with regions of elevated chronic contact stress-time exposure. Surgical intervention to address both femoroacetabular impingement and dysplasia to reduce contact stress was recommended to improve pain and dysfunction with the goal of reducing osteoarthritis risk.

Understanding what radiographic findings and patient characteristics are at risk for progression to osteoarthritis is important so that surgical interventions can be applied appropriately. Periacetabular osteotomy (PAO) is the gold-standard surgical treatment of pre-arthritic hip dysplasia in skeletally mature adolescents and young adults.[37,38] However, there are subgroups of patients with persistent symptoms despite surgical treatment. Goetz et al., examined quality of deformity correction and associated changes in joint contact stress as a potential risk factor for persistently elevated contact stress and joint dysfunction.[21] In this study, the authors used discrete element analysis (DEA) computational modeling to assess the contact mechanics of corrected dysplastic hips. Although the study found that corrected dysplastic hips using PAO more closely resembled normal hips radiographically, there remained elevated and smaller contact stress areas which suggest additional or residual mechanical abnormalities in the joint even after correction.

There are limitations to this narrative review. First, we only employed one database, PubMed. This could have limited our search and the number of papers covering similar topics and findings that we could have included in this review. Second, the bodies of work presented in this review were filtered, screened, and reviewed by three individuals. The possibility of bias is present as a paper could have been excluded based on the criterium of a single individual. However, we believe these limitations are permissible within the scope of a narrative review.

The aim of this review was to summarize the progression of untreated hip dysplasia in skeletally mature individuals to osteoarthritis over time. Various predictors and radiographic indices were used to determine the likelihood of progression to osteoarthritis. While these studies generally make a case that untreated dysplasia causes damage to hip joint cartilage, labrum, and associated structures, it must be noted that many of the studies are on small cohorts, with various definitions of dysplasia, and limited follow up. Overall, the progression of degenerative changes to the hip secondary to dysplasia can be predicted radiographically and with patient-specific factors. Young females or those with associated femoroacetabular impingement, labral tears, subluxation of the hip, higher and lower body mass, and enhanced mechanical workload may be at higher risk of developing osteoarthritis.

As surgical treatment of pre-arthritic hip dysplasia becomes more common, it is important to identify individuals with dysplasia at greatest risk for progression to osteoarthritis at a young age. Therefore, there is a need to further refine radiographic and patient characteristics associated with premature hip joint failure. Future studies should identify skeletally mature adolescents with pre-arthritic hip dysplasia, before developing symptoms, to carefully document onset of symptoms and joint degeneration longitudinally over time. Surgical treatment with periacetabular osteotomy should be reserved for skeletally mature young adults with pre-arthritic radiographic hip dysplasia and persistent pain and disability despite non-surgical treatments.

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IS FEMORAL HEAD TO ACETABULAR CUP RATIO ASSOCIATED WITH DISLOCATION AFTER TOTAL HIP ARTHROPLASTY?

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ABSTRACT

Background: Dislocation remains a common complication following total hip arthroplasty (THA). Previous literature has shown that the femoral head-to-neck ratio is essential in hip motion, function, and stability. While large femoral heads and dual mobility bearings have been developed to improve stability, it remains unknown if the ratio between femoral head size to acetabular cup size also plays a role in stability. This study aimed to investigate if the relationship between the femoral head size and the acetabular cup size factors into the risk of hip dislocation.

Methods: 3155 patients who underwent primary THA for the indication of osteoarthritis between 2016 and 2019 were identified. Patient demographic, radiographic, implant and procedural data were analyzed. The primary outcome was determining head-to-cup ratios calculated by dividing the femoral head size by the acetabular cup size. Head-to-cup ratios were then compared in patients who suffered a dislocation after THA to those who did not. Univariate and logistic regression was conducted to determine additional dependent variables for hip dislocation.

Results: Patients in this study had an average age of 64 ± 11 years. Females comprised 51% of the cohort, and BMI was 29.2 ± 5.2. A total of thirty-six (1.1%) patients sustained a dislocation at a median of 51 days following surgery. The dislocation cohort was similar to the non-dislocation cohort in age, gender, BMI, CCI, and ASA scores. The head-to-cup ratio was also identical between the dislocation (0.64 ± 0.05 mm) and non-dislocation (0.64 ± 0.05 mm) patients, P=0.317. Logistic regression adjusting for age, sex, BMI, and surgical approach demonstrated that the head-to-cup ratio was not associated with an increased risk of dislocation (p=0.728).

Conclusion: Head-to-cup ratio was not found to be predictive of dislocation. Hip dislocation is complex and multifactorial, and it is difficult to isolate specific risks, such as the head-to-cup ratio analyzed in our study. Further investigation is needed to define groups benefiting from specialized implants such as large-diameter or dual mobility heads and the optimal head-to-cup size ratio.

Level of Evidence: III

Keywords: arthroplasty, dislocation, femoral head to acetabular cup ratio, revision

INTRODUCTION

Total hip arthroplasty (THA) is a highly successful procedure that is increasing in frequency yearly, with a projected 635,000 primary THAs and 72,000 revision THAs by 2030.[1,2] Despite efforts to increase component stability, dislocation remains among the most common reasons for revision THA, along with aseptic loosening, osteolysis, and instability.[3] Increased dislocation rate is associated with previous dislocation, abductor deficiency, and acetabular morphology.[4] As a result, strategies have been implemented to reduce dislocation rates, such as muscle-sparing approaches, constrained liners, large femoral head components, and modular dual mobility bearings.[4-6] Muscle-sparing approaches, such as the direct anterior (DA) approach, have shown lower dislocation rates; however, this approach is associated with a steeper learning curve consisting of higher complication rates than other approaches.[7] Constrained liners are one of the more popular methods in revision arthroplasty to treat instability and is associated with a mean dislocation rate of 10%. The limitations of constrained implants include restricted range of motion and impingement of the femoral neck on the cup.[5] These have led to reported long-term failure rates upwards of 40% in some studies.[5] Dual mobility has been shown to lead to excellent results regarding stability,[8,9] as the system introduces an improved head-neck ratio that supports an increased impingement-free range of motion.

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It is unknown whether these findings are attributable to the biomechanical properties or whether they result from the relatively larger outer head diameter compared to fixed bearings.[10] A recent investigation found similarly low dislocation rates in primary THA when comparing dual mobility to jumbo femoral heads, suggesting that large femoral head size may be a protective factor in limiting hip dislocations.[11] Multiple studies have shown that large femoral heads (36 mm or larger) are associated with lower dislocation rates than smaller heads.[12-14] However, the effect of head size alone remains unknown and may not adequately explain differences in dislocation rates. A recent study opposed existing literature by showing that head size was not significantly associated with dislocation rates when adjusting for factors including surgical approach, indication, and spinopelvic pathology.[16] Additionally, larger acetabular cup size has been associated with increased dislocation rates.[15] Given that femoral head size has mixed findings on the dislocation rate, combined with data that links large acetabular cups to greater dislocation likelihood, there is a need to analyze dislocation rates through the relationship of the femoral head to the acetabular cup.

Therefore, the purpose of this study was to investigate the ratio between the femoral head and the acetabular cup. Due to the inverse relationships between femoral head size and acetabular cup size on dislocation rate identified in individual studies, we investigated if this ratio would influence dislocation.

METHODS

Study Design

This study utilized a retrospective chart review and cohort study design to compare patients who dislocated following primary THA indicated for osteoarthritis. Institutional Review Board (IRB) approval was obtained, and no outside funding was utilized. Three thousand one hundred and fifty-five patients undergoing a primary THA at a large metropolitan practice with complete implant data were identified. Procedures were performed between January 1st, 2016, to December 31st, 2019, by 18 surgeons at two high-volume centers (one tertiary care center and one orthopaedic specialty hospital). All patients had a minimum of a 2-year follow-up from the date of surgery to the time of analysis. Given that the surgical approach is a known risk factor for dislocation, the surgical approach of each procedure was recorded as being done via a direct anterior, direct lateral, or posterior approach.

Variables and Outcomes

Patient demographics, Charlson Comorbidity Index,[17] American Society of Anesthesiologists (ASA) class, implant sizes, and surgical approach were recorded. The primary outcome was dislocation at any point up to two years after THA. Complications such as dislocation data were obtained via our nurse navigator program, which prospectively tracks patient outcome data. Dislocations were then chart-reviewed via radiographic images and provider notes.

The femoral head and acetabular cup sizes were obtained from implant records and operative reports. The head-to-cup ratio was calculated by dividing the femoral head size by the acetabular cup size. In the dislocated hips cohort, post-operative radiographs were examined, which determined that the acetabular position was successful within a normal range of 33-38 degrees, and acetabular cup mispositioning was not present.

Data Analysis

Data was analyzed for normal, parametric distribution, and statistical tests were chosen accordingly. Categorical variables were analyzed using Fisher Exact and Chi-squared tests. Continuous variables were analyzed using two-way, unpaired t-tests. To test association and correlation, Spearman's correlations tests were used. Linear regression was conducted for continuous dependent variables that reached significance from the previous tests. Binomial logistic regression was performed for dislocation and revision adjusting for age, sex, body mass index (BMI), and surgical approach. A 95% confidence interval and p-value of 0.05 was set for statistical significance. All statistical analysis was performed using R software (R Foundation for Statistical Computing, Vienna, Austria). A post hoc analysis demonstrated a power of 0.14 with an effect size of 0.14.

Demographics

3155 patients who underwent primary THA between January 1st, 2016, to December 31st, 2019, at a single high-volume institution were included. The mean age of patients undergoing primary THA was 64 ± 11 years, with females representing 51% (1611) (Table 1). The average BMI was 29.2 ± 5.2, with a mean Charlson Comorbidity Index (CCI) of 3.4 ± 1.6. Most patients were ASA class 2 or 3 (80.6%). Primary THA was largely done using the anterior and lateral approaches, but the posterior approach was included for data completeness. 44.0% of cases (1388) were done using the anterior approach, 54.1% (1707) via lateral, and 1.9% (60) were performed using the posterior approach (Table 2). Femoral head sizes ranged from 22 to 40 mm, the most common size being 36 mm (50%), followed by 32 mm (40%). Acetabular cup sizes ranged from 42 to 62 mm, with the most common sizes being 52 mm (26.7%), 54 mm (21.0%), and 50 mm (17.6%).

RESULTS

The average femoral head size was 33.7 ± 2.8 mm, while the average acetabular cup size was 53.0 ± 3.3 mm. The mean head-to-cup ratio was 0.64 ± 0.05 (range 0.44-0.78). Of the total 3155 patients in the study, 36 (1.1%) sustained a dislocation at a median of 51 days following surgery (quartile 1: 29 days; quartile 3: 315 days). The head-to-cup ratio did not significantly differ between patients who sustained a dislocation and those who did not (0.64 vs. 0.64, p = 0.317). Femoral head sizes were similar between the dislocation and no-dislocation groups (33.7 ± 3.7 mm vs. 33.7 ± 2.8 mm, P = 0.670), Table 2. Acetabular cup sizes were also similar between the dislocation and no-dislocation groups (52.5 ± 4.0 mm vs. 53.0 ± 3.3 mm, P = 0.216), Table 2. There was a greater percentage of females in the dislocation group, but demographics were otherwise similar between groups (Table 1).

Logistic regression adjusting for surgical approach type, age, sex, and BMI did not show that the head-to-cup ratio was associated with increased rates of dislocation, as displayed in Table 3. The posterior approach was associated with a higher dislocation rate compared to a reference of anterior (OR 4.2, p=0.026). In contrast, the lateral approach did not have a difference in risk compared to the anterior approach. Male sex was associated with a lower dislocation rate (OR 0.3, p=0.001). Age and BMI were not associated with differences in risk.

DISCUSSION

This study showed that the femoral head-to-acetabular cup ratio was not associated with increased risk for dislocation following primary THA when controlling for age, sex, BMI, and surgical approach. While the cohort of dislocations was a relatively small amount (36 patients), the head-to-cup ratio between the dislocation and no-dislocation groups was the same (0.64 vs. 0.64, p = 0.317). We did find that the posterior approach and female sex were associated with higher rates of dislocation. However, the posterior approach was the least common, used in 1.9% of the cases. Although the femoral head-to-neck ratio is a significant factor in hip stability, this study shows that the head-to-cup ratio may not be as substantial. These findings support contemporary literature that hip dislocation is a multifactorial issue, and it is difficult to isolate specific risks, such as the head-to-cup ratio analyzed in our study.

The size of the femoral head used in total hip arthroplasty has steadily increased over time from roughly 22mm in the 1960s to 32 mm with the onset of the 2000s.[18] Since the mid-2000s, the use of a 36 mm head size has increased steadily.[18] The evolution of modern sockets with highly cross-linked polyethylene has allowed for this. Larger femoral heads allow for an increased range of movement that occurs without impingement while increasing jump distance, which reduces the risk of dislocation.

Multiple studies have also shown the association between smaller heads and increased dislocation rates.[19-21] On the other hand, Peter et al. showed that larger acetabular cup size is also associated with higher dislocation rates.[22] Thus, exploring the inverse relationship between the two is of important consideration. In our study, the mean head-cup ratio was 0.64, with the most common femoral head size being 36 mm and cup sizes ranging from 42-62 mm. The study findings are important in the context of more and more surgeons utilizing

Table 1. Demographics and Implant Sizes

	No Dislocation (n=3119)	Dislocation (n=36)	P Value
Age	64.4 +/- 11.2	61.4 +/- 14.3	0.303
Female	1583 (50.8%)	28 (77.8%)	0.002
BMI	29.2 +/- 5.2	30.0 +/- 7.2	0.582
CCI	3.4 +/- 1.6	3.0 +/- 2.1	0.193
ASA III/IV	1027 (39.0%)	10 (37.0%)	0.992
Bilateral	61 (1.9%)	0 (0.0%)	0.999
Head Size (mm)	33.7 +/- 2.8	33.7 +/- 3.7	0.670
Acetabular Size (mm)	53.0 +/- 3.3	52.5 +/- 4.0	0.216
Head to Cup Ratio	0.64 +/- 0.05	0.64 +/- 0.05	0.317

Reported as mean +/- standard deviation or n (%).

Table 2. Cases by Surgical Approach

Surgical Approach	Total N	Dislocation	Dislocation Rate
Direct Anterior	1388	19	1.37%
Lateral	1707	14	0.82%
Posterior	60	3	5.00%

Table 3. Logistic Regression for Dislocation

Variable	OR (95% CI)	P Value
Ratio	0.34 (0.0 – 169.7)	0.728
Approach		
Anterior	Reference	
Lateral	0.6 (0.3 – 1.3)	0.220
Posterior	4.2 (0.96 – 13.2)	0.026
Age	0.98 (0.95 – 1.00)	0.079
Male sex	0.3 (0.1 – 0.6)	0.001
BMI	1.03 (0.97 – 1.09)	0.391

OR=odds ratio, CI=confidence interval, BMI=body mass index. OR for BMI reported per 1 unit increase.

dual mobility components to maximize the femoral head size within the acetabular cup. While this study is not without the limitations listed below and only investigates monopolar heads, it does not identify an optimal femoral head-to-acetabular cup ratio nor argues against a popular technique of surgeons choosing the largest possible femoral head size.

While previous research has looked at the effect of individual components, there needs to be more investigation into the combined effect of bearing surface sizes with acetabular cup sizes. Though multiple prior studies have shown individual relationships between femoral head size and even acetabular cup size in relation to dislocations, our results suggest that taken together, the relationship between the size of the femoral head and the acetabular cup does not directly correlate to a dislocation risk.

In 1998, Kelley et al. randomized two head sizes (22 and 28 mm) to acetabular cups of 56 mm or larger or 54 mm or smaller.[23] They found the 22 mm head size paired with the 56 mm, or larger cup group, increased the dislocation risk. However, two surgical approaches were used, and the sample size was only 30 patients. The study further looked at a larger, second cohort of 308 replacements and found dislocation rates were significantly higher (14% vs 4%) using a 60 mm or larger cup size. It was shown that a larger size difference between the head and cup increased the risk of dislocation. In 2011, Peter et al. expanded upon this work with a larger cohort by adjusting for other risk factors, such as obesity.[22] The relationship still held true. However, the association held true for 28 mm heads even in the more recent study. These sizes are smaller than modern femoral head sizes routinely implanted, assuming a larger mismatch based on previous literature. Interestingly, in our study, with the most common femoral head size being 36 mm, this relationship did not hold true. Further investigation of jumbo head sizes is required to draw significance. Of those who dislocated in our study, females made up a larger proportion (77.8%) and this follows a trend with existing literature.[24,25] In our study, male patients had an average head-cup ratio of 0.62 mm and an average head size of 54 mm compared to female patients, who had an average ratio of 0.65 mm and an average head size of 52 mm (P=0.120). Given the similar head-to-cup ratios and average femoral head sizes, the risk of dislocation is more rooted in being female than the specifics of the components sizing and relative sizes between the femoral head and the acetabular cup.

Strengths of this study include its large patient cohort obtained at a high-volume joint replacement center. Moreover, the multitude of surgeons and differences in surgical technique, approaches, and implants lend to the study heterogeneity and add external validity to our results. Limitations of this study include its retrospective design and few posterior approach cases. Dislocations were identified based on those patients who were either contacted within 90 days of surgery by nurse navigators or those who presented to our institution following dislocation at a later point up until two years. The relatively low number of dislocations (36) compared to the overall cohort (3155) makes it difficult to draw conclusive results regarding the impact of head-to-cup ratios on dislocation rates. Patients presenting outside of our institution following dislocation may have been missed. We also do not have data on offset, limb length, soft tissue quality, and other factors that can impact hip stability. The study did not collect data on the type of socket or the presence of an elevated rim. Additionally, the taper and type of implant were not recorded. Given the potential for multiple factors contributing to dislocation, such as implant positioning, spinopelvic factors, soft tissue tensioning, and more, it is difficult to measure one factor in isolation. Therefore, we cannot comment on whether these factors were equally distributed amongst our comparison groups or how they may further impact the head-to-cup ratio from a stability standpoint.

This study represents a preliminary and novel look at dislocations from the perspective of the relationship between head size and cup size. With total hip arthroplasty increasing in numbers in the coming years, the subject of dislocation will continue to be at the forefront of future research and a common reason for revision arthroplasty. We did not identify that head-to-cup ratio was a factor in hip dislocation, yet this remains an area for more investigation. A complex relationship likely exists with multiple patient and surgical variables playing a role in putting patients at risk for dislocation after THA.

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TOURNIQUET AND/OR ADDUCTOR CANAL BLOCK USE CONFER NO ADDITIONAL EARLY QUADRICEPS WEAKNESS FOLLOWING TOTAL KNEE ARTHROPLASTY: AN ANALYSIS OF 203 PATIENTS

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ABSTRACT

Background: Quadriceps weakness following total knee arthroplasty (TKA) delays rehabilitation and increases fall risk. The combined impact of tourniquets and adductor canal blocks (ACBs) on postoperative quadriceps strength has not been defined. This study evaluated the early effects of tourniquet and/or ACB usage on quadriceps strength following TKA.

Methods: Primary, elective TKA patients were assigned to one of four groups based on whether they received an ACB and/or tourniquet. We prospectively measured bilateral, isometric knee extension strength preoperatively and within 36 hours postoperatively. Pre/post-change (∆) and percent strength change were calculated and standardized to the contralateral leg. Strength, postoperative pain, mobility, knee buckling incidence, and falls were compared across groups. Measurements were collected for 203 patients: 68, 45, 45, and 45 in the tourniquet/ACB, tourniquet/no ACB, ACB/no tourniquet, and no tourniquet/no ACB groups, respectively.

Results: Tourniquet use was associated with shorter operative time (p=0.004), while ACB use was associated with longer lengths of stay (p=0.005). Average preoperative (p=0.53), postoperative (p=0.12), pre/post-∆ (p=0.60), percent change (p=0.14), and standardized percent change (p=0.85) in strength measures were comparable across groups. Postoperative pain (p=0.67) and knee buckling events (p=0.18) were also comparable across groups. The no tourniquet/no ACB group had decreased postoperative mobility (p=0.004), though it was not clinically significant. No patients sustained inpatient falls.

Conclusion: Combined tourniquet and ACB use during TKA does not lead to additional weakness in postoperative knee extension or buckling events. Concern for impaired early postoperative functionality should not influence arthroplasty surgeons' decision to use a tourniquet or ACB.

Level of Evidence: II

Keywords: total knee arthroplasty, tourniquet, adductor canal block, quadriceps strength, knee buckling, fall

INTRODUCTION

Impairment in knee extension following total knee arthroplasty (TKA) is commonly observed due to quadriceps weakness and postoperative pain.[1] Postoperative quadriceps weakness predicts worse short-term functional status and is a risk factor for early knee buckling and falls after TKA.[2,3] Similarly, inadequate pain control limits the postoperative rehabilitation required to regain lower extremity muscle strength and to prevent complications associated with immobility.[4]

While the adductor canal block (ACB) has been adopted as an alternative to the femoral nerve block (FNB) with the aim of preserving quadriceps strength, such motor preservation may not be complete with ACBs, as the motor nerve to the vastus medialis and the anterior branch of the obturator nerve can be found within the adductor canal.[5] Inhibition of these nerves is therefore a potential risk of ACB use, and previous research has demonstrated quadriceps weakness after ACB use in some clinical settings.[6]

Similar concerns have been raised regarding the effect of tourniquet use on postoperative quadriceps strength and knee mobility following TKA. Tourniquets are commonly employed to reduce intraoperative blood loss and to improve operative field visualization and cement interdigitation on bony surfaces.[7-13] However, increased proteolytic action in vastus medialis cells has been demonstrated from muscle biopsies of patients who had a tourniquet on during TKA, suggesting a mechanism for muscular atrophy and weakness.[14] Yet, multiple meta-analyses have yielded conflicting results regarding the effect of tourniquets on postoperative functional status.[15,16]

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Currently, no consensus exists regarding the optimal strategy of preoperative analgesia or intraoperative tourniquet use for preserving quadriceps function and minimizing fall risk after TKA. Additionally, the influences of both ACB and of tourniquet use on postoperative knee extension have yet to be investigated concomitantly. The primary aim of this study was to evaluate the effect of combining ACB and tourniquet use during TKA on quadriceps strength. The secondary aims were to evaluate length of stay, discharge disposition, knee buckling events, and falls. We hypothesized that quadriceps strength impairment following TKA would be greatest with the combined use of a tourniquet and an ACB.

METHODS

Study Design and Patient Enrollment

Patients undergoing primary, elective TKA at a single institution between August 2021 and November 2022 were enrolled. Patients undergoing revision, bilateral, unicompartmental, non-elective arthroplasty, or any additional procedure besides primary TKA were excluded. Patients with a history of ipsilateral knee arthroscopy for ligamentous injuries with implanted hardware were also excluded, as were patients with neurologic or neuromuscular disorders that could impair quadriceps strength measurements.

To avoid potential confounding or excess risk due to surgeons' level of experience with the assigned tourniquet and ACB strategy, groups were at first prospectively assigned in a non-randomized fashion based on each participating surgeons' standard practices for tourniquet and ACB use. To minimize the risk of surgeon-specific confounding effects, the patients of a total of eight board certified, fellowship-trained arthroplasty surgeons were eligible for enrollment. At times during the study period, if patients were not equally being assigned to any of the groups, surgeons were asked to temporarily change their protocol to equalize enrollment numbers for each group. Those patients were then randomly assigned to the different groups. Strength measurements were then prospectively collected across four groups based on whether their surgeons used an ACB and based on whether a tourniquet was used intraoperatively or not: tourniquet/ACB; (+T +B), tourniquet/no ACB; (+T -B), ACB/no tourniquet; (-T +B), and no tourniquet/no ACB; (-T -B). This study met all quality improvement certification statements as listed at our institution and was exempt from institutional review board oversight.

Intraoperative and Postoperative Management

Perioperatively, all patients received spinal anesthetic unless lumbar spine pathology precluded access or medical comorbidities required general anesthesia. A standard, peri-articular injection was given at the surgical site for all patients per institutional protocol (Supplementary Material). All ACBs were performed using ultrasound guidance with a standard dosing of Bupivacaine by board-certified anesthesiologists with regional anesthesia training. No patients received any additional local blocks. For patients assigned to tourniquet use, surgeons placed a tourniquet on the thigh. Limb exsanguination was performed with an Esmarch, and the tourniquet was inflated to between 225-275mmHg.

All patients received a standard, institution-wide opioid sparing protocol (Supplementary Material) for postoperative analgesia. Surgeons adhere to standardized order sets for medication administration perioperatively. One month prior to surgery, patients are medically evaluated by our institution's preadmission testing center and a thorough medication reconciliation is conducted. Patients with active opioid prescriptions are educated and instructed to taper or discontinue their use prior to surgery.

Our institution utilizes an enhanced rehabilitation protocol focused on early mobilization as soon as tolerated following anesthesia recovery for all primary TKA patients. Patients are made weightbearing as tolerated after surgery. Postoperative rehabilitation is initiated by licensed physical therapists on postoperative day zero in the post-anesthesia care unit. Patients progress as tolerated in a supervised fashion from assisted ambulation with assistive devices, to unassisted ambulation, to stair climbing with daily physical therapy sessions while in the hospital.

Patient Demographics

Given the risk of group selection bias, patient baseline clinical and demographic information including age, sex, self-identified race, smoking status, and body mass index (BMI) were collected from the electronic medical record and compared across groups. Patients' preoperative ambulatory functional status was assessed based on their need for an ambulatory assistive device.

Perioperative Characteristics

Perioperative characteristics including surgical laterality, operative time from incision to closure (minutes), tourniquet time (minutes), length of stay (LOS [days]), and discharge disposition were also extracted from the electronic medical record (EMR). In sub-analyses, the operative times were compared between patients who did and did not have a tourniquet used intraoperatively, and tourniquet time was compared between the groups in which a tourniquet was used.

Quadriceps Strength Measurements

Isometric knee extension strength measurements were taken preoperatively on the day of surgery and again postoperatively within 36 hours of surgery in both the ipsilateral and contralateral knees. For patients who were discharged on the day of surgery, measurements were captured in the recovery area prior to discharge. Strength measurements were recorded in pounds (lbs) using the Lafayette Electronic Handheld Dynamometer Model 01165 (Lafayette, IN) due to its robust intra-rater and inter-rater reliability.[17] Average time to postoperative measurements were compared across groups to ensure consistency.

Patients sat in the upright position with their knee flexed at 90 degrees as the device was placed over the mid-shaft of the tibia. Patients were then instructed to extend their knee against resistance with maximal force. Measurements were repeated twice on each leg and average preoperative and postoperative values were calculated. Pre/post-surgical change in knee extension strength was calculated by subtracting the mean preoperative strength from the mean postoperative strength for both the surgical (Surgical Δ) and contralateral (Contralateral Δ) knees. Percent strength change was also calculated in each leg as follows: (postoperative mean strength – preoperative mean strength)/(preoperative mean strength)×100 . The percent strength change in the surgical leg was standardized to the contralateral leg by dividing the surgical percent change by the contralateral percent change (Surgical % Δ / Contralateral % Δ) such that the contralateral percent strength change served as an internal control. To improve measurement consistency and reduce outlier effect, patients with Contralateral Δmeasures greater than two standard deviations from the mean were excluded,[18] as this represented significant variation in preoperative to postoperative strength performance within the internal control. Strength measurements were obtained by a research staff member or the patients' physical/occupational therapist. All research staff and physical therapists were trained on proper dynamometer use.

Postoperative Pain, Mobility, Knee Buckling and Falls

Pain on the visual analog scale (VAS) and mobility on the activity measure for post-acute care (AM-PAC) scoring system were recorded prior to discharge on postoperative day zero or one. AM-PAC is a validated tool for assessing mobility and function, with lower scores representing worse functional independence.[19] The incidence of knee buckling events was evaluated by patients' physical therapists during physical therapy sessions. Outside of physical therapy sessions, patients are monitored by nursing staff for knee buckling and falls. As per hospital protocol, all perioperative and inpatient falls are recorded and stored in a hospital-wide database, which was retrospectively reviewed to identify patient falls in each group.

Data Analysis

To detect an effect size between groups of 0.25 for quadriceps strength, the sample size was calculated to be 45 patients per group to achieve an 80% powered study with a p-value of 0.05. Categorical variables were compared using chi-squared analyses or Fisher's Exact tests, and continuous variables were compared using independent samples t-tests or an analysis of variance (ANOVA). Comparison within groups of preoperative and postoperative measurements was done using paired samples t-tests. Significance was set at $p<0.05$. Categorical variables are represented as the count (percentage), and continuous variables are represented as the mean ± standard deviation or mean (range). Data analyses were done using R (version 2.4.1; 2022; R Foundation for Statistical Computing, Vienna, Austria).

Patient Enrollment and Demographics

Measurements were collected for a total of 203 patients: 68 (33.5%) in the +T +B group, 45 (22.2%) in the +T -B group, 45 (22.2%) in the -T +B group, and 45 (22.2%) in the -T -B group. To ensure equal enrollment throughout the study, 45 of the 203 total (22.2%) patients were randomized to a different treatment group than that standardly used by their surgeon (+T +B: 3 [4.4%], +T –B: 14 [31.1%], -T +B: 12 [26.7%], -T -B: 16 [35.6%] patients per group). No differences between groups were observed in baseline demographics or preoperative ambulatory assistive device requirement (see Table 1).

RESULTS

Perioperative Characteristics

There were no significant differences in surgical laterality and discharge disposition (see Table 2). Tourniquet time was also similar between the +T +B and +T -B groups (+T +B: 60.0 ± 20.1 vs +T -B: 58.3 ± 10.3, p=0.601). A significant difference was observed in operative time between the four groups (p=0.030) (see Table 2). Sub-analysis comparing all patients who received a tourniquet to all patients who did not receive a tourniquet revealed that operative times were longer for patients not receiving a tourniquet (+T: 114 [43 to 212], -T: 129 [64 to 246] minutes, p=0.004). A significant difference in LOS was also observed (p=0.01) with the longest stays observed in the +T +B and -T +B groups. Sub-analyses demonstrated that ACB recipients had longer LOS than non-ACB recipients (+B: 1.8 [0.2 to 14.2], -B: 1.3 [0.3 to 5.2] days, p=0.005), though no significant difference in LOS was associated with tourniquet use (p=0.070).

Table 1. Patient Baseline Demographics Stratified by Group Assignment

	Total N = 203	+ Tourniquet + Block N = 68	+ Tourniquet - Block N = 45	- Tourniquet + Block N = 45	- Tourniquet - Block N = 45	P-Value
Age (years)	66.7 ± 9.1	67.9 ± 8.0	67.7 ± 7.6	64.3 ± 9.7	66.5 ± 11.0	0.210
Sex						
Male	58 (28.6%)	17 (25.0%)	14 (31.1%)	14 (31.1%)	13 (28.9%)	0.871
Female	145 (71.4%)	51 (75.0%)	31 (68.9%)	31 (68.9%)	32 (71.1%)	
Race						
White	98 (48.3%)	35 (51.5%)	17 (37.8%)	19 (42.2%)	27 (60.0%)	
Black	45 (22.2%)	12 (17.6%)	12 (26.7%)	11 (24.4%)	10 (22.2%)	0.088
Asian	8 (3.9%)	2 (2.9%)	5 (11.1%)	0 (0.0%)	1 (2.2%)	
Other	52 (25.6%)	19 (27.9%)	11 (24.4%)	15 (33.3%)	7 (15.6%)	
Smoking Status						
Never	128 (63.1%)	40 (58.8%)	30 (66.7%)	30 (66.7%)	28 (62.2%)	0.943
Former	69 (34.0%)	26 (38.2%)	13 (28.9%)	14 (31.1%)	16 (35.6%)	
Current	6 (3.0%)	2 (2.9%)	2 (4.4%)	1 (2.2%)	1 (2.2%)	
ASA Class						
Class I	5 (2.5%)	1 (1.5%)	2 (4.4%)	1 (2.2%)	1 (2.2%)	0.609
Class II	139 (68.5%)	45 (66.2%)	31 (68.9%)	35 (77.8%)	28 (62.2%)	
Class III	59 (29.1%)	22 (32.4%)	12 (26.7%)	9 (20.0%)	16 (35.6%)	
BMI (kg/m2)	32.8 ± 6.7	32.9 ± 7.2	32.9 ± 6.2	33.3 ± 6.3	31.7 ± 6.8	0.699
Hx Contralateral TKA	58 (28.6%)	21 (30.9%)	15 (33.3%)	8 (17.8%)	14 (31.1%)	0.335
Preoperative Ambulation Aid	69 (34.0%)	22 (32.4%)	19 (42.2%)	13 (28.9%)	15 (33.3%)	0.579

ASA, American Society of Anesthesiologists. BMI, body mass index. Hx, history of. TKA, total knee arthroplasty.

Table 2. Perioperative Characteristics Stratified by Group Assignment

	Total N = 203	+ Tourniquet + Block N = 68	+ Tourniquet - Block N = 45	- Tourniquet + Block N = 45	- Tourniquet - Block N = 45	P-Value
Laterality						
Right	95 (46.8%)	32 (47.1%)	22 (48.9%)	24 (53.3%)	17 (37.8%)	0.51
Left	108 (53.2%)	36 (52.9%)	23 (51.1%)	21 (46.7%)	28 (62.2%)	
Anesthesia Type						
Spinal	187 (92.1%)	58 (85.3%)	44 (97.8%)	42 (93.3%)	43 (95.6%)	0.10
General	16 (7.9%)	10 (14.7%)	1 (2.2%)	3 (6.7%)	2 (4.4%)	
Operative Time (minutes)	120 [43 to 246]	112 [61 to 212]	116 [43 to 193]	130 [64 to 217]	127 [78 to 246]	0.030
Length of Stay (days)	1.6 [0.2 to 14.2]	1.6 [0.2 to 6.0]	1.1 [0.3 to 3.3]	2.1 [0.4 to 14.2]	1.5 [0.3 to 5.2]	0.003
Same day discharge	42 (20.7%)	10 (14.7%)	20 (44.4%)	4 (8.9%)	8 (17.8%)	<0.001
Discharge Disposition						
Home	187 (92.1%)	62 (91.2%)	42 (93.3%)	43 (95.6%)	40 (88.9%)	0.30
Acute Rehab Facility	9 (4.4%)	5 (7.4%)	0 (0.0%)	1 (2.2%)	3 (6.7%)	
Skilled Nursing Facility	7 (3.4%)	1 (1.5%)	3 (6.7%)	1 (2.2%)	2 (4.4%)	

Quadriceps Strength Measurements

Average preoperative and postoperative quadriceps strength was comparable between groups in both the surgical and contralateral knees (see Table 3). Significant decreases in the average quadriceps strength were observed in the surgical knee (Surgical Δ) for all groups. However, in the contralateral knee no such significant decrease was observed.

Intragroup analyses showed that the Surgical Δ was significantly greater than the Contralateral Δ for all groups (+T +B: p=0.0004, +T -B: p=0.001, -T +B: p=0.010, -T -B: p=0.0007). However, between-group comparisons revealed no significant differences in the Surgical Δ (p=0.60) or Contralateral Δ (p=0.60) for all groups (see Table 3).

Percent change in quadriceps strength in both the surgical (p=0.14) and contralateral (p=0.24) legs were comparable between groups (see Table 4). Similarly, after normalizing the percent strength change in the surgical leg to the contralateral leg, strength measures were comparable between all groups (p=0.85) (see Table 4).

Postoperative Pain, Mobility, Knee Buckling and Falls

VAS pain scores were comparable between groups (p=0.65) (see Table 5). Postoperative AM-PAC scores statistically differed among groups, with those in the +T -B having the highest scores (21.6 ± 3.0) and those in the -T -B having the lowest scores (19.4 ± 2.9) (p = 0.004), though these differences were not clinically significant.[20] The incidence of knee buckling events did not differ between groups (p=0.18) (see Table 5). None of the patients in all four groups had a recorded fall during their postoperative care.

Table 3. Preoperative, Postoperative, and Postoperative - Preoperative (Δ) Quadriceps Strength Measurements Stratified by Group

	+ Tourniquet + Block N = 68	+ Tourniquet - Block N = 45	- Tourniquet + Block N = 45	- Tourniquet - Block N = 45	P-Value (Between Group)
Time elapsed to measurement (hours)	10.8 ± 8.1	9.3 ± 7.0	8.9 ± 7.2	12.8 ± 8.9	0.096
Surgical Knee Strength (lbs)					
Preoperative	22.2 ± 13.1	22.0 ± 11.2	19.3 ± 10.3	21.1 ± 8.5	0.53
Postoperative	13.9 ± 7.4	12.9 ± 9.6	11.3 ± 6.3	10.9 ± 7.7	0.12
Δ	-8.3 ± 12.5	-9.1 ± 11.9	-8.0 ± 7.6	-10.2 ± 8.4	0.60
P-Value (Pre and Postoperative)	<0.0001	<0.0001	<0.0001	<0.0001	
Contralateral Knee Strength (lbs)					
Preoperative	24.2 ± 13.7	25.1 ± 11.6	22.8 ± 10.3	22.8 ± 10.3	0.70
Postoperative	23.7 ± 8.3	23.1 ± 11.5	21.4 ± 9.5	19.4 ± 9.7	0.10
Δ	-0.5 ± 12.7	-2.0 ± 13.9	-1.4 ± 10.8	-3.4 ± 10.1	0.60
P-Value (Pre and Postoperative)	0.80	0.51	0.42	0.11	

Between-group analyses (listed in the rightmost column) represent ANOVA comparisons of preoperative, postoperative, and Δ measurements between all four groups. Pre/Post analyses listed for surgical and contralateral knees represent paired samples t-test comparisons of preoperative and postoperative quadriceps strength within each group.

Table 4. Percent Change in Quadriceps Strength in the Surgical (Surgical % Δ) and Contralateral (Contralateral % Δ) Leg Compared Between Groups, and the Percent Change Ratio Compared Between Groups

Treatment	Surgical % Δ	P-Value
+ Tourniquet, + Block	-32.1 ± 36.6	0.14
+ Tourniquet, - Block	-39.9 ± 32.5	
- Tourniquet, + Block	-40.2 ± 22.0	
- Tourniquet, - Block	-46.9 ± 24.3	
Treatment	**Contralateral % Δ**	**P-Value**
+ Tourniquet, + Block	8.3 ± 38.7	0.24
+ Tourniquet, - Block	-0.9 ± 36.4	
- Tourniquet, + Block	-5.3 ± 29.9	
- Tourniquet, - Block	-5.1 ± 39.9	
Treatment	**(Surgical % Δ) / (Contralateral % Δ)**	**P-Value**
+ Tourniquet, + Block	0.2 ± 10.1	0.85
+ Tourniquet, - Block	-0.7 ± 10.0	
- Tourniquet, + Block	0.8 ± 5.4	
- Tourniquet, - Block	0.05 ± 6.8	

Table 5. Patient Pain, Knee Buckling Events, and Mobility Scores Collected Within 36 Hours Postoperatively, Stratified by Group Assignment

	+ Tourniquet + Block N = 68	+ Tourniquet - Block N = 45	- Tourniquet + Block N = 45	- Tourniquet - Block N = 45	P-Value
VAS Pain Scale	4.3 ± 2.8	4.6 ± 26	4.0 ± 2.9	4.7 ± 3.0	0.67
Knee Buckling Events	2 (2.9%)	0 (0.0%)	4 (8.9%)	1 (2.2%)	0.18
AM-PAC Score					
Turning over in bed	3.6 ± 0.6	3.8 ± 0.4	3.6 ± 0.5	3.5 ± 0.5	0.002
Sitting/standing from chair	3.3 ± 0.7	3.6 ± 0.5	3.3 ± 0.6	3.2 ± 0.6	0.02
Lying on back to sitting on side of bed	3.3 ± 0.6	3.6 ± 0.5	3.2 ± 0.6	3.2 ± 0.5	0.002
Moving bed to chair	3.5 ± 0.6	3.8 ± 0.4	3.6 ± 0.5	3.5 ± 0.5	0.02
Walking in hospital room	3.3 ± 0.7	3.5 ± 0.7	3.1 ± 0.6	3.1 ± 0.6	0.02
Climbing 3-5 stairs	3.1 ± 0.8	3.4 ± 0.8	3.0 ± 0.6	2.9 ± 0.8	0.02
AM-PAC Total	20.1 ± 3.4	21.6 ± 3.0	19.8 ± 2.9	19.4 ± 2.9	0.004

AM-PAC, Activity Measure for Post-Acute Care. VAS, visual analog scale.

DISCUSSION

This is the first study to evaluate the combined effect of ACB and tourniquet use on early postoperative quadriceps strength, knee buckling, and falls after TKA. The primary findings are (1) tourniquet use is associated with a shorter operative time, (2) ACB administration is associated with a longer LOS, (3) ACB and/or tourniquet use confers no significant additional early postoperative quadriceps weakness, (4) VAS pain scores are comparable for tourniquet/ACB recipients and non-recipients, (5) AM-PAC mobility scores were modestly worse without tourniquet or ACB use but did not reach the minimal clinically important difference (MCID),[20] and (6) the use of an ACB or tourniquet does not increase the incidence of inpatient falls.

The existing literature on ACB and quadriceps strength primarily focuses on comparing strength after FNB to ACB, with very few studies comparing quadriceps weakness after ACB use to controls or baseline values. In a randomized controlled trial, Lan et al. compared quadriceps strength using manual muscle testing in patients who received either an ACB with Ropivacaine or a sham injection during unicondylar knee arthroplasty, finding that postoperative quadriceps strength was worse in the ACB cohort.[6] Hubler and colleagues found a significant decrease on postoperative day one in knee extension dynamometer strength after standard and liposomal Bupivacaine use in ACBs, but didn't compare their results to patients who did not receive a block.[21] Li et al. evaluated quadriceps strength by manual muscle testing and similarly found a significant decrease in strength after ACB, though this study also lacked a non-ACB control group.[22]

Separate investigations of functionality and tourniquet use in TKA have yielded similarly limited results, with few studies using dynamometers and no previous studies to our knowledge analyzing muscle strength prior to 48 hours postoperatively. In a randomized trial comparing tourniquet use for 28 patients undergoing bilateral TKA, Dennis et al. demonstrated weakened quadriceps strength at 3 weeks and 3 months postoperatively when a tourniquet was used, but not on postoperative day two.[23] Zhao et al. performed a randomized controlled trial and found that patients that had a tourniquet inflated during their surgery were weaker as measured by manual muscle testing at three days and three weeks postoperatively.[24] Unlike the other randomized studies, Harsten and colleagues found no increased knee extension weakness after tourniquet use in 64 TKA recipients, measuring strength at 48 hours postoperatively with an isokinetic dynamometer.[25]

In our study, we observed no difference between groups in the preoperative to postoperative change in muscle strength, even after standardization to the contralateral leg. These findings suggest that no additional, meaningful quadriceps impairment is conferred by these interventions. Further, we found no difference in the occurrence of knee buckling events between all four intervention groups. Previous research has supported an association between buckling events and falls due to ACB or tourniquet use in TKA, but each of these studies lacked comparison to a control group receiving no block.[26,27] Additionally, none of the patients in our study sustained a fall during their perioperative care. Given the close association between postoperative falls and quadriceps weakness, we suggest that the decision to employ a tourniquet or ACB in TKA likely does not portend an increased fall risk, as these interventions resulted in no strength impairment in knee extension.

ACB recipients had longer LOS in our study. It is likely that recovery from the regional block extends LOS as patients await complete return of sensory and motor function and achieve adequate functional status for discharge. Interestingly, postoperative pain scores were comparable regardless of ACB or tourniquet use. Prior meta-analyses comparing postoperative pain based on analgesic strategy have not demonstrated a clear advantage of ACBs when compared to isolated use of PAI or epidural analgesia for postoperative pain control,[28,29] and similarly our study did not demonstrate superior pain control with ACBs. Likewise, though thigh pain following tourniquet use in TKA has been reported, a clear relationship between worsened pain and the use of a tourniquet has still yet to be demonstrated, and this was reinforced by our findings.[12,15] Higher AM-PAC scores have been shown to predict earlier discharge following arthroplasty procedures,[30] which may in part explain the shorter LOS observed in the +T -B group. However, overall AM-PAC score differences between groups in our study were marginal, and prior estimates of the MCID for AM-PAC assessments suggest that our mobility results lacked clinical significance.[19,20]

Limitations

The primary limitation of our analysis is the absence of a fully randomized study design. Rather, we elected to primarily assign groups based on surgeons' standard ACB and tourniquet use practices to reduce potential excess risk or confounding based on surgeon experience with the assigned protocol, and randomization was only used as needed to achieve adequate group enrollment. Thus, it is possible that variations in experience or practices among individual surgeons may have introduced bias and influenced our results. Though this partially randomized design does not fully address bias between surgeons, when comparing patient baseline characteristics, we found no differences between groups. Further, we accounted for individual patient variability by normalizing strength measurements to the contralateral knee, and accounted for surgeon-specific variability by enrolling patients treated by eight different surgeons. In addition it was not possible to fully blind providers to the treatment assignments of each patient. However, the dynamometer provides an objective measure of kinematic strength, and thus is less susceptible to observer bias. Lastly, though we evaluated strength and falls in the early postoperative period, we could not assess these outcomes over a longer time-period after discharge.

CONCLUSION

The use of an ACB and/or tourniquet in TKA confers no additional postoperative quadriceps weakness and does not increase the incidence of knee buckling or inpatient falls. Pain scores within the first postoperative day are comparable with and without the use of an ACB or tourniquet. Concern for postoperative impairment in knee extension and fall risk should not be a factor in arthroplasty surgeons' decision-making to use a tourniquet or ACB for TKA, though larger randomized trials are needed to better understand this relationship.

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APPENDIX Table 1.

Appendix Table 1. Supplementary Materials

Pre-op	Day Before Surgery	Immediate Pre-op	Intra-op	Post-anesthesia care unit	Post-Op	Discharge
• Continue NSAIDs • Opiates→ Initiate opiate taper	• Pre-op NSAIDs permitted • Initiate Hydration Protocol • Acetaminophen 1g PO q6-8h • Meloxicam 15mg qd • Aspirin 81mg qd	• Meloxicam 15mg PO • Acetaminophen 1g, PO	• Spinal (opiate free) • Dexamethasone 10mg IV • Fentanyl IV (Induction) • Cocktail: 60mL Bupivacaine (.25% w/v) + Ketorolac 15mg • TXA 2g IV	Dexamethasone 10mg IV Mild Pain (1-3): • Ice therapy PRN Moderate Pain (4-6): • Tramadol 50 mg q8h PRN -OR- • Fentanyl 25 mcg IV q10m (3 doses max) Severe Pain (7-10): • Tramadol 100 mg PO q8h PRN, -OR- • Fentanyl 50 mcg IV q10m (3 doses max) Breakthrough: • Oxycodone 5mg PO once PRN	Mild Pain (1-3): • Ice therapy PRN Moderate Pain (4-6): • Tramadol 50 mg q8h PRN Severe Pain (7-10): • Tramadol 100 mg q8h PRN Breakthrough: • Oxycodone 5mg q6h PRN • Ketorolac 30 mg IV one-time dose (POD 1 only; limit 15 for age ≥65 and/or renal impairment) Standing: • Acetaminophen 1g PO q6-8ha • Meloxicam 15mg PO qd	Standing: • Acetaminophen 1g PO q6-8ha • Meloxicam 15mg PO qd • Aspirin 81 mg PO BID Breakthrough: • Tramadol 50 mg PO q4-6h PRN (36 tablets)

Institutional opioid sparing protocol for primary total joint arthroplasty. NSAIDs, nonsteroidal anti-inflammatory drugs; PO, per os. qd, once daily. q6-8h, every 6-8 hours. IV, intravenous. PRN, as needed. BID, twice daily. a Review liver function before admission.

EVALUATING ONE-WEEK POST-CASTING ALIGNMENT CHECKS AND SURGICAL INTERVENTION RATES IN PEDIATRIC TYPE IIA SUPRACONDYLAR HUMERAL FRACTURES

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ABSTRACT

Background: This study aims to determine the rate of surgical intervention in children with type IIA supracondylar humerus fractures (SCHF) following routine post-casting radiographic assessment. We hypothesized that no cases would convert to operative management following one-week post-casting alignment assessments.

Methods: This single-center retrospective study focused on pediatric patients diagnosed with type IIA SCHF from 2019 to 2022. Patients were treated with initial long arm cast immobilization, followed by a one-week post-casting radiographic alignment check in cast. Fractures were graded in consensus using the Wilkins-Modified Gartland classification system by three fellowship-trained pediatric orthopaedic surgeons. Demographics, casting details, follow-up dates, and treatment histories were examined. Alignment was considered acceptable or requiring surgery based on the treating surgeons' discretion. The study excluded patients with concomitant ipsilateral upper extremity fractures, flexion-type fractures, lost to follow-up before cast removal, or with type I, IIB or III SCHFs.

Results: Of the 128 patients reviewed in our study, 85 were classified as type IIA SCHF by consensus. The cohort had an average age of 4.2 years (range: 1.1-10.2 years) and was 52% male. The patient population was ethnically diverse, with Hispanic patients constituting the majority (56%), followed by White patients (26%), Black patients (9%), and Asian patients (8%).

Patients presented for definitive treatment an average of 2.8 days post-injury and spent an average of 28.8 days in casts. Alignment checks occurred an average of 10.3 days post-injury (SD ±2.5 days). Alignment shifts were noted in 7.1% of cases (n=6). Of these six cases, two were assessed by surgeons as having acceptable alignment, not requiring further intervention. The remaining four cases underwent closed reduction and percutaneous pinning. The rate of conversion to surgical treatment for type IIA supracondylar humerus fractures in our study was 4.7%.

Conclusion: This investigation found that 4.7% of nonoperative type IIA SCHFs converted to operative treatment at the one-week post-casting alignment check. Future studies are warranted to determine specific risk factors for alignment loss in type IIA SCHFs.

Level of Evidence: IV

Keywords: fracture stability, pediatrics, post-casting care, routine radiographs, supracondylar fracture, type IIA SCHF, type 2A SCHF, pediatric supracondylar fracture

INTRODUCTION

Supracondylar humerus fractures (SCHF) are common in pediatric orthopaedics, leading to approximately 63,000 emergency department visits annually.[1] The Wilkins-Modified Gartland classification system classifies these fractures into type I-IV.[2,3] Specifically, type II fractures are characterized by displacement (>2 mm) and a partially intact posterior cortex, leading to varying injury severities within the type II group. To address this variation, Wilkins subdivided type II into type IIA, without rotational displacement, and type IIB, featuring rotational displacement. The distinction between type IIA and IIB SCHFs is critical due to ongoing debate regarding their management.[4] The American Academy of Orthopedic Surgeons (AAOS) suggests closed reduction and percutaneous pinning (CRPP) for type II SCHFs with moderate recommendation in their 2011 clinical practice guideline.[5,6] A survey by Tangadulrat et al. indicates that 58% of pediatric orthopaedic surgeons believe that differentiating between type IIA and IIB fractures is essential for treatment decisions.[7] Furthermore, many surgeons favor nonoperative treatment for type IIA fractures, while considering surgery necessary for type IIBs.[8-10]

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This divergence in treatment approaches underscores the need for more nuanced decision-making protocols in managing type II fractures.

The current literature on type II SCHFs suggests that certain fracture characteristics, such as initial rotation deformity, coronal malalignment, and significant extension of the distal fragment, may increase the risk of alignment shift or loss, potentially leading to surgical management.[10-14] Given the varied severity within type II SCHFs and the lack of a clear consensus on management, many patients treated nonoperatively are closely monitored with radiographic evaluation. However, studies focusing on patients with SCHF who underwent CRPP reveal that routine radiographic evaluations typically do not lead to further surgical procedures.[15-18] The literature lacks exploration of routine radiographic follow-up in nonoperative patients with type II SCHF.

This study aimed to characterize the incidence of surgical intervention at the one-week follow-up appointment for type IIA SCHFs initially treated with casting. We focused on documenting clinical variables, including surgeon decisions and comments on alignment, while rigorously verifying the classification of each case as type IIA. Our hypothesis posited that none of the patients receiving nonoperative management with casting for type IIA SCHF underwent surgical intervention, as determined by the treating surgeon at subsequent alignment check follow-up.

METHODS

Study Design and Participants

This single-center retrospective study focused on pediatric patients diagnosed with type IIA SCHF from 2019 to 2022. We included patients under 18 years old whose treatment plan involved initial nonoperative management, followed by a scheduled radiographic alignment check approximately one-week post-casting. Those meeting the inclusion criteria underwent radiographic review. This study was approved and granted a waiver of consent by our institutional review board.

Data Collection

Patients diagnosed with type II SCHF were identified using Philips IntelliSpace PACS (Koninklijke Phillips N.V., 2004-2024). The process began by reviewing patient records to exclude those who received operative treatment within 7 days of the initial injury. Following the exclusion of surgical cases, the nonoperative group underwent further review to include only patients with scheduled one-week post-casting alignment check appointments (Figure 1).

After confirming that participants met the study's inclusion criteria, a thorough review of their medical charts was conducted. This review collected demographic and clinical data for each patient, including age, sex, casting details, follow-up dates, and treatment histories.

All patients in the study were treated with long-arm immobilization either at an emergent/urgent care facility or Orthopaedic clinic, and subsequently had a one-week post-casting alignment check appointment. Patients with a concomitant ipsilateral upper extremity fracture, those with flexion-type fractures, cases lacking injury radiographs, and those lost to follow-up before cast removal were excluded from this study. Additionally, we excluded patients diagnosed with type I, type IIB and type III SCHFs to maintain a specific focus on type IIA fractures.

Fracture Classification

Injury radiographs were systematically graded by three fellowship-trained pediatric orthopedic surgeons using the Wilkin-Modified Gartland classification system (Table 1). Each surgeon independently assigned a grade, with the process blinded to ensure that they were unaware of each other's assessments and any relevant

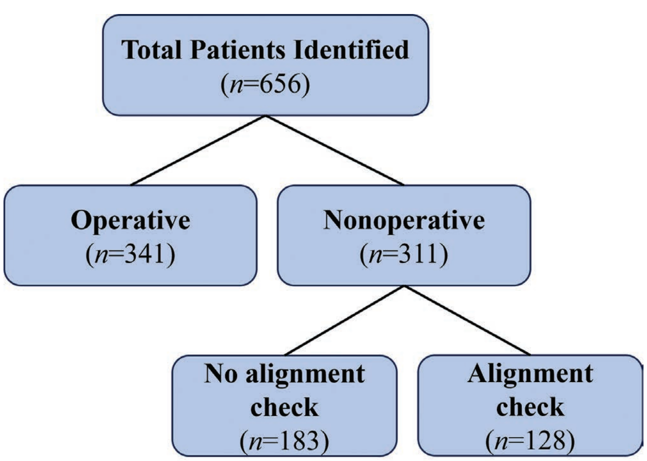

Figure 1. Data Collection and Patient Selection Methods.

Table 1. Wilkin-Modified Gartland Classification System

Type of SCHF	Description
Type I	Nondisplaced
Type IIA	Extended, without rotational abnormality, intact posterior hinge
Type IIB	Extended, straight or rotatory displacement, intact posterior hinge
Type III	Complete displacement, no cortical contact

Gartland classification as modified by Wilkins, adapted from Rang's Children's Fracture (2005).[19]

Table 2. Demographic Characteristics of Patients with Type IIA SCHFs

Demographic Characteristics	Value (SD or %)
Age (yrs)	4.2 (±2.2)
BMI (%)	62 (±33)
Sex	
Male	44 (52%)
Female	41 (48%)
Race	
Hispanic	48 (57%)
White	22 (26%)
Black	8 (9.4%)
Asian	7 (8.2%)

Values are represented as the mean (SD, standard deviation) or as the no. of patients (% of cases).

Table 3. Comparison of Patient Characteristics by Alignment Shifts Status

Characteristics	Shifted (n=6)	No Shift (n=79)	P-Value
Age (yrs)	4.5 [1.3, 6.5]	4.2 [1.1, 10]	0.58
BMI (%)	70 [14, >99]	62 [<1, >99]	0.46
Sex			
Male	3 (52%)	41 (52%)	1.00
Female	3 (48%)	38 (48%)	
Race			
Hispanic	4 (67%)	44 (56%)	0.24
White	0 (0%)	22 (28%)	
Black	1 (17%)	7 (9%)	
Asian	1 (17%)	6 (7%)	
Time from Injury to Definitive Treatment (days)	2.0 [1, 4]	2.9 [0, 7]	0.22
Time from Injury to Alignment Check (days)	9.8 [8, 16]	10.3 [7, 20]	0.36

Note: Percentage values may not sum to 100% due to rounding. Values are represented as average [min, max] or as the number of patients (% of cases). Mann-Whitney U and Fisher's Exact tests were used.

clinical data or outcomes. We adopted a consensus-based approach for grading, requiring agreement from at least two of the three surgeons for a classification to be finalized. Subsequently, patients with fractures classified as type I, IIB, or type III were removed from the study.

Fracture Alignment

The decision to categorize an alignment as acceptable or as requiring intervention was based on surgeons' discretion. Fractures were classified as having a change in alignment based on the surgeon's observations noted in clinical records. Whether or not those patients underwent surgical treatment was left to the discretion of the attending surgeon.

Statistical Analysis

Continuous variables, such as age and body mass index (BMI), were compared using the Mann-Whitney U test. Categorical variables, such as sex and race, were analyzed using the Pearson chi-square test and Fisher's exact test where appropriate. Data was analyzed using IBM SPSS Statistics for Windows, version 29 (IBM Corp., Armonk, N.Y., USA), with significance set at $P \leq 0.05$.

RESULTS

Among the 128 cases evaluated, 85 were classified as type IIA SCHFs. The remaining 43 cases included seven type IIB and 36 type I SCHF and were subsequently removed from the study pool.

The study cohort included 44 male patients (52%), with an average age of 4.2 years (range: 1.1-10.2 years). Most of the participants were of Hispanic (57%) descent, followed by White (26%), Black (9.4%) and Asian (8.2%) descent (Table 2).

On average, patients arrived at the fracture clinic for definitive treatment 2.8 days post-injury (range: 0 to 7 days), where all were subsequently fitted with long arm casts. Alignment checks were conducted at an average of 10.3 days post-injury (SD ±2.5 days). The average duration of casting was 28.8 days (SD ±5.0 days).

In our study, a change in alignment was noted in 7.1% of cases (n=6). Of these, two were assessed by the attending surgeons as still within acceptable alignment, therefore not requiring further intervention. The remaining four cases underwent closed reduction and percutaneous pinning. Notably, all 6 cases were classified as type IIA SCHFs, and there was 100% agreement among raters in assigning these grades. Therefore, the incidence of conversion to surgical treatment in our study was 4.7%.

Comparative analysis of the six fractures with a change in alignment and the rest of the cohort revealed no significant differences in demographic or clinical variables including age, sex, race, and BMI (Table 3).

Number Needed to Treat

The number needed to treat (NNT) can be illustrated by using our conversion rate to represent the difference in the rate of a negative outcome between patients with and without an alignment check. In this calculation, we are considering the absolute risk reduction as equivalent to the conversion rate itself, which assumes that the alignment check intervention detects all such conversions to surgery. Thus, the NNT yields an approximation of 21 in this illustration.

DISCUSSION

The management of type IIA SCHFs in children remains a controversial topic, lacking a clear consensus.[4,5,7,13,20-22] The ongoing debate over the optimal treatment for type IIA SCHFs prompted our investigation of the rate of surgical intervention in children with type IIA SCHF following routine radiographic assessments. Our initial hypothesis posited that none of such patients would require subsequent surgery. Our findings refute this hypothesis.

Our study found a 4.7% incidence of nonoperative type IIA SCHFs transitioning to surgery, a figure that currently lacks a clear consensus in the literature. Research in this area shows a heterogeneity of practice. Silva et al. reported a 9% rate of nonoperative fractures requiring later surgery,[23] while Ojeaga et al. found a 23% rate of conversion from nonoperative to operative treatment for specifically type IIA fractures.[14] Additionally, a more recent study by Silva et al. showed a 14.7% conversion rate.[24] This wide range in reported rates, from 0% to 25%,[9,10,13,14,23-26] underscores the variability in treatment of Type II SCHF, which may be influenced by factors such the reliability of the Gartland classification system, challenges interpreting poor quality radiographs, and institutional specific standards.[27-29] Furthermore, the study by Gamble and Vorhies on the remodeling potential of sagittal plane malunion after SCHF suggests a significant capacity for remodeling, especially in children younger than 5 years, with 60% showing complete remodeling within an average of 21 months.[30] The rate of transition to surgery in our study, while still within the broader spectrum of findings reported in the literature, is on the lower end of this range. Different thresholds for deciding on acceptable alignment across various institutions likely contribute to the diversity in reported rates of surgical intervention for nonoperatively treated type IIA SCHF.

In our study, the NNT quantifies the impact of alignment check appointments in identifying type IIA SCHFs at risk of losing alignment and requiring surgical intervention. By interpreting the 4.7% conversion rate to surgery post-alignment check as a proxy for absolute risk reduction, we assume that the radiographic alignment check effectively identifies all patients who would benefit from surgical intervention. Thus, the NNT illustrates that one patient is recognized as necessitating surgery for every 21 alignment checks performed. Given that x-rays are not benign,[31] we present this figure to offer an additional perspective on our data despite its limitations.

Recent studies have challenged the utility of routine serial radiographs in pediatric fracture healing, finding that routine radiographs for SCHF infrequently influence fracture management.[16-18,32] These studies, however, examined cases following surgical procedures, not nonoperative cases. Given the escalating healthcare costs, particularly related to unnecessary imaging,[33-35] our study concentrates on routine post-casting radiographic evaluations in nonoperative cases. This focus is intended as considerations for future healthcare strategies, potentially reducing expenditures, mitigating unnecessary imaging practices, and raising the value of health care.[36] Further research is needed to establish clear indicators for alignment loss in nonoperative patients, which may prove useful in selecting patients for post-casting checks, ultimately contributing to more cost-effective healthcare.

This study has several limitations. The retrospective nature and the single-center design may limit the validity and generalizability of our findings, particularly due to the controversies regarding the Gartland classification and management of type II SCHF. Although we attempted to mitigate these issues through consensus grading, the subjective determination of alignment loss by surgeons and the absence of collected radiographic parameters constrain our ability to draw definitive conclusions or identify predictors for alignment shift or loss. This subjectivity extends to the surgeon's decision to operate in cases of alignment shift, affecting the confidence of our reported conversion rate to operative treatment. The calculation of the NNT, traditionally dependent on comparing treatment groups, introduces inherent limitations in our context. Calculating this figure necessitates assumptions, rendering its theoretical application to our study type limited. Additionally, the small sample size significantly lowers the power and generalizability of our study. Future prospective studies with larger sample sizes are necessary to validate our findings and identify risk factors for alignment loss or conversion to surgical intervention in type IIA SCHF.

In conclusion, our study revealed that a small proportion (4.7%) of children with type IIA SCHFs treated with casting ultimately underwent conversion to surgical intervention following their one-week post-casting alignment check. Future research should aim to pinpoint specific characteristics of type IIA SCHFs that are more susceptible to alignment loss. Such insights could lead to the development of standardized treatment protocols, enhancing care efficiency and potentially reducing the costs associated with unnecessary imaging and appointments.

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IDENTIFYING PREDICTORS OF EXTENDED INTENSIVE CARE UNIT STAY FOLLOWING POSTERIOR SPINAL FUSION FOR ADOLESCENT IDIOPATHIC SCOLIOSIS: AN ANALYSIS OF 101 ACS NSQIP PEDIATRIC PARTICIPATING CENTERS

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ABSTRACT

Background: While prolonged operative time and increased levels fused have been shown to increase the risk of prolonged intensive care unit (ICU) length-of-stay (LOS), studies are limited in guiding decision-making regarding the need for intensive care postoperatively. This is especially the case among the cohort of adolescent idiopathic scoliosis (AIS) patients undergoing posterior spinal fusion (PSF); associations between comorbidities and ICU LOS are not well-delineated.

Methods: AIS patients who underwent PSF from January 1st, 2016 to December 1st, 2016 at 101 participating centers were identified using the American College of Surgeons (ACS) National Surgical Quality Im-provement Project (NSQIP) Pediatric database. Patients were subsequently grouped by ICU LOS 0-1 day; 2-3 days; and >3 days. Multivariate regression identified predictors of increased ICU LOS.

Results: 2,346 AIS patients were included. The >3 days and 2-3 days groups had higher asthma rates compared to 0-1 day. The >3 days group had higher rates of structural airway abnormalities and he-matologic disorders. Cognitive impairment rates were highest for >3-day ICU LOS. Hemato-logic dis-orders, structural airway abnormalities, asthma and cognitive impairment were associated with prolonged ICU LOS.

Conclusion: These results help inform targets for optimization of acute short-term postoperative care as well as assisting in risk stratification to improve outcomes and reduce costs for ICU-level care of AIS patients at ACS NSQIP Pediatric program-participating hospitals.

Level of Evidence: III

Keywords: adolescent idiopathic scoliosis, posterior spinal fusion, postoperative outcomes, intensive care unit, length of stay, complications, pediatric spinal deformity

INTRODUCTION

Adolescent idiopathic scoliosis (AIS), characterized by a three-dimensional deformity of the spine, is diagnosed after excluding other causes of spinal deformity such as congenital and neuromuscular scoliosis. It is estimated that AIS is present in 0.3% to 3% of the population, with a lower prevalence of higher magnitude curves.[1,2] While observation and bracing can be effective treatments for some cases of AIS, severe cases often necessitate poste-

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rior spinal fusion (PSF).[3,4] In an analysis of 43 hospitals contributing to the Pediatric Health Information System (PHIS) database from 2004 to 2009, pediatric inpatient care for idiopathic scoliosis ranked as the fifth highest standardized total cost of care, totaling $610 million and costing an average of $41,146 per encounter.[5]

Posterior spinal fusion has widely been accepted as safe, with low rates of complications.[6] However, complications can arise, including neurological damage, which may manifest months after the index surgery. In a prospective study analyzing 3,582 patients, Bartley et al.[7] have shown two-year follow up complication rates of 4.1% following PSF. In addition, Boylan et al.[8] found that every additional day in the hospital following spinal fusions was associated with higher rates of postoperative complications and 90-day readmissions.

Despite the recent shift in the American healthcare system to emphasize the importance of cost containment in medicine, the cost of healthcare in the United States continues to rise rapidly. Both hospital administrators and practitioners are striving to provide quality care at a lower cost through the utilization of cost-saving measures.[9,10] As healthcare costs rise rapidly, so too has the cost of surgical man-agement of AIS. Martin et al.[11] have shown an over two-fold increase in cost from $72,780 in 2001 to $155,278 in 2011, with a continued increase of 11.3% annually. Additionally, Harris et al.[12] demonstrated how extended length of stay (LOS) for patients with AIS undergoing posterior spinal fusion was associated with significantly increased net hospital payments. Similarly, Malik et al.[13] analyzed the 90-day hospital cost distribution and also found one significant independent predictor was extended LOS.

Harris et al.[12] demonstrated how longer fusion construct, thoracoplasty, postoperative wound problems, respiratory problems, urinary tract infections, and constipation were associated with longer LOS following PSF in AIS patients. However, little data exists regarding predictive factors, including comorbidities, associated with prolonged postoperative intensive care unit (ICU) LOS following PSF in AIS patients. Although some studies were able to identify decreased FVC, congenital heart disease, cardiomyopathy, arrhythmia, chronic renal failure, epileptic seizures, and hematological conditions as being risk factors for prolonged ICU LOS, they were limited by small sample size.[14] This study sought to further identify factors associated with prolonged postoperative ICU LOS in order to better risk-stratify patients preoperatively as well as understand the drivers behind prolonged ICU LOS during the immediate postoperative course at specialty pediatric hospitals participating in a national pediatric surgical registry.

METHODS

Data Source

Patient information was obtained using the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Pediatric Procedure Targeted Spinal Fusion database. The NSQIP Pediatric database details preoperative demographic information and 30-day postoperative outcome data including complications, hospital morbidities, and mortalities associated with surgical admissions at participating hospitals, which represent freestanding general acute care children's hospitals, specialty children's hospitals, and specialty children's hospitals.[15]

The Procedure Targeted database has additional information beyond the typical NSQIP data focused on spinal fusion, including information on ICU LOS.[16]

Patient Population and Variables

AIS patients who underwent PSF at 101 participating centers in 2016 were identified by the Current Procedural Terminology (CPT) codes 22800, 22802, and 22804, which correspond to arthrodesis procedures for spine deformity up to 6 levels, 7 to 12 levels, and ≥13 levels, respectively. Procedures performed by either orthopaedic or neurosurgeons were included. The ICU LOS, included in the Spinal Fusion Procedure Targeted dataset, was extracted and the cohort separated into 3 groups according to LOS: 0-1 day, 2-3 days, and >3 days. Basic patient demographics (age, sex, and race) as well as comorbidities (pulmonary, cardiac, gastrointestinal, neurologic, musculoskeletal, and cancer) were retrieved.

Statistical Analysis

A retrospective cohort analysis was performed. Descriptive analysis included the means and proportions of the patients' demographic variables. Univariate analysis was used to compare patient demographics and comorbidities with post-hoc Bonferroni-corrected analysis across the different ICU LOS groups. Multivariate regression was used to identify potential baseline factors as predictors of a lengthier ICU LOS. All statistical analyses were performed in SPSS version 24 (IBM Corp., Armonk, NY, USA) and a p-value <0.05 was considered statistically significant.

RESULTS

A total of 2,346 AIS patients undergoing PSF were identified and then separated based on the 3 ICU LOS groups. The 0-1 day, 2-3 days, and >3 days groups accounted for 81.8%, 16.5%, and 1.7% of patients, respectively. Patient demographics, including age, sex, and race, were comparable across cohorts (all, p>0.05; Table 1). Patients with a >3-day ICU LOS had the highest percentage of >13-level fusions (>3-day: 51.2%) compared to 0-1-day ICU LOS (26.5%) and 2-3-day ICU LOS (20.7%) (p<0.001). Patients with a 0-1-day ICU LOS and 2-3-day ICU LOS contained significantly more 7-12 level fusion patients (0-1-day: 65.6%; 2-3-day: 70.0%) compared to patients with a >3-day ICU LOS (39.0%) (p<0.001). All 3 groups had comparable percentages of patients with <6-level PSF (0-1-day: 7.8%, 2-3-day: 9.3%, >3-day: 9.8%). Operating room (OR) times increased as ICU LOS increased (0-1-day: 260 minutes; 2-3-day: 293 minutes; and >3-day: 346 minutes) (p<0.001).

The three ICU LOS cohorts varied by comorbidity rates (Table 2). Patients with 2-3-day ICU LOS and >3-day ICU LOS had higher asthma rates (10.1% and 19.5%) compared to patients with 0-1-day ICU LOS (5.5%) (p<0.001). Patients with >3-day ICU LOS also had higher structural airway abnormalities (>3-day: 19.5% vs. 0-1-day: 1.1%; 2-3-day: 1.6%) and hematologic disorders (>3-day: 9.8% vs. 0-1-day: 1.0%; 2-3-day: 1.8%) (both, p<0.001), but these rates were comparable between patients with 0-1-day and 2-3-day ICU LOS. For each increase in duration of ICU LOS, there was a larger proportion of patients with developmental delay/cognitive impairment (0-1-day: 6.2%; 2-3-day: 10.9%; >3-day: 26.8%; p<0.032). Of note, preoperative conditions related to gastrointestinal, nervous system, neuromuscular, or cancer did not impact the duration of ICU LOS (all, p>0.05) (Table 2).

Multivariate regression revealed that the odds of 1-2-day ICU LOS and >3-day ICU LOS increased with baseline asthma (OR=1.7, 95%CI [1.2 - 2.6] and OR=2.7, 95%CI [1.0 - 7.2], respectively) as well as cognitive impairment (OR=1.9, 95%CI [1.3 - 2.9] and OR=2.7, 95%CI [1.01 - 7.2], respectively), when compared to 0-1-day ICU LOS (all, p<0.047) (Table 3).

DISCUSSION

This study retrospectively analyzed duration of ICU LOS in 2,346 AIS patients undergoing PSF. Patient demographics were comparable across ICU LOS cohorts, while certain perioperative factors were associated with increased ICU LOS in AIS patients. A spinal fusion of >7 levels and longer OR time increased the odds of >3-day ICU LOS. These findings aligned with the results from Basques et al.[17] and Harris et al.,[12] who found that fusions of >13-levels and OR time >365 minutes were both as-sociated with extended ICU LOS. Across all these studies, ICU LOS cutoffs were not consistent. Singh et al.[18] reports an average ICU LOS of 3.1 days for patients undergoing elective spine surgeries. Basques et al.[17] defined an extended ICU LOS as >6 days, Harris et. al.[12] defined an extended ICU LOS as >7.2 days, while our study separated cohorts into 0-1 days, 2-3 days, and >3 days. In addition, Basques et al.[17] had a higher cutoff for both the level of spinal fusions (>13-level) and OR

Table 1. Patient Demographics

	0-1 days	2-3 days	>3 days	p-value
n	1,918 (81.8%)	387 (16.5%)	41 (1.7%)	
Mean age (years)	14.24 ± 1.02	14.19 ± 1.31	13.43 ± 2.04	0.079
Sex				
Male	456 (23.8%)	85 (22.0%)	10 (24.4%)	0.738
Female	1462 (76.2%)	302 (78.0%)	31 (75.6)	
Race				
White	1471 (76.7%)	289 (74.6%)	31 (75.7%)	0.709
Black	386 (20.1%)	88 (22.8%)	8 (18.9%)	
Other	61 (3.2%)	10 (2.6%)	2 (5.4%)	
Fusion Levels				
<6	150 (7.8%[a])	36 (9.3%[a])	4 (9.8%[a])	<0.001
7-12	1258 (65.6%[a])	271 (70.0%[a])	16 (39.0%[b])	
>13	508 (26.5%[a])	80 (20.7%[b])	21 (51.2%[c])	
Operation Time (mins)	260 ± 15.1[a]	293 ± 19.3[b]	346 ± 21.1[c]	<0.001

Superscript numbers reflect intergroup comparisons post Bonferroni correction, with a p-value threshold of 0.05.

Table 2. Univariate Analysis of Cohorts by Comorbidities

Preoperative Conditions	0-1 days	2-3 days	>3 days	p-value
History of asthma	5.5%[a]	10.1%[b]	19.5%[b]	<0.001
Bronchopulmonary dysplasia/ chronic lung disease	2%[a b]	1.3%[b]	7.3%[a]	0.032
Structural pulmonary/airway obstruction	1.1%[a]	1.6%[a]	19.5%[b]	<0.001
Esophageal/gastric/intestinal disease	2.6%[a]	4.1%[a]	7.3%[a]	0.066
Previous cardiac surgery	1.6%[a]	2.8%[a b]	7.3%[b]	0.008
Developmental delay/impaired cognitive status	6.2%[a]	10.9%[b]	26.8%[c]	<0.001
Seizure disorder	1.1%[a]	2.3%[a]	2.4%[a]	0.159
Cerebral palsy	0.4%[a]	0.8%[a]	0.0%[a]	0.483
Structural CNS Abnormality	4.7%[a]	5.4%[a]	9.8%[a]	0.305
Neuromuscular disorder	5.4%[a]	6.7%[a]	9.8%[a]	0.305
Hematological disorder	1.0%[a]	1.8%[a]	9.8%[b]	<0.001
Past or current cancer	0.4%[a]	0.8%[a]	2.4%[a]	0.145

Superscript numbers reflect intergroup comparisons post-Bonferroni correction, with a p-value threshold of 0.05.

Table 3. Multivariate Regression Analyses Comparing 0-1 Day with 2-3 Days and 0-1 Day with >3 Days to Identify Predictors of ICU LOS

	Asthma			Cognitive impairment			Hematological disorders			Structural airway abnormalities		
	OR	95% CI	p-value	OR	95% CI	p-value	OR	95% CI	p-value	OR	95% CI	p-value
2-3 days	1.749	1.162 - 2.632	0.007	1.927	1.283 - 2.893	0.002	1.725	0.659 - 4.517	0.267	0.711	0.244 - 2.072	0.532
>3 days	2.709	1.013 - 7.246	0.047	2.718	1.047 - 7.053	0.040	8.972	2.442 - 32.966	0.001	6.467	1.826 - 22.898	0.004

time (>365 minutes) that were considered significant for increasing ICU LOS. Our findings corroborate the authors' results and suggest that an even lower threshold for the levels of spinal fusions and OR time can be used to predict an ICU LOS of 4 days or greater.

The current study found comorbidities of asthma, structural airway abnormalities, cognitive im-pairment, and hematologic disorders all increased the risk of >3 days ICU LOS by 2.7, 6.5, 2.7, and 9.0-fold, respectively, which is similar to what Akesen et al.[14] determined. Berry et al.[19] demon-strated that chronic respiratory insufficiency was the highest predictor of increased hospital LOS by 2.1 days following spinal fusions. However, the authors analyzed the effect that the patient's chronic comorbidity burden, rather than specific comorbidity types, had on hospital LOS and found that LOS increased as the number of comorbidities increased. On the contrary, Sultan et al.[20] noted many similar comorbidities present in 407 AIS patients undergoing PSF, but none were statistically significant for an extended hospital LOS as defined as >4-days. Instead, they found a female sex and higher levels of spinal fusions (9 + 2 levels) to have an independent association with extended hospital LOS. Although our current study found similar results with levels of spinal fusions being associated with extended ICU LOS, we did not find an association between gender and duration of ICU LOS.

As surgical spinal fusion techniques have improved in recent years, hospital LOS have decreased from 6.1 days in 1998 to 5.4 days in 2011.[21-24] The present study can help surgeons stratify patients based on preoperative risk of prolonged ICU LOS. Fletcher et al.[25,26] developed an accelerated discharge pathway for AIS patients following PSF, which reduced inpatient stay and hospital costs with no increase in complications or readmissions rate. However, studies using the accelerated discharge program with AIS patients following PSF in the ICU have not been well-documented. Given that many comorbidities and operative factors were identified in the present study as predictive of prolonged ICU LOS, this data may be used to better target accelerated discharge to patients with a lower burden of comorbidities. Conversely, AIS patients undergoing PSF who have concomitant hematologic disorders, structural airway abnormalities, asthma, or cognitive impairment would likely not benefit from an ac-celerated discharge program given their need for extensive ICU care. Further research is warranted to optimize the multidisciplinary care they will require postoperatively to improve their immediate postoperative course and reduce the length of ICU-level care they need following surgery.

Recently, Malik et al.[27] published a study of predictors of ICU stay after PSF for patients with pediatric spinal deformity, also using the pediatric NSQIP database. While the majority of the overall population had idiopathic scoliosis, over half of those admitted to the ICU had causes of deformity other than AIS. This is in contrary to the present study that only included patients with AIS. The authors also focused substantially on surgical variables, reporting anterior-only and combined anterior-posterior ap-proaches to increase the odds of ICU stay >2 days. Like our study, the authors also report comorbidities such as asthma, structural pulmonary abnormalities, developmental delay, and concurrent neuromuscular disorder as factors associated with ICU stay >2 days. Our study expands on this by delineating factors associated with 2-3-day ICU and >3-day ICU stays in order to better identify these risk factors. Taken together, these studies provide a more complete picture of risk factors for prolonged ICU LOS.

Previous research showed that mortality rates increased when non-cardiac surgical patients were upgraded to the ICU following non-ICU level postoperative care.[28] Another study in the United Kingdom from 1999-2004 found that high-risk surgical patients accounted for just 12.5% of procedures, but 83.8% of deaths. Yet fewer than 15% of the high-risk surgical patients were admitted to the ICU.[29] There is a need to improve risk-stratification prior to surgery in order to improve quality of care. This, followed by an individualized patient management plan, could increase hospital efficiency, quality of care, and patient outcomes. Future research should determine if the number of comorbidities present have a compounding effect on a patient's risk of a prolonged postoperative

ICU LOS. Further studies may also lead to a predictive model using the comorbidities identified in this study and OR time to identify the patient population at higher risk for an increased ICU LOS.

There are several limitations to this study. Data was collected using CPT codes, which are subject to inconsistencies based on education and training of those who enter the codes as well as documentation errors. While errors may exist,[30] ACS NSQIP employs Surgical Clinical Reviewers to help mitigate, though not fully eliminate, coding errors. Additionally, performing a study with NSQIP data is retrospective in nature. The NSQIP database may not collect all relevant variables that could influence the results of the study. Using a large national database such as NSQIP does provide the benefit of reducing hospital-specific biases that may exist. Data in NSQIP only covers 30 days and thus data on readmission or upgrade to the ICU outside of this timeframe is unavailable. Additionally, the data was only available for 1 year of patients undergoing PSF. Moreover, the data submitted to the ACS NSQIP Pediatric database are from hospitals that are participating in the program and do not represent a statistically valid nationally representative sample, as is declared by the ACS NSQIP Procedure Targeted PUF User Guide.[16] Additionally, the database lacks other clinical data, such as magnitude of the scoliosis curve, that can also impact outcomes. Finally, the database does not include information on admissions or dispositions to other monitoring units or levels of care, such as a step-down unit.

CONCLUSION

In conclusion, this study demonstrates that the presence of specific comorbidities was associated with increased ICU LOS in AIS patients. Hematologic disorders, structural airway abnormalities, asthma and cognitive impairment increased the risk of >3 days ICU LOS. Higher levels of spinal fusions and operative times were also associated with an extended ICU LOS of >3 days. These results help identify targets for optimization of acute postoperative care and allow the design of care pathways for patients with AIS undergoing PSF in order to reduce their needs of ICU-level care in the immediate postoperative period.

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THE COST OF ROUTINE CLINIC VISITS FOLLOWING SPINAL FUSION FOR ADOLESCENT IDIOPATHIC SCOLIOSIS

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ABSTRACT

Background: The institutional standard follow-up schedule for patients undergoing spinal instrumentation and fusion for adolescent idiopathic scoliosis (AIS) is return to clinic at 6-weeks and 3 months post-procedure for radiographs. COVID-19 prompted a change in this practice and most routine post-op visits were performed virtually during that time. The purpose of this study is to estimate the cost and benefit of in-person visits to inform the relative value of in-person follow-up using data from the year prior to COVID changes.

Methods: This was a retrospective study including all patients with AIS who underwent spinal instrumentation and fusion in 2019 by a single surgeon at a tertiary medical center. The cost of radiographs, travel, and parental lost wages associated with follow-up visits at 6-weeks and 3-months were estimated. Transportation costs were estimated by multiplying the distance between home and clinic by the standard IRS travel reimbursement rate ($0.58/mile). Parental lost wages were estimated using the average 2019 US census income for men and women. Each patient's electronic medical record was reviewed to see whether radiographs and physical assessment resulted in any changes in orthopaedic management at each visit.

Results: The sample included 63 patients (75% female, 94% Caucasian) with an average age of 15.22 years. The average round-trip distance traveled was 94.4 miles (range 3.2-476), resulting in an average travel cost of $109.47. The total time spent for a visit (travel, wayfinding and the clinic visit itself) averaged 330 minutes, resulting in an estimated lost parental wage of $125.47. Estimated cost of radiographs at each visit was $693. This combined cost burden totaled $927.94 for each visit, and no changes in management were prompted by clinical or radiographic findings at any of the 126 visits.

Conclusion: COVID-19 presented many new challenges to healthcare, including a necessary increase in virtual healthcare delivery. This study estimated the cost of in-person follow-up visits the year prior to COVID-19. Patients and their families traveled hundreds of miles and spent hundreds of dollars to attend these visits. No changes in clinical management were prompted by findings at these in-person follow-up visits, and implementation of virtual post-operative visits could potentially lead to cost savings for families in these instances.

Level of Evidence: III

Keywords: scoliosis, cost, COVID-19, follow-up

INTRODUCTION

COVID-19 created many new challenges across the healthcare field. Access to clinic visits was made very difficult throughout the country and many visits were performed virtually.[1] Multiple studies have investigated the efficacy of virtual visits throughout multiple orthopaedic subspecialties.[2-4]

Healthcare costs in the United States surpassed $3.0 trillion in 2014 and have continued to trend upward.[5,6] Previous studies have estimated the cost of post-operative visits in a variety of orthopaedic subspecialties.[7,8] Post-operative visits may not pose a large cost burden to the healthcare system, but they may pose a significant cost to patients and families.[7] There is emerging evidence regarding the cost-effectiveness of virtual clinic visits in orthopaedics and other surgical subspecialties, which could potentially decrease costs to patients.[2,3,9,10] Additionally, other studies investigating routine post-operative orthopedic visits have shown that management does not routinely change following these appointments.[11,12] To our knowledge, no previous investigations have quantified the cost of routine post-operative clinic visits and radiographs for AIS patients following spinal fusion.

Prior to COVID-19 shutdowns, the standard follow-up visits at our institution for patients undergoing spinal fusion for adolescent idiopathic scoliosis (AIS) was 6 weeks, 3 months, 6 months, and 1 year, and radiographs

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were obtained each of these visits. The purpose of this study is to determine the value of the 6-week and 3-month post-operative clinic visits by estimating the costs to families and assessing the clinical necessity of these in-person visits.

METHODS

Patient Sample

This retrospective review included all patients with the diagnosis of AIS who underwent spinal instrumentation and fusion by a single orthopedic surgeon (SLW) at a tertiary care center in 2019. Patients with the diagnosis of neuromuscular, congenital, or other non-idiopathic scoliosis were excluded. Demographic data (age, sex, race, body mass index (BMI), home address) and clinical data (results of clinical and radiographic examinations, new prescriptions, orders for additional testing or referrals, and return to the operating room or change in routine post-operative patient instructions) were abstracted from the electronic medical record (EMR) for each patient.

Cost Accounting

We adapted the methodology and estimates from a previous cost-estimation study at our institution for AIS.[13] Meirick et al. determined the costs of unnecessary referrals for AIS evaluation to our institution in 2013-2014.[13]

Transportation

Travel cost was estimated by calculating the total number of miles driven from each patient's home address to the clinic using an online distance calculating program via Google Maps. If the patient's street address was not included in the program, the center of the hometown was used to calculate distance traveled. Distance was then multiplied by the standard business mileage rate ($0.58 per mile) from the Internal Revenue Service (IRS) for the year 2019.[14] This per mile rate reflects the combination of fixed and variable costs for vehicle operation.

Parental/Patient Lost Wages

The presence of the mother, father, or both parents at the clinic was determined by review of the clinic note for each visit. If the patient was older than 22 years of age (n=3), their wages were also included. The average salary according to US Census Bureau 2019 estimates was $67,123 and $52,035 for men and women, respectively. Salaries were then divided by 2087 hours to estimate an hourly wage for each parent.[15] We used the wayfinding time (navigating from the parking lot to the clinic) and clinic visit duration estimates reported by Meirick et al.[13] Lost wages were then estimated by adding the round-trip travel time, wayfinding time,[13] and average clinic visit duration, and multiplying the sum by the estimated hourly wage.

Post-operative Clinical Follow-ups

The standard post-operative protocol for AIS patients includes return to clinic at 6 weeks and 3 months for standing anteroposterior and lateral full spine films with direct clinical examination of the patient. Clinic notes were reviewed for the presence of any complications resulting in the need for antibiotics or other medications, additional testing, or referral, return to the operating room, or a change to the standard post-operative protocol. We specifically looked for complications that were found via direct physical examination and/or radiographs.

RESULTS

Sample Characteristics

Sixty-three patients met the inclusion criteria. Their mean age at surgery was 15.22 ± 2.9 years and 47 (75%) were female. The racial breakdown was representative of the institution's catchment area (94% white, 5% Hispanic, 1% African American). The average BMI was 22.2 ± 6.4 (range: 13.9-43.8).

Transportation and Clinical Costs

The average round-trip travel distance for follow-up appointments was 188.74 ± 114.78 miles (range: 3.2-476). This resulted in an average cost of $109.47 ± $66.57 (range: $3.20-$476.00). A total of 126 scoliosis films were obtained during the 126 clinic visits. The estimated cost per film was $693.

Parental/Patient Lost Wages

The estimated round-trip travel time was 184.44 ± 104.65 minutes (range: 12-442). Meirick et al.[13] estimated average wayfinding time at 6.4 ±1 2.0 minutes and time in clinic at 128.4 ± 12.0 minutes. Of the 126 visits, both parents were present at 24%, the mother only at 35%, and the father only at 3%. Multiplying the estimated travel time by the appropriate salary figures resulted in estimated parental/patient lost wages of $125.47 ± $90.37 (range: $0.00-$407.56).

Total Cost and Clinical Findings

The estimated cost of each visit was $927.94 ± $156.94 (range: $694.86-1376.64). The clinical examinations were all within normal limits for the stage of recovery. The radiographs did not reveal any cases of instrumentation failure. No new medications or changes in the standard post-operative management were recommended based on the physical examination or radiographs obtained at any of these visits.

DISCUSSION

In this study, in-person 6-week and 3-month post-operative visits did not lead to any changes in standard management. On average, patients traveled a total of 188 miles and faced an estimated loss of $927.94 for each follow-up visit. Given the absence of changes in clinical management, this raises the question of whether these in-person follow up visits are worth the cost to each family.

There is no current consensus on when standard post-operative visits for patients undergoing spinal fusion for AIS should occur or when radiographs should be obtained. Garg et al. investigated the frequency with which radiographs were obtained during the first year after spinal fusion for patients with AIS.[16] They found an average of 6 radiographs were obtained during the first post-operative year, and implant failure was found in 2% of their patients. Additionally, they reported increased pain as the only clinical finding associated with implant failure. Similarly, Garcia et al., found only 0.6% of post-operative films demonstrated an abnormal finding.[17] and, only 0.17% of radiographs in addition to clinical findings led to revision procedures. These studies suggest that standard post-operative films may not be necessary if pain is absent and clinical exam is benign.

While there is no evidence reporting the cost of follow-up visits following spinal fusion for AIS, cost estimates of follow-up visits in other orthopaedic subspecialties do exist. Hendricks et al. estimated the cost of total joint arthroplasty follow-ups visits to average $135.20,[8] and that 84% of patients felt these follow-up visits were necessary. Predmore et al. surveyed patients regarding their preference of in-person versus virtual clinic visits and found that 53% of patients preferred in-person visits, while 21% of patients preferred video visits.[18] This supports a growing body of evidence that in-person post-operative visits may not be necessary if patients are not having pain or other concerning symptoms.

To our knowledge, this is the first investigation quantifying patient cost-burden at post-operative follow-up visits after spinal fusion for AIS. This study demonstrates high estimated costs of roughly $927 per visit or $1,854 for both visits at the 6-week and 3-month post-operative time points. Given the high financial burden this may pose to some families, it may be reasonable to offer patients the option of a phone call or telehealth visit in the absence of pain or other abnormal symptoms. Our study did not identify any signs of radiographic hardware failure at these time points and suggests that these visits are unlikely to result in any changes to clinical management. We believe further investigation is warranted to discern whether AIS patients and their families may prefer the option of a virtual visit in lieu of an in-person appointment at the early postoperative time points following spinal fusion. Given these data, we believe it would be safe to offer a virtual visit at the 3- and 6-week post-procedure time points depending on patient preferences.

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THE EFFICACY OF PROPHYLACTIC VANCOMYCIN IN DECREASING SURGICAL SITE INFECTIONS IN ADOLESCENT IDIOPATHIC SCOLIOSIS PATIENTS: A LARGE MULTICENTER COHORT STUDY

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ABSTRACT

Background: The use of vancomycin powder in spine surgery has been supported in adult populations, however, its efficacy in preventing postoperative surgical site infections in AIS patients is yet to be determined.

Methods: A multi-center review was conducted from June 2010 to February 2019, using ICD and CPT codes to identify AIS patients who underwent primary PSF. The patients were divided into two groups: the vancomycin cohort (receiving local vancomycin powder prior to wound closure) and the non-vancomycin cohort. Demographic and surgical data, microbial data, and SSI rates were compared between the two groups.

Results: A total of 1,917 AIS patients underwent PSF during the study period. There were no significant differences in age at surgery, BMI, sex, or presence of osteotomy between the two groups. The vancomycin cohort had 65.3% patients (n=1,252) with 0.5% (n=6) diagnosed SSIs, while the non-vancomycin cohort had 34.7% patients (n=665) with 0.8% (n=5) SSIs (p=0.451). Four (66.7%) gram-negative bacteria were isolated in the vancomycin cohort, compared to one (20%) in the non-vancomycin cohort.

Conclusion: The results showed no significant reduction in surgical site infections with the use of prophylactic, local vancomycin in AIS patients undergoing PSF (0.5% versus 0.8%). Further studies are needed to fully assess the effectiveness of vancomycin in this population.

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INTRODUCTION

Pediatric scoliosis patients undergoing posterior spinal fusion (PSF) with instrumentation continue to be at risk for surgical site infections (SSI). In this population, SSIs cause significant morbidity including prolonged readmission, reoperation, increased healthcare costs, and psychological distress for both the patient and family.[1-5] Reported rates of SSI after scoliosis correction in children vary widely from 0.4% to 20% or even higher depending on the underlying etiology and patient population.[6-9]

Adolescent idiopathic scoliosis (AIS) is the most common form of spinal deformity in children with an overall prevalence of 0.5%–5.2% and accounts for 80% of all pediatric scoliosis.[10] It is also the most common etiology to require surgical treatment, with the annual incidence of AIS patients undergoing posterior spinal fusion increasing over the past two decades.[11-14] Deformity surgery for AIS is associated with lower rates of SSI compared to other etiologies, with a reported range between 0.2% to 1.6%.[7-9,15] However, due to the large number of AIS patients undergoing surgery, even a low SSI rate can result in a significant number of infections that pose a tremendous burden on the patient and healthcare system. For these reasons, numerous measures have been taken to try to minimize the incidence of SSI in this population, but efforts that target a 0% infection rate remain.[16,17]

The use of local vancomycin powder as antibiotic prophylaxis is a preventative measure recently popularized throughout the spine community. Several studies since 2011 have shown that it reduces SSI rates after PSF while maintaining a good safety profile within the pediatric population.[18-23] While consensus exists among pediatric spine surgeons that local vancomycin powder should be used to prevent SSI in high-risk pediatric patients, its role in the AIS population has yet to be established.[16] The purpose of this study was to investigate whether local administration of vancomycin powder significantly reduced the rate of early SSI in AIS patients after PSF as well as the causative pathogens identified.

METHODS

This study was reviewed by an Institutional Review Board (IRB) and determined to be exempt as defined under federal regulation 45 CFR 46.

Data was extracted from nine interrelated healthcare sites specializing in the treatment of pediatric patients. Using the interconnected electronic medical record for a multicenter children's hospital system, a limited data set containing patient data from nine care sites, a systematic review of retrospective surgical data was conducted from June 2010 to February 2019. Standard query language (SQL) programming was used to isolate surgical cases of PSF with instrumentation within the given timeframe using International Statistical Classification of Diseases and Related Health Problems (ICD)-9, ICD-10, and Current Procedural Terminology (CPT) codes. Spinal fusion and surgical approaches including anterior approach, cervical fusion, sacral fusion, pelvic instrumentation, and revisions were excluded from the query. Based on the data output, the query was joined with ICD-9 and ICD-10 codes specifying the diagnosis of AIS. The list was parsed to exclude patients with syndromic conditions, congenital cardiothoracic defects, and neuromuscular conditions.

Using the data set, we were able to further delineate and group patients into two cohorts based on aggregate data on the application of prophylactic, local vancomycin use during surgery. Administrations of vancomycin, not via an intravenous route, but on the surgical field were categorized into the cohort labeled as the vancomycin cohort. Lack of topical vancomycin utilization during PSF was categorized into a second cohort listed as the non-vancomycin cohort. Between the two cohorts, positive microbial culture data and hospitalizations involving irrigation and debridement procedures were identified within a 90-day post-surgical follow-up period. This 90-day surveillance period is defined by the Centers for Disease Control (CDC) and the National Healthcare Safety Network (NHSN) for spinal fusion procedures.[24] The subset of patients with either positive cultures or who underwent irrigation and debridement were analyzed to identify rates of deep surgical site infections. For a patient to be considered as having a surgical site infection, a positive culture was required.

Demographic information including age at time of surgery, gender, and body mass index (BMI) was collected. Surgical data collected included anesthesia billing time, the number of levels fused, and whether osteotomies were performed. Anesthesia billing time was the most available proxy for the duration of surgery.

An a priori power analysis was performed based on results from a similar retrospective study by Meza et al.[25] Using dichotomous endpoint, two independent sample calculations, an SSI incidence of 0.2% for those who received topical vancomycin and 1.7% for those who did not, and an alpha of 0.05, a minimum of 877 patients in each group were needed to achieve a power of 0.90.

Table I. Preoperative and Operative Data

Variable	Vancomycin Cohort†	Non-Vancomycin Cohort†	p value††
Age (years)	14.9 ± 4.4	14.9 ± 4.7	0.294
Sex			0.331
Female	1005 (80.3%)	546 (82.1%)	
Male	247 (19.7%)	119 (17.9%)	
Body Mass Index	24.3	23.9	0.369
Osteotomy Performed			0.115
Yes	568 (45.5%)	327 (49.2%)	
No	681 (54.5%)	337 (50.8%)	
Levels Fused			
Unknown	222 (17.7%)	183 (27.5%)	<0.0002
3-6 levels	45 (3.6%)	23 (3.5%)	0.878
7-12 levels	580 (46.3%)	290 (43.6%)	0.243
13+ levels	339 (27.1%)	134 (20.1%)	0.0007
Anesthesia Time (mins)	625.2 (n=833)	407 (n=233)	0.32

† data presented as count (%) or mean ± SD, †† p values correspond to the Students T-test or chi-square test.

RESULTS

A query from June 2010 to February 2019 returned 1,917 unique surgical visits across nine care centers, where primary PSF surgery was performed on AIS patients. Tabulation of vancomycin used as topical surgical prophylaxis concluded a total of 65.3% (n=1,252) cases

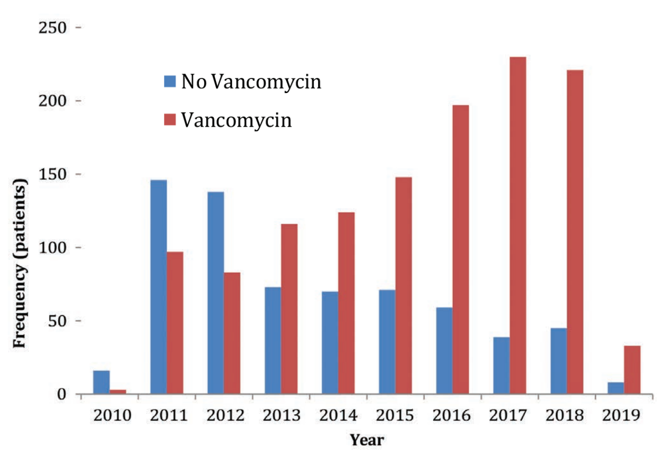

Figure 1. Frequency of Use of Prophylactic, Local Vancomycin Powder.

Table II. Cases of Infections Among the Vancomycin Cohort

Patient	Culture	#Days after PSF	Levels Fused	Osteotomy
1	Staphylococcus aureus	29	7-12	No
2	Enterobacter cloacae	10	7-12	Yes
3	Escherichia coli, Streptococcus	28	7-12	Yes
4	Staphylococcus aureus	33	13+	Yes
5	Escherichia coli, Morganella morganii, Pseudomonas aeruginosa	22	5-12	No
6	Pseudomonas aeruginosa	16	7-12	Yes

PSF: Posterior spinal fusion.

Table III. Cases of Infections Among the Non-Vancomycin Cohort

Patient	Culture	#Days after PSF	Levels Fused	Osteotomy
1	Staphylococcus aureus	50	7-12	Yes
2	Pseudomonas aeruginosa	15	7-12	Yes
3	Staphylococcus aureus	41	3-6	No
4	Methicillin resistant staphylococcus aureus	14	7-12	No
5	Staphylococcus aureus	24	7-12	Yes

PSF: Posterior spinal fusion.

of topical vancomycin used operatively (vancomycin cohort) versus 34.7% (n=665) who did not receive any (non-vancomycin cohort).

There were no significant differences between groups in age at surgery, BMI, sex, or having an osteotomy performed (p>0.05). A larger proportion of the non-vancomycin cohort lacked the number of levels fused by CPT code (27.5% v 17.7%; p=0.0002). This was due to the chronological use of ICD-9-CM codes, which do not provide details on the number of levels fused, as CPT or ICD-10-CM do. Among those with levels fused reported by CPT code, the proportion of 13+ levels fused was greater for the vancomycin group (27.1% v 20.2%, p=0.0007). Anesthesia billing time for the vancomycin cohort was 625.2 minutes (n=833, 67.1%) and 407 minutes for the non-vancomycin cohort (n=233, 35%; p=0.32). Demographic and surgical data are summarized in Table I. Temporally, the frequency of prophylactic, local vancomycin use increased during the time frame of this study with a corresponding decrease in the non-vancomycin cohort (Figure 1).

In total, 31 (1.6%) patients were identified as having either a positive culture and/or having undergone irrigation and debridement during the 90-day post-surgical follow-up period. One patient reported having a superficial skin abscess, three patients showed no infection or further treatment denoted in their medical records, and eight patients were diagnosed with a urinary tract infection. Of the remaining patients, 19 had undergone irrigation and debridement, 11 of which had positive cultures. Six (0.5%) of these infections were identified in the vancomycin cohort and five (0.8%) in the non-vancomycin cohort (p=0.451). The remaining 8 patients were diagnosed with non-infectious wound complications, and all were found to have negative cultures.

Of the six SSIs in the vancomycin cohort, two cases (33%) were caused by gram-positive bacteria, while the remaining four cases (67%) resulted from gram-negative or polymicrobial infections. In the non-vancomycin cohort, four (80%) patients returned cultures with gram-positive bacteria and one (20%) case of gram-negative bacteria. Time from surgery to irrigation and debridement was 23 days in the vancomycin cohort and 28.8 days in the non-vancomycin cohort (p=0.23). Infection data are summarized in Tables II and III.

DISCUSSION

In the past decade, significant improvements have been made in the surgical care of AIS patients through the development of consensus and adoption of standardized perioperative protocols.[17,26-28] Nonetheless, significant variability exists in the current practices of infection prevention in this population due to the lack of high-level evidence to help guide recommendations.[29,30] Best-practice guidelines advocate for use of vancomycin powder for high-risk pediatric patients undergoing spine fusion to decrease the incidence of SSIs.[16] As a result, many spine surgeons have turned to vancomycin powder for adjunctive infection prophylaxis in otherwise healthy, low-risk AIS patients despite the scarce evidence to support this practice.

To our knowledge, this is the first study to date that investigates the specific impact of topical vancomycin powder on preventing deep surgical site infections in the AIS population. After comparing nearly 2,000 PSF procedures, we found no significant difference in the incidence of acute SSI with the use of prophylactic, local vancomycin powder compared to non-vancomycin controls (0.5% versus 0.8%; p=0.451).

Despite previous investigations into the use of vancomycin powder prophylaxis in pediatric spine surgery patients, most studies have focused on including high-risk patients in their cohorts, which limits the generalizability of their findings to low-risk AIS patients.[23,31-33] For instance, Garg et al. also found vancomycin powder did not reduce the incidence of SSI following PSF in 527 pediatric patients, but only half were low-risk AIS patients.[32]

Two studies found to exclusively investigate low-risk AIS patients were recently conducted by Meza et al. and Mallet et al., which both assessed the effect of vancomycin powder and povidone-iodine irrigation on reducing rates of SSI.[25,34] These studies found the combination of the vancomycin powder and antiseptic irrigation led to a significantly decreased incidence of SSI compared to controls. However, neither included a vancomycin powder-only study arm. Because povidone-iodine irrigation has strong evidence it reduces rates of SSI alone, these studies do not provide information on the potential contributions that vancomycin powder itself may have on reducing rates of SSI.[35,36]

While vancomycin powder has been shown to lower the infection risk in certain high-risk populations, there is concern that widespread use may increase the incidence of vancomycin-resistant, gram-negative, or polymicrobial spinal infections.[37] Results from a recent meta-analysis found that topical vancomycin in spine patients is associated with nearly double the risk of developing a gram-negative or polymicrobial SSI compared to controls.[38] We found that infections in the non-vancomycin group were most consistent with prior literature, with S. aureus being identified in 80% (n=4) of cases, including one case involving methicillin-resistant S. aureus (MRSA).[39] In comparison, infections in the vancomycin cohort grew a higher proportion of gram-negative and polymicrobial organisms, a trend more commonly seen in non-idiopathic cases.[7] With the gram-positive antimicrobial coverage of vancomycin, a lower incidence of gram-positive microorganisms in the vancomycin cohort than in the non-vancomycin cohort was to be expected, and vice versa, but the difference between the two groups did not reach statistical significance. Nevertheless, this trend raises the important question of whether the use of local vancomycin powder leads to a higher prevalence of gram-negative and multi-organism surgical site infections in the AIS population while providing little clinical benefit.

Due to the low infection rate in AIS, studies of this nature are often challenged by obtaining a patient sample large enough to detect statistically significant differences between groups. When planning the study, an a priori power analysis was performed based on the best available and most relevant peer-reviewed literature.[25] It was calculated that a minimum of 877 patients were needed in each group to achieve a power of 0.90. While our vancomycin cohort exceeded this value, the number of patients in the non-vancomycin cohort did not. Determining the accurate effect size of vancomycin powder in preventing SSI in AIS patients is difficult due to the low baseline incidence of SSI and the limited availability of appropriate reference studies. For instance, the power analysis performed by Garg et al. was based on results from a study of adult patients undergoing complex deformity reconstruction with significantly higher rates of SSI.[32,40] Had our power analysis been based on results by Mallet et al., a minimum of only 237 patients would be needed per group, highlighting the flaws of power calculations for this specific question.

The limitations of this study are primarily related to data acquisition from a large database of interconnected hospital systems that output aggregate data with limited individual data available. Thus, subgroup analysis of certain output variables was unable to be performed to provide a granular analysis of other factors that may play a role in susceptibility to infection. This also required us to define SSI by positive culture as this was the most objective and accessible metric available to extract from the dataset. Superficial surgical site infections were excluded from our study, as they typically do not require return trips to the operating room. We focused our efforts on deep infections, as there are the most costly to the patient, family, and healthcare system. Our methodology resulted in detecting SSI with high specificity but low sensitivity, leading to the possibility some deep SSI cases were not captured. Other challenges include the wide variation in reporting across institutions and the differences in available coding data during the transition from ICD-9-CM to ICD-10-CM codes. The assumption was made that the institutions in our inter-related network all followed best practice guidelines for AIS including appropriate intravenous antibiotic prophylaxis perioperatively.

This is the first study to examine vancomycin powder use and early infection outcomes in AIS, with a large database from an inter-connected network of hospitals. While this is the largest study of its kind to date, more patients may be required. We do not consider this to detract from the value of our study, however, as it is the first to specifically examine this topic and adds to the existing body of literature. Furthermore, the sample size needed to reach statistical power on this topic may be prohibitively too large for prospective studies, thus a large retrospective multicenter database query is our best current option to gain information on this topic. We hope that this study will spur more interest, introduce better-designed studies, and further our understanding of infection prevention strategies in AIS.

CONCLUSION

In summary, we found that among 1,917 AIS patients undergoing PSF the use of topical, local vancomycin powder did not significantly reduce the incidence of surgical site infections. Even larger studies may be required to fully assess the efficacy of vancomycin powder in reducing SSIs in this low-risk population as well as thoroughly evaluate the potential consequence of it leading to the emergence of more virulent microorganisms.

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TROCHLEOPLASTY IN PEDIATRIC PATIENTS - A SYSTEMATIC REVIEW

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ABSTRACT

Background: Trochleoplasty is a surgical consideration for the treatment of high-grade trochlear dysplasia. The safety profile of this procedure remains particularly unclear in the skeletally immature population where concerns exist regarding physeal arrest and the development of premature patellofemoral arthritis. The purpose of this study was to systematically review the literature to evaluate trochleoplasty use, outcomes and complications observed among pediatric patients.

Methods: A systematic review was performed in accordance with PRISMA guidelines reviewing PubMed, SCOPUS, and Embase databases. Inclusion criteria were studies with a mean cohort age ≤ 18 in which individualized patient characteristics and resultant outcomes were reported after trochleoplasty. Patient demographics, dysplasia type, procedure type and patient outcomes were abstracted when available and summarized with descriptive statistics.

Results: Our search strategy identified 7 studies published from 2006-2020 that included 108 patients (mean age = 14.3) with a mean follow up of 27.6 months (range 12-60 months). All but one were classified as Level IV evidence (mean MINORS score of 10.5 [6-13]). Most patients were classified according to Dejour (107/108). The Bereiter technique was used most often (83/108). In studies including patient-reported outcome measures, mean Kujala and Lysholm scores increased postoperatively. Recurrent instability occurred in 1 patient (1%) following trochleoplasty. Postoperative complications, most commonly arthrofibrosis, were observed in 13% of patients (14/108). Premature radiographic osteoarthritic changes were identified in a single study using the Albee lateral wedge augmentation and observed in 4 of 23 (17.4%) of patients. No study identified premature physeal arrest or growth disturbance.

Conclusion: There remains a limited evidence base regarding trochleoplasty use in pediatric patients. Overall, favorable outcomes have been observed with infrequent recurrent instability and no reported growth disturbance from physeal arrest. Patellofemoral arthritic changes were observed radiographically in a small subgroup of patients undergoing a single trochleoplasty technique. Further work is necessary to determine if this is a result of the procedure itself or the underlying pathology being treated. As interest grows in implementing trochleoplasty in the pediatric population and among skeletally immature individuals, further work is necessary to clarify the complication profile in this population to appropriately counsel patients and inform surgical decision-making.

Level of Evidence: III

Keywords: trochleoplasty, skeletal maturity, trochlear dysplasia

INTRODUCTION

Trochleoplasty is an adjunct surgical procedure for treating patellar instability in patients with trochlear dysplasia. Of the varied surgical techniques for patellar stabilization, trochleoplasty most directly addresses dysplastic trochlear anatomy, the most consistent risk factor for recurrent patellar instability and has shown promising results in the limited published literature.[1-4] A high proportion of skeletally immature patients have recurrent patellar instability due to trochlear dysplasia.[5,6] Trochleoplasty, however, is not without risk and therefore its application and use in younger populations has been limited.[7-9]

Trochleoplasty remains controversial, as some argue that certain trochleoplasty techniques pose little risk of growth disturbance in adolescents near skeletal maturity while others feel the procedure should be contraindicated in all patients with growth remaining.[10-12] Concerns also exist regarding the potential for hastening arthrosis of the patellofemoral joint in younger patients with these techniques. Nevertheless, the procedure's promising

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results among adult patients with high grade trochlear dysplasia has resulted in growing interest in procedure's potential use in at-risk pediatric and skeletally immature populations. This systematic review aims to assess existing evidence on trochleoplasty in skeletally immature populations. There is limited available evidence guiding the use of trochleoplasty in pediatric patients, and we sought to perform a systematic review of trochleoplasty in this population to summarize the utilization and associated complications of this procedure.

METHODS

Screening process

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines. This systematic review was performed by searching PubMed, Embase and Scopus databases. The Rayyan Intelligent Systematic Review software[13] was used for the abstract and manuscript screening process. Search terms from existing published systematic reviews[3,7,14] were identified and included: Trochleoplasty OR trochleaplasty.

Inclusion and exclusion criteria

Databases were searched from inception to April 21, 2022. The inclusion criteria for our review were studies reporting outcomes in pediatric cohorts (mean cohort age ≤ 18 years old) treated with trochleoplasty for patellar instability. Studies with a mean cohort age more than 18 years old were excluded. Two investigators (K.J.O and K.H.) screened abstracts for inclusion captured by search criteria. Full-text journal articles were then obtained and reviewed for eligibility criteria.

Data collection

Included studies were reviewed and the following datapoints were extracted when reported: patient demographics (age, sex), radiographic characteristics (physeal status, Dejour classification), treatment data (trochleoplasty technique, fixation type, concomitant procedures) and outcomes (Patient-reported Outcome Measures [PROM], functional outcomes, radiographic outcomes, and complications).

Quality assessment and data analysis

A quality assessment of the included studies was completed using the methodological index for nonrandomized studies (MINORS) criteria, a validated instrument designed to assess the methodological quality of non-randomized surgical studies.[15] Extracted study variables were summarized with descriptive statistics. Due to the inconsistency of variable reporting across the studied literature, no comparative analyses could be performed.

RESULTS

Study selection

Our search identified 779 individual titles and abstracts with 335 studies available for screening after removal of duplicates. After abstract and full-text review, 7 studies published from 2006 to 2020 were identified and included in the final analysis. The search strategy following PRISMA guidelines is presented in Fig. 1.

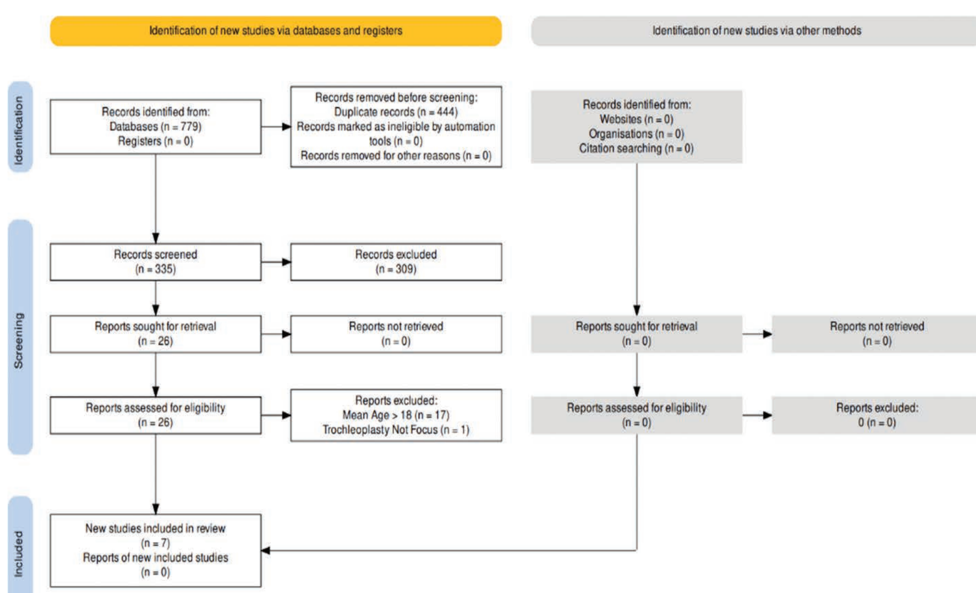

Figure 1. PRISMA Flow Diagram.

Quality and level of evidence

6 studies were classified as level IV evidence, with one other being classified as level III. The overall mean MINORS score was 11.7. Noncomparative studies (n=6) had a mean MINORS score of 10.5 [6-13], whereas the sole comparative study had a MINORS score of 19. Subcategory breakdowns are reported in Table 1.

Demographics

Overall, 108 patients were studied with 120 trochleoplasties in 120 knee joints. Patients were predominantly female (N = 63) with a mean age of 14.3 [8-19.6] years. Mean follow up was 2.3 [1-5] years post-operatively. Two studies characterized patients based on physeal status, with one study qualitatively stating that all included patients were at or near physeal closure, while another stated that all included patients had open physes.

Presentation and Treatment

The Dejour classification was utilized in most (107/108) patients as the primary indication for trochleoplasty. Three studies classified 82 patients as Dejour B, C, or D, two studies classified 24 patients specifically as Dejour B, one study classified one patient specifically as Dejour D, and one study classified one patient as 'severely' dysplastic.

Regarding surgical technique, the most common trochleoplasty procedure type was the thin-flap Bereiter procedure performed in 83 patients. The most common fixation methods reported were either vicryl tape and suture anchors (62 patients) and screws (2 patients). Of note, 21 cases did not specify what fixation type, if any, was used. Twenty-three cases did not use fixation by author report. Concomitant procedures included lateral retinacular release (24 cases), medial reefing (2 cases), medialization of the tibial tubercle (2 cases), patellar osteotomy (1 case), medial patellofemoral ligament reconstruction (42 cases), and lateral condyle lengthening with bone block (44 cases). Patient presentation and treatment is summarized in Table 2.

Clinical Outcomes and Complications

Forty-three cases reported range of motion at final follow up, with a knee flexion range of 135-150 degrees and a knee extension range of -5-0 degrees. Three studies reported on return to sports, with 41 cases describing full clearance at 3 months, and 44 cases at 6 months post-operatively. Four studies reported on complications, with one study reporting four patients with lateral patellofemoral osteoarthritic lesions, three of which had persistent knee pain. Another study described one revision patellar stabilization and trochleoplasty performed in a

Table 1. MINORS Score Breakdown

Author	Ammann, E., et al.	Williams, S.R., et al.	Pesenti, S., et al.	Camathias, C., et al.	Horikawa, A., et al.	Koch, P.P., et al.	Donell, S.T., et al.
A clearly stated aim	2	2	2	2	2	2	2
Inclusion of consecutive patients	2	2	2	2	2	2	2
Prospective collection of data	2	2	2	2	0	0	0
Endpoints appropriate to the aim of study	2	2	2	2	0	2	2
Unbiased assessment of the study endpoint	0	0	1	0	0	0	0
Follow-up period appropriate to the aim of the study	1	2	2	2	0	2	1
Loss to follow-up<5%	2	2	2	2	2	2	2
Prospective calculation of the study size	2	0	0	1	0	0	0
An adequate control group	2	N/A	N/A	N/A	N/A	N/A	N/A
Contemporary groups	0	N/A	N/A	N/A	N/A	N/A	N/A
Baseline equivalence of groups	2	N/A	N/A	N/A	N/A	N/A	N/A
Adequate statistical analysis	2	N/A	N/A	N/A	N/A	N/A	N/A
Total	19/24	12/16	13/16	13/16	6/16	10/16	9/16

0, not reported; 1, reported but inadequate; 2, reported and adequate.

Table 2. Patient Demographics, Indications and Treatment

Variable	N (%) or M ± SD
Age	14.3 ± 1.1
Sex	
Male	22 (20)
Female	63 (58)
Unreported	23 (21)
Follow-up Duration (years)	2.3 ± 1.4
Presenting Symptoms	
Recurrent patellar dislocations	108 (100)
Hemarthrosis	1 (1)
Dysplasia Type	
Dejour B, C, or D	82 (76)
Dejour B	24 (22)
Dejour D	1 (1)
Severe	1 (1)
Trochleoplasty Type	
Bereiter	83 (77)
Albee	23 (21)
Dejour	2 (2)
Fixation Type	
Vicryl tape and suture anchors	62 (57)
None	23 (21)
Unspecified	21 (19)
Screws	2 (2)
Concomitant Procedures	
Lateral condyle lengthening with bone block	44 (41)
MPFLR	42 (39)
Lateral patellar retinacular release	24 (22)
Medial reefing	2 (2)
Medialization of the tibial tubercle	2 (2)
Patellar osteotomy	1 (1)

high-grade dysplasia patient with Noonan syndrome due to surgeon dissatisfaction with trochlear depth achieved during index procedure.[16] The same study reported 4 intra-articular scar tissue revisions.[16] Another study described a flexion contracture treated with arthroscopic lysis of adhesions. The final study to report complications detailed one surgical adhesion, one subcutaneous hematoma, and 2 reductions in knee hyperextension to -5 degrees. There were no reports of premature physeal arrest in two studies that monitored 62 patients for this outcome. Clinical outcomes and complications are summarized in Table 3.

Table 3. Clinical Outcomes and Complications

Variable	N (%) or Range
Range of Motion	
Knee flexion (deg)	135-150
Knee extension (deg)	-5-0
Return to sports	
6 months	44 (41)
3 months	41 (38)
Unspecified	23 (21)
Intraarticular scar tissue revisions & surgical adhesions	6 (5.5)
Lateral patellofemoral osteoarthritic lesions	4 (3.3)
Reductions in leg extension to -5 degrees	2 (1.7)
Congenital revisions	1 (0.8)
Subcutaneous hematoma	1 (0.8)

Table 4. Patient Reported Outcome Measure Pre- to Post- Operative Change

Instrument	Mean Increase [Range]
Kujala (83 patients)	16.9 [5-22.5]
Lysholm (64 patients)	22.5 [21.2-23.7]
Tegner (18 patients)	0 [0-0]

Patient Reported Outcomes

Eighty-three cases administered the Kujala instrument, with mean pre to post operative increase in total score of 16.9 [5-22.5]. Sixty-four cases administered the Lysholm instrument, with mean pre to post operative increases of 22.5 Eighteen cases administered the Tegner instrument, with no change in score from pre to post operation.[10] Patient reported outcomes are summarized in Table 4.

DISCUSSION

This systematic review identified 7 trochleoplasty studies performed in largely pediatric cohorts including 120 knees in 108 patients. Surgical indications varied, but procedures were performed in those with moderate to severe trochlear dysplasia, mostly as determined by the Dejour Classification (Dejour B-D). A variety of trochleoplasty techniques and concomitant procedures were implemented across the identified studies. With a mean follow-up of 2.3 years, patients experienced low rates of recurrent instability (1%) and complications (13%) while reliably returning to sport (79%). Although the existing evidence is limited in its detailed description of skeletal age or consistency of radiographic monitoring, growth disturbance or limb deformity resulting from this procedure has yet to be described. While radiographic evidence of premature arthritis was observed, this was only described in a single study which used a trochleoplasty technique different from other included studies.[17] Given the increased risk of recurrent instability in pediatric patients with trochlear dysplasia, further work is necessary to further define its safety profile and to elucidate the appropriate-use criteria in this population.

Given the dearth of literature regarding trochleoplasty in the pediatric population, comparison with literature is based on previously published studies in adult patients. In the skeletally immature population, trochleoplasty was more commonly performed in female patients (58%), which follows the trend seen in studies that include adults. Mean follow-up in the studies reviewed here was 2.3 years, in contrast to up to 25 years of follow-up seen in some adult studies.[7] The trochleoplasty approaches detailed in this review were aligned with existing literature, with the only available method not captured here being the recession wedge.[7] However, previous reviews did not specifically describe fixation types and usage.[3,14] One review isolated a cohort undergoing trochleoplasty with MPFL reconstruction but did not examine other concomitant procedures.[7]

Previous literature has not quantified postoperative range of motion or return to sports but has captured PROMs and complication rates. Common instruments include Kujala, Lille knee, Lysholm, and international knee documentation committee (IKDC). The PROMs reported in this study maintain fair agreement with prior reviews in this area that have observed mean pre- to post-operative increases ranging from 20 to 35 points for each of these instruments.[3,7,14] Of note, none of these scores have been specifically validated in skeletally immature patients with patellofemoral instability.[18] With respect to complication rates, prior reviews have described arthrofibrosis (17-25%), patellofemoral osteoarthritis (27%), stiffness limiting range of motion (7-20%), residual instability (1-8%), and wound related complications (2-3%).[3,7,14] The complication types and rates reported among the examined pediatric cohort is thus in agreement with the adult literature.

The current study is not without limitations, many of which are attributable to the variation in reporting practices in the existing literature. While the existing PROM data indicates patients achieve functional improvement after trochleoplasty, we identified a heterogeneous mixture of PROMs used in the included studies. Further, studies inconsistently report key radiographic variables such as physeal status and critical outcome variables including range of motion and return to activity. While premature physeal arrest has not been reported in the literature following trochleoplasty, only a subset of studies specifically monitored for this outcome. Future work examining trochleoplasty in skeletally immature patients should include radiographic evaluations to monitor for growth disturbance. Moving forward, more consistent outcomes reporting should be used to allow for study comparison, validation, and future aggregate analyses. Further, the vast majority of pediatric trochleoplasty studies were case reports and case series with a low level of evidence (level IV). This reinforces the value of a systematic review on this topic.

This review serves to summarize the current evidence regarding trochleoplasty use in pediatric patients. While findings indicate low rates persistent instability symptoms following trochleoplasty, surgeons considering utilization of this technique in these patients should be aware of the associated risks. Further work evaluating the comparative risk of physeal disturbance from the varied trochleoplasty techniques is warranted if this procedure is to be considered in skeletally immature individuals. Longer follow-up studies are necessary to examine the risk of trochleoplasty as it relates to the development of premature patellofemoral arthritis.

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DID THE COVID-19 PANDEMIC IMPACT TIME TO SURGERY, LENGTH OF HOSPITAL STAY, OR DISCHARGE LOCATION FOR SUBAXIAL CERVICAL SPINE FRACTURES REQUIRING SURGICAL INTERVENTION?

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ABSTRACT

Background: The COVID-19 pandemic disrupted healthcare systems across the United States resources were consumed caring for COVID-19 patients. Past research on trauma activations during COVID-19 has found changes to hospital length of stay and discharge locations. Subaxial spine fractures are potentially debilitating injuries that require timely surgery and extensive rehabilitation. Accordingly, the objective of this study was to compare the severity of cervical spine injuries, time to surgery, hospital length of stay, and discharge disposition for patients presenting during COVID-19.

Methods: 128 patients with subaxial fractures from a Level One Adult Trauma Center that required surgical intervention were reviewed. The primary outcomes included hospital length of stay, ICU days, time to surgery, complications, and discharge location in patients with subaxial cervical fractures during COVID-19 pandemic versus immediately before the pandemic.

Results: When comparing the pre-COVID-19 period to the COVID-19 group, there was no difference in time to surgery or overall length of stay (2.47 vs. 2.35 days and 12.93 vs. 13.82 days, p>0.05). There was no difference in number of patients discharged home during COVID-19 (41% (32/79) vs. 37% (18/49) p>0.05) or patients discharged to hospital rehab (33%, (26/79) vs. 35% (17/49), p>0.05). A similar percentage of patients had complications within 90 days of discharge (16% (12/75) vs. 22% (10/46), p>0.05).

Conclusion: Despite the burden COVID-19 placed on healthcare systems, it did not affect post-operative hospital course of subaxial fracture patients with potentially debilitating injuries. This vulnerable subset of patients presenting during COVID-19 was still able to undergo timely surgery, have an appropriate hospital length of stay, and be discharged to rehabilitation centers. In future stresses to the healthcare system, deferring elective and non-emergent procedures can allow proper care for emergencies such as subaxial fractures.

Level of Evidence: II

Keywords: subaxial fracture, cervical spine, spine surgery, orthopaedics, COVID-19, hospital length of stay

INTRODUCTION

Cervical spine fractures and dislocations occur in approximately 3% of all trauma accidents. Of these cervical injuries, two out of every three are in the subaxial region.[1,2] Fractures receiving a score of four or higher generally undergo surgical intervention.[3] The long-term prognosis of subaxial fractures is worse in patients with delays in surgical intervention, higher Subaxial Injury Classification (SLIC) system scores, and increased spinal cord compression.[2,4] Patients without neurologic involvement may have longer delays to surgery provided they are kept in strict immobilization. However, in the case of instability, surgery will always be necessary.[5] In order to optimize recovery, these cervical spine patients need to begin rehabilitation and mobilization shortly after surgical stabilization, especially when there is neurologic involvement. Thus, it is imperative that these patients seek the necessary therapy and rehabilitation placement after surgery in a timely fashion.[6-9]

The COVID-19 virus began in China in 2019, and by March 11, 2020, it had spread across the globe and was declared a pandemic.[10,11] This led to stay-at-home orders and drastic changes in American society and economics. Additionally, the pandemic placed immense stress on the healthcare system as hospital systems and rehabilitation centers were forced to allocate many resources to COVID-19 positive patients while facing staff shortages.[12] This ultimately disrupted the regular flow of inpatient hospital stays and eventual discharge into appropriate

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facilities.[13] As a result of these disruptions, elective procedures and surgeries were delayed to focus resources on emergencies and COVID-19 patients.

Due to the changes in hospital workflow during the COVID-19 pandemic, we sought to investigate the effect on postsurgical cervical spine trauma patients, which are an especially vulnerable population. The purpose of this study was to compare mechanism and severity of cervical spine injuries, hospital length of stay, and discharge disposition between the peak months of COVID-19 to just prior to the pandemic. This will ultimately allow us to understand the impact the pandemic and canceling elective procedures had on treatment and rehabilitation of subaxial cervical spine fractures. We hypothesize that due to the need for timely treatment and rehabilitation of subaxial cervical spine fractures, no significant differences will be observed for the intrahospital length of stay and discharge disposition.

METHODS

Data Source and Collection

Data were collected from a retrospective chart review of subaxial fractures at a Level 1 Adult Trauma Center. We identified 139 patients who underwent surgical intervention for subaxial fractures from January 1, 2017, to December 31, 2021. Of these 139 patients, 128 met inclusion criteria (>18 years old, acute subaxial cervical spine fracture or dislocation). 11 patients were excluded: (7) <18 years old, (1) statistical outlier for length of stay, (1) no surgical intervention for subaxial fracture, (1) no acute fracture, and (1) leaving against medical advice. 79 patients (62%) presented between January 1, 2017, and March 15, 2020, and were in the pre-COVID-19 group. 49 patients (38%) presented between March 16, 2020, and December 31st, 2021, and were in the post-COVID-19 study group.

The approach to managing traumas, particularly those involving the cervical spine, remained consistent throughout the COVID-19 pandemic. Surgical protocols remained unchanged, while elective procedures were postponed and heightened measures were taken to prevent the spread of the virus. As a Level One Adult Trauma Center, robust support was provided for trauma cases and patients, with a focus on ensuring the availability of operating rooms as necessary. Post-operative care for spinal trauma surgical patients mirrored pre-operative standards. Elective procedures were postponed, and we expanded our bed capacity on both the general floor and in the trauma ICU to ensure all patients received adequate care. Due to the mechanism similarities causing cervical spine injuries, surgical intervention and management were consistently applied, leading to similar patient outcomes.

Data collected included patient demographics and baseline characteristics as well as SLIC score and any neurologic involvement. The SLIC system provides a method for grading subaxial fractures.[3] Patients receive a scored result depending on injury morphology (0-4), integrity of the disco-ligamentous complex (0-2), and neurologic status (0-4).[3] Neurologic status was determined by a detailed motor and sensory exam from an orthopedic spine surgeon at presentation. Any motor impairments were considered a spinal cord injury.

Outcome Measures

Data for three aims were collected: the hospital LOS, number of days in the ICU, and time to surgery were collected. Finally, each patient's discharge location and if they were readmitted within 90 days of discharge were collected.

Data collected included hospital length of stay, number of days in the ICU, time to surgery, inpatient mortality, post-operative medical complications, development of a complication within 90 days of discharge and discharge location. Discharge locations were divided into three groups: home discharge, hospital rehab center, or an outside rehab center/long term facility. Medical complications included wound issues, and development of cardiac, vascular, neurologic, respiratory, gastrointestinal, urinary, or renal complications. Patients' charts were reviewed, and the number of days delayed for medical complications and hospital related delays were recorded. Hospital related delays included waiting for an available bed or operating room, delays due to insurance approval, or delays in finding a rehab facility. Patients delayed four or more days because of medical complications, hospital related delays, or delays due to pain were considered a major delay. Patients delayed one to three days were grouped as minor delays.

Statistical Analysis

All statistical analysis was performed using SPSS Version 28 (IBM; Chicago, IL). Continuous variables such as age, SLIC scores, surgical delays, and length of stay were compared between the pre-COVID-19 and COVID-19 groups using t-Test, while categorical variables such as sex, spinal cord injuries, intra-hospital mortality, and medical complications, and discharge location were compared between the study groups using Chi-Squared Test. P values less than 0.05 were considered statistically significant.

RESULTS

Patient Characteristics and Injuries

Between January 1, 2017, and December 31, 2021, 139 patients presented to a Level 1 Adult Trauma Center with subaxial fractures that required surgical intervention. Of these, 128 met inclusion criteria. Seventy-nine patients presented in the pre-COVID-19 time period (January 1, 2017- March 15, 2020) and forty-nine presented during the COVID-19 pandemic (March 15, 2020-December 31, 2021). The distribution of gender was similar between the two time periods (72% male and 28% female pre-COVID-19, 76% male and 24% female during COVID-19, p>0.05). The median age was similar between the two study groups (60 vs. 58 years, p>0.05). The average SLIC score for patients with subaxial fractures before and during COVID-19 did not change (5.30 vs. 5.61, p>0.05). A similar proportion of patients with subaxial fractures had spinal cord injury (30% (24/79) vs. 45% (22/49) p>0.05) (Table 1).

Patient Hospital Course

Patients presenting during COVID-19 had a similar delay to surgery as those patients pre-COVID-19 (2.47 vs. 2.35 days, p>0.05). There was no statistical difference in length of stay between the pre-COVID-19 group and the COVID-19 study group (12.93 vs. 13.82 days, p>0.05). As Table 2 demonstrates, when matching patients between the two study groups based on number of days delayed in the hospital, there were no significant differences in length of stay. 28% of patients before COVID-19 (21/75) had post-operative medical complications: (7) Gastrointestinal, (6) respiratory, (6) cardiac, (1) wound, (1) renal. 35% of patients (16/46) had post-operative medical complications in the COVID-19 study group: (6) respiratory, (4) cardiac, (3) gastrointestinal, (2) wound, (1) renal. There was no significant difference between the groups (28% (21/75) vs. 35% (16/46), p>0.05).

Table 1. Patient Characteristics and Injuries

Variable	Patients No, (%)		
	Before COVID-19 (Jan 1, 2017-March 15, 2020)	During COVID-19 (March 16,2020-December 31, 2022)	P-Value
Age (Median, IQR)	60 (45.5-71)	58 (46-71)	0.94
Sex			
Male	57 (72)	37 (76)	0.68
Female	22 (28)	12 (24)	0.68
Spinal Cord Injuries	24 (30)	22 (45)	0.097
SLIC score (Average, 95% CI)	5.30 (4.85-5.76)	5.61 (4.49-6.73)	0.4

SLIC- Subaxial Injury Classification.

Discharge Locations and Re-Admissions

There was no significant difference in the percentage of patients discharged to each location between the pre and during COVID-19 study groups (Table 3). A similar number of people were discharged to the hospital rehab in each group (33%, (26/79) vs. 35% (17/49), p>0.05). The same percentage of patients were discharged to outside rehab or long-term facilities (22% (17/79) vs. 22% (11/49) p>0.05). A similar number of people were discharged home during COVID-19 (41% (32/79) vs. 37% (18/49) p>0.05). Additionally, a similar number of people expired between the two study groups (8% (4/79) vs. 6% (3/46) p>0.05). 12 patients (16%) before COVID-19 had complications within 90 days of discharge: (5) respiratory, (5) cardiac, (2) wound, (2) infection, (1) renal, (1) deep vein thrombosis, (1) instrumentation failure, (1) death. 10 patients (22%) in the COVID-19 group had complications within 90 days of discharge: (5) cardiac, (5) respiratory, (2) wound, (1) infection, (1) gastrointestinal, (1) death. Complication counts includes patients with multiple complications.

Table 2. Hospital Course for Each Study Group

Variable	Mean (95% CI)		
	Before COVID-19 (Jan 1, 2017-March 15, 2020)	During COVID-19 (March 16, 2020-December 31, 2022)	P-value
Days to Surgery	2.47 (2.08-2.86)	2.35 (1.79-2.91)	0.73
Hospital Length of Stay (days)	12.93 (10.06-15.81)	13.82 (10.27-17.39)	0.7
LOS for Patients with Major Delay (days)	29.22 (21.5-36.9)	29.45 (20.3-38.6)	0.97
LOS for Patients with Minor Delay (days)	10.9 (9.2-12.6)	12.1 (9.6-14.6)	0.43
LOS for Patients with No Delay (days)	5.82 (4.9-6.8)	5.9 (4.7-7.1)	0.94
LOS for patients discharged to hospital rehab (days)	16.58 (10.69-22.46)	19 (11.84-26.16)	0.61
LOS for patients discharged home (days)	6.84 (5.18-8.57)	7.33 (4.19-10.47)	0.79
LOS for patients discharged to outside Rehab or long-term facility (days)	18.82 (12.01-25.63)	16.45 (10.19-22.72)	0.62
ICU LOS (days)	8.87 (5.47-12.26)	7.14 (4.59-10.83)	0.63
Medical Complication During Hospital Stay (excluding patients who died) (Patients No, %)	21 (28)	16 (35)	0.42

LOS- Length of Stay, ICU- Intensive Care Unit.

Table 3. Discharge Disposition and Readmission Rates

Variable	Patient No, (%)		
	Before COVID-19 (Jan 1, 2017-March 15, 2020)	During COVID-19 (March 16, 2020-December 31, 2022)	P-value
Discharge Location			
Hospital Rehab	26 (33)	17 (35)	0.84
Home	32 (41)	18 (37)	0.67
Outside Rehab or Long term Facility	17 (22)	11 (22)	0.9
Expired	4 (8)	3 (6)	0.67
Medical Complication 90 Day Post Discharge	12 (16)	10 (22)	0.43

DISCUSSION

The COVID-19 pandemic significantly impacted American society and the US healthcare system. Many hospitals were strained and depleted of resources due to the number of COVID-19 positive patients requiring hospitalizations, forcing them to delay surgeries and change hospital workflow. Given these changes we sought to investigate the impact the pandemic had on patients with subaxial cervical spine fractures requiring surgery, a population at risk for devasting and debilitating outcomes if not properly cared for. We retrospectively reviewed patients undergoing surgical treatment for subaxial fractures before and during the COVID-19 pandemic to compare changes in hospital course and outcomes between the two groups.

Our study determined that patients with subaxial cervical spine fractures requiring surgical intervention presented to the hospital with similar SLIC scores and number of concomitant spinal cord injuries during the pandemic as compared to immediately before the pandemic (5.30 vs. 5.61, $p>0.05$ and 30% (24/79) vs. 45% (22/49) $p>0.05$). Devarkonda et al. found no difference in injury severity scores (ISS) during the pandemic (10.51 vs. 10.81, $p>0.05$).[14] Contrary to our study, Chiba et al. found more patients had ISS less than 9 during the pandemic (53.3%, 609/1,143 vs. 61.3% (734/1202), $p<0.001$).[15] Also contrary to our study, past research on trauma during COVID-19 has found increased injury severity during the pandemic period.[16-18] Subaxial fractures occur with high impact forces in the younger population and are commonly associated with low impact forces in the elderly.[2,19,20] Despite the numerous societal changes COVID caused, people still had accidents that resulted in significant forces to cause subaxial fractures.

There was no significant difference in time to surgical intervention between the pre-COVID-19 study group and the COVID-19 study group (2.47 days vs. 2.35 days, $p>0.05$). Delayed surgical intervention can lead to worse outcomes for patients with subaxial fractures.[21,22] Despite the resource strain COVID-19 created on hospitals, patients presenting with subaxial fractures that required surgery still underwent prompt surgical decompression and stabilization in our cohort.

Additionally, patients during COVID-19 that underwent surgery for subaxial fractures had a similar length of stay (12.93 vs. 13.82, $p>0.05$). Patients also spent a similar number of days in the ICU during COVID-19 compared to prior to the pandemic (8.87 vs. 7.14, $p>0.05$). When matching for discharge location, there were no differences in length of stay for patients before and during COVID-19. When matching based on the number of days delayed because of medical or administrative-related delays, patients also had a similar LOS. Past research has also found no difference in LOS for trauma patients during COVID-19.[23,24] Other research on trauma activations during COVID-19 shorter hospital length of stays during the pandemic period.[18,25] Additionally, some trauma studies have found longer length of stays during COVID-19.[14,26] Due to the need for hospital beds during COVID-19, it was essential to ensure patients were discharged in a timely fashion. Likewise, it is critical that patients with subaxial fractures be admitted to rehabilitation centers promptly in order to optimize their recovery.[6-9] Although there are many factors that play a role in hospital length of stay in trauma patients, these two factors likely contributed to the LOS not changing during the pandemic despite the burden COVID-19 placed on the healthcare system.

When evaluating post-hospital disposition, there were no significant changes in the discharge location for patients in between the two study groups. Approximately half the patients were discharged to either the hospital rehabilitation center or a similar outside center. Previous research has demonstrated that more patients were discharged home during the pandemic. Zhong et al. and Dub et al. found hip fracture patients were more likely to be discharged home during COVID-19 (OR 1.57, $p<0.001$ and 16.2% (18/111) vs. 41.5% (34/82) $p<0.001$).[27,28] Because of the severity of cervical spine injuries and need for rehabilitation, it is no surprise that patients with subaxial fractures did not have more discharges home during the pandemic.[6-9]

The lack of significant changes in SLIC scores, number of spinal cord injuries, LOS, ICU days, and discharge location confirms our hypothesis. Because of the severity of subaxial fractures that require surgical intervention, early intervention and prompt treatment was carried out to optimize patient outcomes. By deferring elective procedures and allocating resources to emergencies, subaxial fracture patients during COVID-19 did not have different hospital courses. This change in hospital processes allowing proper attention to subaxial patients contributed to both groups having a similar readmission rate for medical complications within 90 days of discharge (16% (12/75) vs (22% (10/46), p>0.05).

Our study is not without limitations. First, as a retrospective analysis, so it is inherently limited by selection bias. There are also a relatively small number of people that have subaxial fractures that require surgical intervention each year which may have under-powered our analysis. Additionally, there were certain variables such as insurance type and comorbidities that may have affected discharge disposition and length of stay that weren't taken into statistical consideration. Lastly, there was no sub-analysis of severity of polytrauma that could have also affected the outcome measures. However, we did determine that both study groups had similar baseline demographics, SLIC scores, and incidence of spinal cord injuries which are likely the largest potential confounders to hospital length of stay and discharge disposition. The strength of this investigation is the fact that it is in the setting of a single institution with patients being compared at time points during the peak COVID-19 months to immediately before the pandemic, which ultimately minimizes any regional or institutional variances.

CONCLUSION

The COVID-19 pandemic placed an immense burden on the healthcare system changing hospital system workflow and leading to resource depletion. This investigation sought to determine the impact COVID-19 had on severity of subaxial cervical spine trauma, surgical timing, length of hospital stay, and discharge location. Patients presenting during COVID-19 had similar SLIC scores and incidence of spinal cord injuries. Additionally, patients spent the same number of days in the hospital and the ICU. Surgically treated subaxial cervical spine fracture patients were also discharged to similar locations during peak COVID-19 months as compared to immediately before the pandemic. The lack of significant effects on patients with subaxial fractures during COVID-19 relates to how debilitating these injuries can be if not treated with prompt surgical intervention and strict rehabilitation protocols. By postponing elective procedures and focusing on patients needing emergency surgery, our hospital system was able to maintain a high level of care for these patients with severe injuries. Future studies are needed to investigate other stresses to hospital systems impact the care for subaxial cervical spine fractures and other spine traumas.

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EFFICACY OF INTRAOPERATIVE INTRA-ARTICULAR MORPHINE ON POST-OPERATIVE PAIN AND OPIOID CONSUMPTION FOLLOWING HIP ARTHROSCOPY

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ABSTRACT

Background: The use of intraoperative intra-articular morphine has been suggested to lower postoperative pain scores and opioid use. We sought to evaluate the effectiveness of intra-articular morphine with 0.75% ropivacaine when compared to the use of ropivacaine alone. Our study's purpose was to determine the efficacy of intra-articular morphine on pain control, opioid consumption, and discharge times in the immediate post-operative period.

Methods: We retrospectively reviewed the charts of 100 patients who underwent hip arthroscopy with repair for femoroacetabular impingement (FAI) between 2021 to 2023. 50 patients who received 5 mg of intra-articular morphine injections intraoperatively were identified, and 50 who did not. Patients undergoing hip arthroscopy without repair, revision surgery, or combined hip arthroscopy and femoral osteotomy or periacetabular osteotomy were excluded. Demographics including age, sex, race, ethnicity, BMI, and tobacco use were recorded. Procedural factors included total operative time, traction time, and time to discharge. Pain scores were assessed using the Visual Analog Scale (VAS), and the initial Post-Anesthesia Care Unit (PACU) and final VAS score prior to discharge were recorded. Total acute opioid use was recorded using morphine milligram equivalents (MME) during post-operation to discharge. We used the Wilcoxon rank sum test and chi-square statistics on continuous and categorical variables, respectively. Statistically significant level was set as $p<0.05$.

Results: No significant differences were found between demographics, operative time, traction time, or discharge time. The median age of patients in the non-morphine group was 29 (48% M, 52% F) and 24.5 (34% M, 66% F) in the morphine group. Differences between the morphine and non-morphine group in postoperative VAS scores were insignificant, with the mean initial PACU VAS scores (4.6 ± 3.0 vs 5.5 ± 3.0) and mean final PACU VAS scores (3.5 ± 1.9 vs 3.7 ± 1.4) respectively. Postoperative MME consumption difference was also insignificant (17.1 ± 7.4 vs 17.9 ± 7.3).

Conclusion: Intraoperative intra-articular morphine injection with ropivacaine does not provide a significant reduction in acute postoperative pain scores or opioid use when compared to ropivacaine use alone. Further investigation into the efficacy of intra-articular morphine is warranted.

Level of Evidence: III

Keywords: hip arthroscopy, intra-articular injection, pain management, local anesthetic infiltration

INTRODUCTION

Hip arthroscopy is an effective treatment for hip preservation in young adults with conditions such as femoroacetabular impingement (FAI) and labral tears, and its popularity has grown significantly in recent decades.[1] Post operative pain in orthopedic procedures is among the highest of surgical operations and many attempts have been made to reduce post operative pain in arthroscopic orthopedic patients.[2] Opioid use in the United States is one of the leading epidemics, with orthopedic patients being some of the highest prescription recipients in the acute postoperative phase.[3] Recent studies have found that 6% of opioid naive patients undergoing surgery in the United States continue to use opioids after 90 days.[4,5] Efforts to reduce the opioid epidemic's impact on orthopedic surgeries such as hip arthroscopy can begin at the initial phases of intervention when patients are educated on the procedures.

The use of multimodal pain control, which may include intra-articular injections, to decrease post operative pain and opioid consumption has become popular among orthopedist surgeons.[6,7] Recent studies conducted in other areas of orthopedic surgery, including knee ar-

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throscopy and trauma have looked at the efficacy of adding morphine to the intraarticular analgesic infiltrate.[8,9] Intraoperative intra-articular morphine during orthopedic procedures has been suggested to lower postoperative pain scores and postoperative opioid use.[10,11]

With the increase in volume of hip arthroscopy cases, we sought to evaluate the utilization of intra-articular morphine for postoperative pain control while hoping to decrease the total opioid consumption of each patient. The aim of this study was to determine the effectiveness of 5 mg of intra-articular morphine with 20cc 0.75% ropivacaine when compared to the use of intra-articular 20cc 0.75% ropivacaine alone and determine its effects on (i) patient reported pain scores, (ii) total postoperative time to discharge, and (iii) total acute postoperative opioid consumption. We hypothesized that intra-articular morphine would not significantly decrease patient reported VAS score, total time to discharge, or post- operative opioid consumption.

METHODS

Patient selection

This study was approved by the University of Iowa Institutional Review Board. We performed a consecutive series study, and retrospectively reviewed the charts of 100 patients who underwent outpatient hip arthroscopy between 2021 and 2023 from a single surgeon. Inclusion criteria were patients who underwent hip arthroscopy with repair for femoroacetabular impingement (FAI). Exclusion criteria were patients undergoing hip arthroscopy without repair, revision surgery, or combined hip arthroscopy with concomitant femoral osteotomy or periacetabular osteotomy. We identified 50 patients who received 5 mg of intra-articular morphine with 20cc of 0.75% ropivacaine injections intraoperatively, as well as 50 patients who received only intra-articular 20cc of 0.75% ropivacaine. This coincided with a change in practice and cases were collated in consecutive series. Intra-articular injections were administered into the hip joint through fluoroscopic guidance immediately following hip capsule closure of the iliofemoral ligament.

Data Collection

Through chart review, demographic and procedural factors were collected. Demographic factors included age, sex, race, ethnicity, BMI, and tobacco use at the time of the procedure. Procedural factors included total operative time, time in traction during the operation, and total time from entering the PACU to discharge. All pain scores were assessed using the Visual Analog Scale (VAS) recorded by the nursing staff. Initial pain score was the VAS score recorded when patient arrived at the PACU. The final VAS score was the last recorded score before patient discharge. Total acute opioid use was recorded using morphine milligram equivalents (MME) used by the patient from arrival to the PACU to discharge from secondary recovery.

Statistical analysis

All patients were grouped by either receiving 5 mg of intra-articular morphine with 20cc of 0.75% ropivacaine (n=50) or not receiving intra-articular morphine with 20cc of 0.75% ropivacaine (n=50). We used the Wilcoxon rank sum test and chi-square statistics on continuous and categorical variables, respectively. Statistically significant level was set as $p<0.05$.

RESULTS

After review of 100 patients, no statistically significant demographic differences were found between the two groups in age, BMI, sex, ethnicity, and tobacco use at the time of the procedure (Table I). The median age of patients in the ropivacaine group was 29 years, with 52% being female, and the median age of the group receiving morphine with ropivacaine was 24.5 years 66% female, showing no significant difference in age or sex between the two groups. BMI differences were insignificant with 27.13 ± 5.73 in the non-morphine group and 29.95 ± 6.10 in the morphine group. Differences in race were significant (p-value <0.05) between the two groups.

All response variables recorded were insignificant between the two groups (Table II). Differences between the morphine and non-morphine groups in postoperative VAS scores were insignificant. The mean initial PACU VAS scores were 4.64 ± 2.99 in the morphine group and 5.46 ± 2.96 in the non-morphine group. Mean final PACU VAS scores were 3.5 ± 1.9 and 3.7 ± 1.4, respectively. Postoperative MME consumption difference was also insignificant with a mean of 17.07 ± 7.44 in the morphine group and 17.88 ± 7.27 in the non-morphine group.

DISCUSSION

While intraoperative intraarticular injections for postoperative pain control in hip arthroscopy is a highly debated topic, our findings suggest that intraarticular morphine combined with ropivacaine, when compared to ropivacaine alone, appeared to have no significant impact on postoperative pain scores in recovery. It also did not appear to impact duration of recovery or total acute postoperative opioid consumption.

Hip arthroscopy for treatment of FAI and labral repair can cause considerable post-operative pain for patients. This can prolong hospital stays and add additional expenses, while also decreasing patient satisfaction.[2] It is important for providers to prevent postoperative pain in hip arthroscopy patients while also minimizing

Table I. Demographic Analysis for Groups Receiving 20cc of Ropivacaine with Morphine Compared to No Morphine

	Morphine –			Morphine +			
Variable	n	Mean	Standard deviation	n	Mean	Standard deviation	P
Age (years)	50	29.1	9.93	50	26.3	9.36	0.1602
BMI (kg/m2)	50	27.13	5.73	50	29.95	6.10	0.8550
Sex (% female)	26	52%		33	66%		0.1547
Race (% White)	47	94%		40	80%		**0.0374**
Ethnicity (% Hispanic)	5	10%		5	10%		0.4895
Tobacco use (% yes)	2	4%		4	8%		0.6777

P-value <0.05 is in **bold**.

Table II. Procedural Analysis for Groups Receiving 20cc of Ropivacaine with Morphine Compared to No Morphine

	Morphine – (n=50)		Morphine + (n=50)		
Response variable	Mean	Standard deviation	Mean	Standard deviation	P
Operative Time (min)	72.24	14.46	70.82	22.29	0.1418
Traction Time (min)	44.86	44.86	42.60	42.60	0.1851
First PACU VAS pain score	5.46	2.96	4.64	2.99	0.2137
Final VAS score prior to discharge	3.72	1.37	3.48	1.88	0.6943
Postoperative MME's	17.88	7.27	17.07	7.44	0.4829
Time from PACU to discharge (min)	156.41	41.00	152.94	48.13	0.3085

P-value <0.05 is in **bold**.

the amount of perioperative and postoperative opioid consumption. Increased postoperative pain after orthopedic procedures has been shown to decrease patient satisfaction, prolong recovery, and place patients at increased risk for complications.[12] Multiple combinations of intraoperative pain management techniques are being used to combat postoperative pain.[6-9] We chose ropivacaine for its decreased chondrotoxicity compared to other local anesthetics, especially in single dose intraarticular injections.[12-14] Our study showed there was no significant decrease in either post-operative pain or acute post-operative opioid use by the patient. For providers seeking to lower total MME while still receiving adequate post-operative pain control, adding intraarticular morphine to an injection appears to offer no additional relief to the patient.

Cogan et al.[15] studied the effects of morphine and clonidine to intraarticular injections during hip arthroscopy. They found a significant reduction in postoperative pain and MME consumption when compared to patients that did not receive an intraarticular injection. Intraarticular morphine has now been shown to work on μ-opioid receptors in chondrocytes with the joint.[15] While this study showed the efficacy of intraarticular morphine when compared to no intraarticular injection, we sought to study the efficacy of intraarticular morphine when combined with ropivacaine in order to reduce overall opioid consumption.

Previous pain methods have included nerve blocks to reduce postoperative pain control after hip arthroscopy. Studies have accessed the efficacy of femoral nerve blocks for reduction of postoperative hip pain, with the results showing that while post-operative pain is reduced for up to 6 hours, the resulting quadriceps weakness significantly increased the incidence of falls up to 22% in the first 24 hours.[2] This greatly increases chances of damage to the repair that was just completed during the surgery, or more traumatic injuries such as femoral neck fractures. Facia illiaca blocks have also been tested in post-operative pain control, but have been found to have incomplete coverage of the hip capsule due to the highly complex nerve innervation of the capsule, particularly the medial, posterior, and lateral aspects of the capsule which are innervated by the sacral plexus.[2] Lumbar plexus blocks have shown minimal difference in peri-operative pain reduction compared to controls and are associated with short term adverse events of falls and urinary retention; perhaps attributed to reported complications of epidural spread from LBP in around 3% and 27% of publications.[16] Furthermore, postoperative hospital stays remained higher with LPB use.[17] Overall, it appears nerve blocks may provide some immediate relief to post-operative pain but carry with it additional considerations for risks involving ambulation and protection of the repair. In a study completed by Childs et al.,[15] intraarticular injections were shown to be just as efficacious postoperative pain control as nerve blocks without the risks of postoperative falls or peripheral neuritis.

Limitations of this study include the retrospective nature of the data review and not being randomized. The study was conducted at a single institution by a single surgeon, limiting generalizability. Demographic variability of our patient sample was limited, which was shown in the statistically significant difference in race (Table I) between the two groups. The variability of the amount of intraoperative MME given by different anesthesia providers during the procedure was not recorded, possibly leading to different patient outcomes. The study also did not evaluate long-term pain and opioid use by patients after being discharged from the hospital.

CONCLUSION

Intraoperative intra-articular morphine injection with ropivacaine does not provide a significant reduction in acute postoperative pain scores, postoperative time to discharge, or acute opioid consumption when compared to ropivacaine use alone. Further investigation into the efficacy of intra-articular morphine compared to other multimodal pain control regimens is warranted.

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THE ALBRIGHT-LOSEE LOW PROFILE PIVOT SHIFT TEST FOR ACL DEFICIENCY

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ABSTRACT

Background: Recognizing ACL injuries on the field and in the office can be very challenging in awake and apprehensive patients. Despite high specificity, many published "pivot-shift" techniques have limited acceptance mainly because of unsatisfactory sensitivity. We describe in detail, four specific modifications and provide a critical review of our clinical experiences to empower the new user's readiness to master a novel screening procedure for ACL disruption.

Methods: 18 cadavers assessed instability kinematics of the novel technique. Clinical Exam Study Part II-A (ACL Disrupted): 208 awake, hemarthrosis patients with MRI evidence of ACL deficiency underwent 363 examinations by 41 examiners. Clinical Exam Study Part II-B: (ACL Intact) 47 consecutive posttraumatic hemarthrosis patients with intact ACLs underwent 76 examinations by 30 examiners.

Results: Cadaveric study confirmed patterns of coupled, anterior translation-internal rotation pathologic laxity at 25.6±8.2 degrees flexion. Clinically, the novel test yielded sensitivity of 94.7% and Specificity of 97.3%. Potentially perplexing situations included: MRI availability; pain and anxiety-related traumatic hemarthrosis, protective hamstring antagonism and examiners experience.

Conclusion: When the examiner and patient agree on a feeling of instability, the Albright-Losee Test maximizes ability to establish ACL status in the awake patient to the point that the sensitivity is even greater than the Lachman Test. Armed with background knowledge of our experiences confirms that, despite of impact of various challenging factors, the Positive Predictive Value 98.8% 95% CI (95.5%-99.7%) that a torn ACL exists in face of a positive exam confirms its value for sports medicine providers to master.

Level of Evidence: II

Keywords: ACL, office examination, anterior cruciate ligament, ACL rupture

INTRODUCTION

While valuable under anesthesia, inadequacy of the published pivot-shift techniques in awake patients, either on the field or in the office; is evident with inconsistent sensitivities ranging from 6-93%.[1-8] Most pivot-shift tests rely on concomitant application of valgus stress with the goal of producing a dramatic pivot-shift, with a biomechanical "jerk "action; eliciting pain proportionate to the amount of applied valgus force. Particularly acutely, even anticipating exam-related pain can create anxiety-related, protective hamstring guarding that yields low test sensitivity.[9]

Decades ago, the senior author collaborated with the late Ronald Losee to find a way to maximize his classic test sensitivity and accuracy by increasing patient relaxation. We initially became focused on modifying Losee's traditional technique because our poor track record with it. We hypothesized that a few modifications would provide a sufficiently high degree of accuracy detecting the status of the ACL in the awake and anxious patient to generate a maximally reliable tool.

Concomitant with a detailed description of the technique, there are two enabling objectives: 1) establish the Low Profile Test's subluxation patterns in cadaveric models 2) provide benefit of our own experiences to fully arm the new examiner about both its value and practical boundaries that will be encountered.

Low Profile Exam Technique (Figures 1-3)

Modifications of the originally insensitive valgus-based Losee test includes four steps designed to allow the patient to consciously relax leg muscles participate in the success of the test by learning to by: 1) Maximize

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relaxation through minimizing range of motion by starting the exam at 30 degrees flexion, or just short of the anticipated subluxation position. (25.6±8.2 degrees) 2) Avoid applied knee valgus at any time during maneuver. 3) Apply anterior force to the lateral tibial compartment through light pressure of the ulnar side of thumb to the posterior fibular head during the gradual passive extension of the knee. Continue until the position is reached where both examiner and patient recognize the beginning of any sensation of abnormal laxity, compared to the normal opposite side. 4) At least on initial encounter, examine the uninvolved knee first to: a) assure that the subsequent involved knee test will maximize patient relaxation and b) educate patients regarding the existence of normal subtle, axial plane tibial-femoral rotations during transition to terminal extension where the "screw home" of terminal extension is universal. Awareness of the subtleties of normal axial plane leg motion enables them to become cognizant of even the slightest abnormal tibial-femoral rotation differences in the involved knee. It is extremely important to realize that eliciting the uncomfortable biomechanical 'jerk' of a full pivot-shift is never a goal of this novel technique. Rather, it occurs when both patient and examiner agree that a subtle, sensation of asymmetrical mal-positioning or slipping is acknowledged.

Exam technique dynamics

(Figure 1) Beginning with lateral side thumb and finger placement and (figure 2) of the static appearance of the slightly subluxed knee. Also, a brief video (supplemental video) demonstrates the smooth limited arc of motion maneuver (without any gross, painful "jerk" involved). Furthermore, a more detailed, 10 minute "open access" video of Albright-Losee Test is also available in VJSM 2022 by Bates et al.)

Figure 1. Hand Placement: palm down with while radial fingers (index to ring) stabilize the anterior aspect of the distal femur above patella and ulnar side of thumb against posterior aspect of fibular head. The thumb provides gentle anterior force on the fibula of 1-3 lbs. as the knee is extended from flexion towards full extension without intentional valgus. The endpoint is reached when the examiner recognizes.

METHODS

Part I Cadaver Study

Both before and after arthroscopic ACL resection; 18 fresh, frozen cadaver knees were examined by the senior author and three clinically inexperienced M-1 medical students. Quantitative assessments utilized a computer assisted navigation system measuring six degrees of freedom identified the characteristics of the 3-dimensional pattern of coupled anterior/posterior translation and internal/external rotations of the tibia were documented as the LPPST force vectors were applied by each examiner multiple times in the limited arc of sagittal plane motion from 30 towards 0 degrees (Figure 4)

Part II: Clinical Studies

Inclusion Criteria: MRI and Albright-Losee Test results of two consecutive cohort case series of all patients examined by the senior author (with or without trainees) in the office setting of post traumatic knees with hemarthrosis. Exclusion criteria: a) patients without MRI images recorded independently by orthopedic radiology faculty and b) lack of senior author LPST medical record documentation.

Part II A (ACL deficient knees) and Part II B (ACL intact knees) ACL uninjured despite presence of other intra-articular knee pathology causing hemarthrosis.

The parameters of interest included: MRI based ACL status; and results of the Albright-Losee test categorized as: "positive", "negative", "equivocal" or, "unable to be performed." "Equivocal" results were entered only when clinician and patient were unable to agree on a uniform

Figure 2. The endpoint occurs with index finger and thumb detection of pathologic lateral tibial translation anteriorly. As the examiner detects subluxation occurring, motion is stopped, and the patient is asked if they feel their knee is "out of place". If the patient does not agree; a gentle, isotonic application of valgus force of 2-5 lbs. is applied in that potentially subluxed position to enhance proprioception. If they still can't acknowledge the abnormality of the position; the test is recorded as "equivocal".

conclusion. Any Lachman's test results documented by the senior author, plus or minus trainees; were also recorded as "positive, negative" or "unable to perform". Also included were other potentially influential factors pertinent to the patient's overall clinical status including; semi-quantitative division of the degree of swelling, pain and anxiety, limitations of knee extension.

If MRIs were not initially available, or the Albright-Losee Test exam could not be adequately performed by the senior author; a repeat visit was scheduled within 7-14 days for changes in test results. Exclusion criteria included post traumatic hemarthrosis knees with obvious multidirectional instability. IRB approval was granted for this study.

Part II A (ACL Deficient Knees)

Between February 2010 and April 2017, 208 patients were included with novel test results and confirmatory MRIs. The senior author examined all 208 patients while 40 orthopedic trainees also independently evaluated 155/208 (74.5%) routinely in advance of the senior author. In total, 363 knee exams were performed by 41 examiners, with 208/363 (57.3%) solely by the senior author and 155/363 (42.7%) by 40 trainees. The latter group consisted mostly of orthopedic residents plus a handful of student or Certified Athletic Trainers and Nurse Practitioners. No attempt was made to quantify the trainee's experience in terms of number of exams previously performed. However, all trainees had recorded at least one previous personal exam experience with most recording 3-4 but none having more than 7 previously recorded LP-LPST attempts.

Part II B: (ACL Intact Knees)

During a similar 7 year time frame; a second, consecutive series of 47 cases was collected with post traumatic hemarthrosis but an intact ACL. The Prevalence of "false positive" Albright-Losee Test exams was assessed in all 47 patients and 37/47 Lachman's Tests were also recorded by the senior author. Given that 29/47 (59.6%) exams were also recorded in advance by the 29 trainees, there was a combined total of 76 novel low profile tests and Lachman's knee exam results in this cohort.

STATISTICAL ANALYSIS

Disease Prevalence, Sensitivity, Specificity, Positive and Negative Predictive Values as well as Accuracy are expressed as percentages. Confidence intervals for sensitivity, specificity and accuracy are "exact" Clopper-

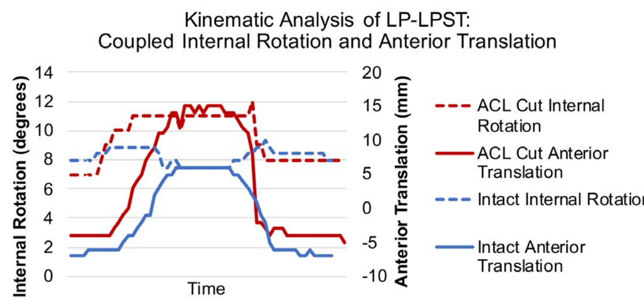

Figure 3. Example of a single trial LP-LPST for ACL intact and deficient conditions on the same specimen. Coupled internal rotation and anterior translation are higher in the ACL deficient condition when compared to the ACL intact condition for both the exit and re-entry pivot. A true pivot sees anterior translation couple with concurrent high internal rotation.

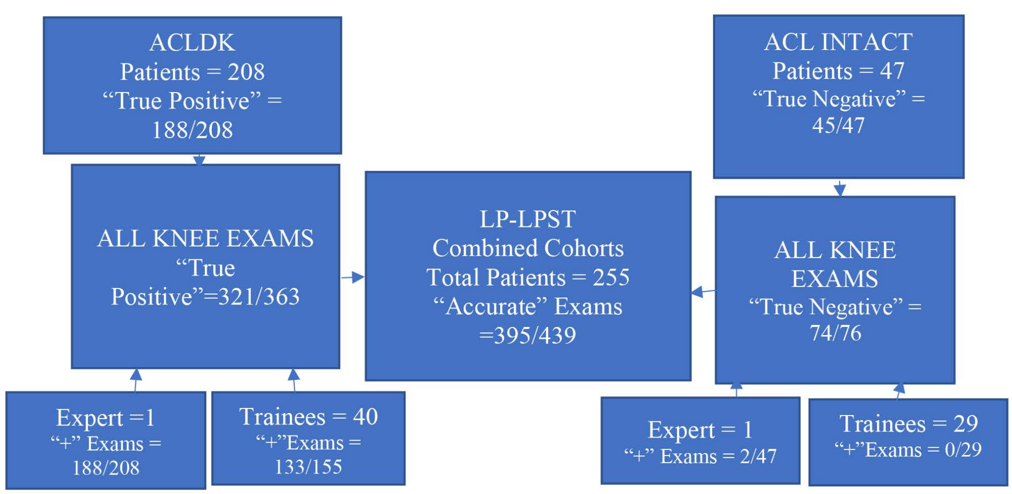

Figure 4. Example of a single trial LP-LPST for ACL intact and deficient conditions on the same specimen. Coupled internal rotation and anterior translation are higher in the ACL deficient condition when compared to the ACL intact condition for both the exit and re-entry pivot. A true pivot sees anterior translation couple with concurrent high internal rotation.

Pearson confidence intervals. Confidence intervals for the predictive values are the standard logit confidence intervals. Given the disproportion of ACL injuries (81.6%) in this study, the calculated probabilities for positive and negative predictive values as well as accuracy; are based on a generally accepted clinical practice estimate that post traumatic knees with hemarthrosis exhibit around 70% prevalence of ACL Disruptions. Chi-squared test for the comparison of proportions observed in two independent samples using "N-1". Proportions are expressed as percentages.

RESULTS

Part I: Cadaver Kinematic Study

(Figure 4) Examiners consisted of the senior author and three pre-clinical medical students inexperienced with the LP-LPST. Each examiner recorded kinematic Orthopilot assessments during a minimum of three test runs before and after cutting the ACL. The presence of both an "exit" pivot subluxation was demonstrated to occur as well as a "re-entry" phenomenon in 61.8 % of the 240 (80x 4) trials. The "exit-pivot" instability pattern was observed to occur at 25.6±8.2 degrees of sagittal plane flexion. Only the "exit pivot" subluxation was evaluated in the clinical study (Part II) where the asymmetric, coupled pattern of excessive internal rotation and anterior translation was charted.

Part II: Clinical Exams in Awake Patients

II-A (ACL Deficient Knees)

There were 321/363 "True Positive" Albright-Losee Test knee exams reported in 208 patients.

II-B: (ACL Intact Knees)

When looking only at the senior author's results, there were 45/47 (95.7%) patients with "True Negative" test (negative for ACL Deficiency) with only 2 (4.2%) patients with "false positive" tests. On the other hand, when combining all exam results, there were 74/76 (97.4%) correct LP-LPST exams in the 47 patients.

Combined II A+B Databases:

Combining the two series for results, regardless of examiner's level of this test experience; resulted in a Prevalence of 395/439 (90.0%) accurate Albright-Losee Test exams yielding a Sensitivity of 94.724% with a 95% CI (92.121%-96.665%) and a Specificity of 97.368% with 95% CI (90.815%-99.680%).

Because the Part II-A database was biased by containing 81% of ACL deficient knees in the presence of post traumatic hemarthrosis; we used the estimate of 70% Prevalence determined in the senior author's general clinical practice to calculate the following: Using this estimate, the novel test's Positive Predictive Value that a positive LPST test corresponded to MRI evidence of ACL disruption was 98.823% with a 95% CI (95.534%-99.698%). The overall low profile test Accuracy that the test reflected the MRI status of the ACL; was 95.517% with a 95% CI of (93.298%-97.167%).

Impact of Influential Factors

The potential user should be immediately aware of the relative impact that several factors may or may not have on the results of the LP-LPST test in this group of post traumatic hemarthrosis patients seen in the clinic setting.

Influence of MRI availability

Part II A (ACLDK) (Table 1)

Albright-Losee Test Results

In 181 /208 patients with a positive initial exam recorded by the "expert" senior author; there was an overall Sensitivity of 91.7% with a CI (86.7-95.3%). However, in 110 cases with knowledge of the MRI results available at exam, the Sensitivity significantly improved to 97.3% with a 95% CI (92.2%-99.4%). On the other hand, in 71 (39.2%), without MRI imaging immediately available; exam Sensitivity significantly dropped to a still reasonable 83.10% with a 95% CI (72.34%-90.95%). Therefore, knowledge of MRI results created a very significant bias for the Albright-Losee Test. In the comparison of proportions, Chi-squared demonstrated significance 11.335, P= 0.0008.

Lachman's Test Results

A similar MRI knowledge bias occurred with Lachman's test interpretation. For patients with "definitive" results (recordings of either "True Positive" or "False Negative"), Lachman's test results recorded by the senior author on the first visit generated an overall Sensitivity of 83.52 (77.20-88.68) n=176. However, in the 64 exams without MRI imaging, the Lachman's test Sensitivity dropped to 68.75% with 95% CI (55.94-79.76%).

With MRI results available in the 112 Lachman's tests, the Sensitivity was improved to 91.96% with a 95% CI (85.29%-96.26%). Therefore, for Lachman's Test results, even in the senior author's hands; knowledge of MRI findings at exam also created a very significant difference with Chi-squared value 15.849, P= 0.00001.

Influence of Experience Alone

We also investigated comparisons between senior author and trainees in LP-LPST performance by limiting the focus to potential performance differences during the more challenging initial visits.

Regardless of MRI knowledge, the senior author's "True Positive" LP-LPST yielded a Sensitivity of 90.39 % and a 95% CI (85.541%-94.541%). In comparison, the trainees performed 155/208 exams prior to the senior author's entering the room. In comparison, they recorded

Table 1. Part II A: (ACLDK) Effects of MRI Results. Senior Author's Albright-Losee Test Exam Sensitivities

Senior author results	Sensitivity with 95% CI	Sensitivity with 95% CI
	"+"Low Profile Pivot Shift Test	"+" Lachman's Test
First Clinical Encounter		
Overall Positive Exams	91.71 (86.70-95.29) n=181	83.52 (77.20-88.68) n=176
Before Imaging Review	83.10 (72.34-90.95) n=71	72.09 (56.33-84.67) n=64
After Imaging Review	97.27 (92.24-99.43) n=110	86.57 (76.03-93.67) n=112
Second Clinical Encounter	90.38 (85.54%-94.03) n=208	93.01 (88.34-96.23) n=196

208 Patients.

a similar (Chi Square 1.815, P= 0.13779) occurrence of "True Positive" results with a Sensitivity of (85.806%) with a 95% CI (79.303%-90.886%).

Impact of MRI Knowledge on Level of Experience

With MRI available, the trainee's "True Positive" Sensitivity: 98.78% with a 95% CI (93.39-99.97) were essentially the same as the senior author. On the other hand, without knowledge of MRI at exam, the trainee's Sensitivity dropped to 87.76% with a 95% CI (75.23-95.37) Therefore, the performance of the trainees with versus without knowledge of the MRI displayed the same impact on the trainees as the senior author. Chi-squared 0.490 P=0.4840.

Part II B: (ACL Intact)
Albright-Losee Test vs Lachman's Test Results

In the series with MRI evidence of an intact ACL, the senior author documented both Albright-Losee Test and Lachman's test results in 37/47 hemarthrosis cases. The "True Negative" LP-LPST Sensitivities, where the negative test results were correct were similar; with Chi-squared 2.398 P= 0.1215 with LP-LPST 83.10% 95% CI (72.34-90.95) vs. Lachman's test 76.9% CI (77.20%-88.68%).

On the other hand, "False Positive" LP-LPST Prevalence 15/208 (7.21%) was significantly less frequently wrong than the Lachman's Test was (Prevalence 29/191 (15.18%). Chi-Squared 6.431 p=0.0112).

Part II (A + B) All Case Comparison of Albright-Losee Test vs Lachman's Clinical Examination Results: (Table 2)

Assessing the combined series, with both disrupted and intact ACL's and all examiners regardless of level of expertise; LP-LPST yielded a Frequency of 395/439 (90.0%) correct exams yielding an excellent Sensitivity 94.724% with 95% CI (92.121%-96.660%) and a near perfect Specificity 97.368% with 95% CI (90.815%-99.680%). In the same setting, the Lachman's Test Frequency of "True positive "Test totals 260/327 = (79.51%) that yielded a lower but still good Sensitivity of 83.33% at 95% CI (78.73-87.29%).

Table 2. Part II A: (ACLDK) Albright-Losee Test vs Lachman's Clinical Examination Frequencies

Senior Author's Results First Clinical Encounter	Low Profile Pivot Shift Test (n=208)	Lachman's Test (n=191)
Positive	166 (79.8%)	147 (77.0 %)
Negative	15 (7.21%)	29 (15.2%)
Equivocal	16 (7.7%)	8 (4.2%)
Un-executable	11(5.3%)	7 (3.7%)

In this setting, despite high values for both tests; the superiority of the Albright-Losee Test Sensitivity over the Lachman's Test was significant at a difference of 10.490% with a 95% CI (5.375%-15.804%) with Chi-squared 16.633 P = 0.0001.

Impact of Elapsed Exam Time (7-14 days) Between 1st vs 2nd Diagnostic Exams)

Patients without an initial encounter "True Positive" result were re-examined at a second diagnostic encounter 7-14 days later. At second exam follow-up, both Albright-Losee Test and Lachman's Test results were statistically improved for all examiners. The senior author's Albright-Losee "True Positive" Incidence rose from the initial encounter 166/208 (79.81%) to 188/208 (90.38%) significantly improving the Sensitivity value from an initial 79.81%% CI (86.70%-95.28); to 90.38% with a 95% CI (85.38%-94.03%) (Chi-squared 9.139 P= 0.0025).

There were only 22/42(52.4%) patients without an initial visit "True Positive" LP-LPST, who remained so at their second visit. Initial visit "False Negative" exams recorded in 12/15 (80%), converted to "True Positives" later. Another 5/16 (31.2%) initial "Equivocal" exams also all converted to "True Positive" exams. Finally, 5/11 (46%) patients, who were either too swollen or painful for any attempt at initial exam to even be attempted, were eventually found to have a "True Positive "exam after the second encounter.

Incidence of Congruent Results Between the Albright-Losee Test and the Lachman's Test

During the initial exam, there was often agreement 135/176 (76.7%) between results of both LP-LPST and Lachman's tests. A great majority of 120/135 (88.9%)

were both "True Positive" and 9/120 (7.5%) were both "False Negatives". On the other hand, conflicting results were noted in 41/176 (23.3%) of cases. Most impressive were the 25 cases where True Positive LPPST's were documented in the absence of a positive Lachman's test (18 "False Negative", 5 "Equivocal" and 2 "Un-Executable").

Effects of Extreme Patient Stress Factors

Influence of gross swelling

Initially, at least "some" swelling was usually recorded 150/203(74%) while only 53/203 (26%) had "excessive" or "gross/tense" swelling. For the latter group, "True Positive" LP-LPST results were still present but with a lower Albright-Losee Test Incidence 33/53 (62.3%) creating a Sensitivity 84.62% with a 95% CI (69.47-94.14). However, 14/53 (26.4%) required a second visit for a positive LP-LPST exam to be confirmed.

Influence of obvious anxiety and/or extreme pain

LP-LPST: At the first clinical encounter 203/208 (97.5%) patients exhibited various levels of guarding with 20/203 (9.85%) noted to be "excessively" painful or anxious for any reason. In this group, even a second visit 7-14 days later for 13 (65%) yielded a LP-LPST that remained not "definitive". On the other hand, 6/20 (30%) did convert to a delayed "True Positive" Albright-Losee Test in the presence of positive MRI's

Lachman's Test: Also at the first clinical encounter, 178/191 (93.2%) patients had documented levels of guarding even for the Lachman's Test. Of these 16/178 (8.99%) were noted to be "excessively" painful or anxious. A second diagnostic visit was needed for only 4 (25%) of these initially uncooperative patients because the Lachman's exam was not definitive. At the second visit, 11/16 (69%) of these patients yielded "True Positives" and 1/16 (6.25%) were "False Negative".

DISCUSSION

We have introduced a novel, maximally accurate and easily learned screening test for assessing the structural integrity of the ACL in the awake patient. We have also provided a variety of details from our own experiences intended as a case-based, educational reference for interested clinicians and researchers.

Part A: Cadaver Study Implications

No previous biomechanical pivot shift studies have focused on the kinematics of the Albright-Losee Test.[10] We found the low-profile forces produced both "exit" and "re-entry" subluxations by all examiners but only evaluated the exit pivot clinically. The instability phenomenon occurred at a mean of 25.6±8.2 degrees, with a subluxation pattern that is manifested by coupled internal rotation and lateral tibial anterior translation. The three novices rapidly achieved accuracies comparable to the expert but the senior investigator required consistently lower anterior translation differences to identify a pivot. Of note is the observation that relying solely on the degree anterior translation during the pivot motion shows that under 40% of the experts' trials identified a successful pivot difference. This may be related to the lack of patient feedback during limited exam forces intentionally made by the senior author who was concentrating on applying only the mild forces employed in the real-life exams. Therefore, clinically, if met with negative results by either examiner or patient on initial exam; it is important to repeat multiple trials to clearly identify a pivot and compare with the contralateral normal knee.

Part B: Part II A (ACLDK) Clinical study Implications

The LP-LPST reliably reflects the MRI documented disruption of ACL with Sensitivity (90.49%), and overall Accuracy (92.5%). The requirement that our "True Positive" exam requires recognition of subluxation by both examiner and examinee, contributes to the excellent "Positive Predictive Value" of 98.8%.

In the English literature, the pivot shift test was initially reported to test for knee rotatory instability by Slocum and Larson.[11] Galway and Macintosh were the first group to publish how ACL insufficiency yielded an unstable knee with a positive pivot shift test.[12] Since these two manuscripts, at least 10 variations of the pivot shift test have been published[10,13-22] with nearly everyone utilizing some degree of valgus force for easier identification of the impressive but potentially violent biomechanical "jerk".

Unfortunately, some authors did not provide a thorough description of the pivot shift technique utilized in their study. We did however, revisit 8 systematic reviews; with 28 manuscripts that did include details of "the pivot shift" as part of their physical examination.[1-8] Of these, only 10 articles provided any sort of detail as to what pivot shift technique was utilized to obtain their results.[23-32] The lack of homogeneity of pivot shift techniques is a large reason for why the published sensitivity and specificity of this test has ranged from 6%-93% and 60%-100%, respectively.[1-8]

Furthermore, six of these 10 techniques were described by either Galway and Macintosh et al., or Slocum, et al.[23-28] and four of them specifically referenced the technique by Galway and Macintosh.[23-26] Within these four studies, the pivot shift sensitivity for detection of complete ACL disruption with and without anesthesia ranged from 60%-89% and 9%-62%, respectively.[23-26] Additionally, the study reporting a sensitivity of 9% used the technique described by Slocum et al.; and another study reported a sensitivity of 63% by using a technique described by both Galway et al. and Slocum et al.[27,28] Given the performance difficulties and sensitivity variation the pivot-shift technique category is frequently set aside in favor of Lachman's Test. The systematic review by Lopomo et al. concluded that widespread utilization of a standardized pivot shift technique is necessary to help reduce future clinician variability.[33]

Our separate consecutive cohort series, looking for "False Positive" tests in patients with intact ACL's; validated the use of both the Albright-Losee Test and the Lachman's test. The only two "False Positive" Albright-Losee Test cases we recorded had concomitant pathology (meniscus tears, chondral fracture, etc.) which may have led to misinterpretation even by the experienced examiner to misinterpret the patient's recognition of discomfort for agreeing that the knee was "out of place".

Inter-rater Reproducibility

Given wide sensitivity variation in published pivot-shift techniques, the general technique category has been understandably set aside in favor of Lachman's Test. However, tested among our 69 inexperienced trainees plus the senior author, all contributing results to the clinical portions of this study; their results suggest that the Albright-Losee Test technique is not only of superior accuracy but relatively easy to learn.

We also took advantage of the opportunity to secondarily compare it to the popular Lachman's test when concomitantly recorded. Given earlier stated limitations of sensitivity and compared to the LP-LPST, the Lachman test accuracy was also reinforced in this study in concert with the existing literature accepting it as a staple for examining ACL integrity. 1579 subjects were reviewed by van Eck et al. with a sensitivity range of 0.34 to 0.99 for the Lachman exam.[8] Huang et al. reported a pooled sensitivity of 0.87 for Lachman's test.[5] In our study the first visit, the overall Lachman Test Sensitivity was 83.52% at 95% CI (77.20%-88.68%). On the other hand, while we agree that the Lachman's Test is valuable, the LP-LPST sensitivity is better by 8.300% with a Chi Squared 10.968, P=0.0009 either with or without MRI knowledge and is significantly less often erroneously negative.

Knee Swelling with Pain

Delayed hemarthrosis with subsequent increasing pain is an on -field hallmark in acute ACL rupture. In our clinic, patients without MRI's and with gross knee swelling to the point of extreme discomfort, the LP-LPST still yielded a sensitivity of 62.26% with re-examination of increased value once swelling subsided at a second clinical visit.

Hamstring Antagonistic Activity

The relatively lower LP-LPST "Negative Predictive Value of 81.280% was partly due patients who were noted to be actively hiding the instability with subtle, dynamic hamstring stabilization effort (see VJSM video). It is important to recognize that there are patients, not formally identified in this retrospective study, who might have been recorded to have a "False Negative" Albright-Losee Test because they possess a refined, protective hamstring muscular control making it difficult to elicit the existing instability of the ACL deficient knee.

In those patients where the level of experience did yield an increased number of positive Albright-Losee Test exams, this was not uncommonly the reason. They are recognized as "Copers"[34] because of their very refined dynamic instability control via their antagonistic hamstring muscles. Observed by Walla et al.[9] was a group of elite athletes functioning competitively without ACL's. More recently, a prospective case series of 44 children has been reported at 8 year follow up by Engelbretsen et al. reporting that up to 50% of children progressed to Adulthood with ACL deficient knees.[34] These "Copers" demonstrated neuromuscular control capability within 6 weeks post injury and have been found to sustain this control on a long-term basis. Banovetz et al. even graded the degree of hamstring control for these "Copers" Ranging from "none "to "complete" voluntary and maximally to "reflexive" or "automatic" control.[35] A positive Low-profile pivot shift test will be nearly impossible to elicit on patients with automatic control of their hamstrings. Patients graded as possessing partial to full "voluntary level" control may still allow for accurate results with the LPPST if instructed to relax their hamstring muscles.

LIMITATIONS

Our study was not without limitations. It was not a prospective, randomized registry of knees with traumatic hemarthrosis. We were not able to consistently assess several items such as: precise degrees of and response to swelling; exact time lapse since injury; differences in Albright-Losee Test results on the field of play versus later in the office setting or a formal identification of sophisticated levels of patient hamstring control; exact numerical assessment of trainee experience with the esoteric test of interest. However, the similarities in results between the senior author and both the clinic and lab trainees suggested that the learning curve for performing this test is relatively shallow. Inclusion criteria confined the main part of the study to knees with MRI proven ACL status.

CONCLUSION

The Albright Low-Profile Modification of the classic Losee Pivot-Shift Test is a well-tolerated, highly sensitive and specific; clinical exam for reproducing early pathologic sensations of the subluxation phenomenon in the ACL deficient knee with a shallow learning curve and an Accuracy of 95.5% with a 95% CI of (93.3%-97.2%). By applying easily learned modifications to a classic, valgus-based subluxation maneuver; this test becomes well tolerated by awake and frequently hesitant patients. Factors significantly impacting the results include: concurrent knowledge of MRI findings; magnitude of factors affecting patient comfort and anxiety level such as gross swelling and/or extreme pain; and changes related to elapsed time. Assuring that, in addition to high sensitivity; great specificity requires both patient and examiner agreeing on the knee feeling "out of place"; insures the impressive Positive Predictive Value of 98.8%. While both the low profile pivot shift and Lachman's tests were often concurrently positive, the Lachman's Test was not as reliable, partly because patients could not help the examiner in that they were not always proprioceptively aware of relative tibial-femoral mal-positioning.

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THE FRAGILITY OF STATISTICAL FINDINGS IN MENISCUS REPAIR LITERATURE: A SYSTEMATIC REVIEW OF RANDOMIZED CONTROLLED TRIALS

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ABSTRACT

Background: Within the realm of orthopedic literature, the determination of statistical significance for outcomes relies on probability analysis and the reporting of P-values. The aim of this study was to employ fragility analysis as a means of evaluating the resilience of randomized controlled trials (RCTs) that assess meniscus surgeries. It was hypothesized that dichotomous outcomes would be statistically fragile and comparable to other orthopedic specialties.

Methods: Included in this study were RCTs reporting dichotomous measures pertaining to meniscus repair, sourced from 14 orthopedic journals indexed on PubMed between 2000 and 2022. The fragility index (FI) for each outcome was determined by iteratively reversing a single outcome event until the significance was reversed. To calculate the fragility quotient (FQ), the FI of each study was divided by its respective sample size. Additionally, the interquartile range (IQR) was calculated for both the FI and FQ.

Results: Out of the 7,844 articles screened, a total of 17 RCTs with 112 dichotomous outcomes were included for analysis. The FI for all the outcomes was 7, with an IQR of 4 to 10. Similarly, the FQ was 0.067, with an IQR of 0.029 to 0.107. However, statistically significant outcomes had a FI and FQ of 4 (IQR 2 to 7) and .057 (IQR 0.03 to 0.108), respectively. The average number of patients lost to follow-up was 2 patients and 17.6% of studies reporting lost to follow up of 7 or greater.

Conclusion: Recent findings suggest that the stability of the literature concerning meniscus repair may not be as robust as previously assumed. Consequently, we strongly advocate for the inclusion of the FI and FQ metrics, alongside the P-value, to enhance the interpretation of clinical findings presented in the meniscus repair literature.

Level of Evidence: I

Keywords: fragility, meniscus, biostatistics, knee, arthroplasty

INTRODUCTION

Enhanced understanding of knee functional kinetics and structural damage has emphasized the inherent importance of reestablishing meniscal continuity and anatomy following injury. Composed predominantly of type 1 collagen, the medial and lateral menisci function to absorb the force transmitted through the knee during weight bearing and physical activity.[1] Meniscal injuries are common, with an estimated incidence of 60 individuals sustaining a meniscus tear per 100,000.[2] Occurring in isolation or with a contiguous ligamentous injury, meniscal damage can be painful and debilitating to knee function.[3,4] Untreated, meniscal injuries have been found to contribute to altered biokinetics of the knee and early onset of osteoarthritis.[5,6] Although some studies have suggested that many patients with meniscal damage remain asymptomatic, determination of the best approach to the treatment of symptomatic meniscal injuries is ongoing.[7,8]

Evidence based medicine has contributed to medical innovation and the optimization of treatment interventions.[9-12] Improved understanding of patient demographics alongside analysis of medical and operative management has facilitated refinements in care options

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while also enhancing patient outcomes. The evaluation of specific aspects of care and analyzing their impact on patients' general health, recovery, ability to engage in activities of daily living and overall post treatment satisfaction has enabled providers to evaluate and tailor treatment plans to the individual patient. Utilizing the literature, clinicians can consult patients with supported statistical data regarding planned interventions. It is a common occurrence for patients to inquire about the "chances of" or "likelihood of" a specific outcome during initial medical/surgical consultations. Statistical analysis generated from studies provide objective data that my aid in patient education. P-value employed to express the significance of data being referenced in patient-centered shared clinical decision-making.

The current reliance on P-value is potentiating treatment plans that may not account for clinical relevance. Continuous assessment of how an intervention impacts a patient's well-being is as important as ensuring the patient's understanding of the potential impact of an intervention. A P-value of <0.05 is most often used in the determination of statistical significance across orthopaedic literature. Calculation of the odds ratios, multilinear logistic regression and ultimately the rejection or acceptance of the null hypothesis all hinge on what side of 0.05 a value lies. Efforts to elucidate clinical pertinent information associated with P-values has led to the application of the concept of fragility. The calculation of fragility seeks to quantify the number of altered outcomes necessary to change statistical significance.[13] Specifically applied to P-value analysis, identification of the fragility index (FI) signifies the number or events necessary to shift a calculated P-value above or below 0.05.[14-21] Assessment of the statistical fragility of P-value analysis has been conducted across multiple subspecialities in orthopaedic surgery, with significant fragility identified.[13,22-24] In such studies, sample size variance FI calculation is accounted for by calculating a fragility quotient (FQ), providing quantitative analysis.[25] The FQ is defined as the ratio of the FI to the sample size. The utilization of FI and FQ metrics facilitates the scrutinization of statistical data and elucidates the robustness of outcome data.

Table 1. Demonstration of Reversal of Significance with a Fragility of 1

	Outcome A	Outcome B	P Value
Scenario 1			
Treatment A	5	34	
Treatment B	18	37	0.031
Scenario 2			
Treatment A	6	33	
Treatment B	15	40	0.092

Fragility methodology evaluation has yet to be applied to the meniscus repair literature. The primary objective of this study was to assess the stability of statistical significance in the operative treatment of meniscal injuries. This was achieved by calculating both the FI and the FQ for dichotomous outcomes. It was hypothesized that both the summative FI and FQ, of published RCTs pertaining to meniscal repair, would reveal that the current literature advocating for operative meniscal interventions exhibits statistically significant fragility.

METHODS

The conduct of this systematic review strictly followed the guidelines set forth by PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The initial search was performed on PubMed with the search criteria "meniscus repair" and limited to studies between 2000 and 2022. The included studies were from the following orthopaedic journals: The American Journal of Sports Medicine, Annals of Internal Medicine, Annals of Rheumatic Disease, Biomed Research International, British Journal of Sports Medicine, Georgia Medical News, Journal of Arthroscopic & Related Research, Journal of Bone and Joint Surgery, Knee surgery, Sports traumatology, Arthroscopy, New England Journal of Medicine, Osteoarthritis Cartilage, and the Bone & Joint Journal. Inclusion criteria was randomized control trials (RCT) reporting dichotomous results. Exclusion criteria were non-RCT, non-dichotomous data, more than two treatment groups, systematic reviews, animal studies and cadaveric data. From the included studies following data was extracted: first author, PMID, journal title, year of publication, RCT, primary or secondary outcome measure, intervention, lost to follow-up and P-value. In cases where dichotomous outcomes did not report a P-value, one was calculated using an online P-value calculator.[26]

Fragility analysis was conducted by iteratively adjusting the reported outcome until a reversal of significance was attained. For statistical significance, a P-value of less than 0.05 was considered as the threshold. An example

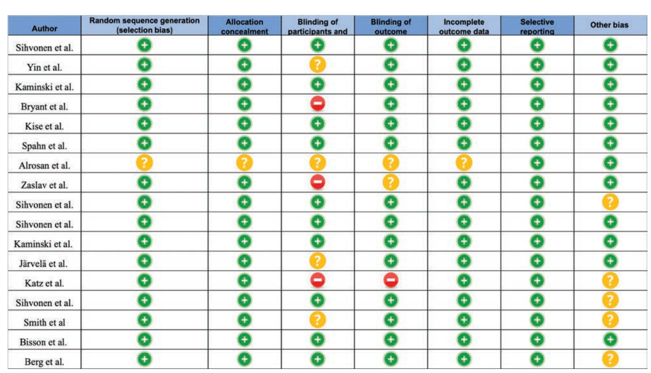

Figure 2. Cochrane Risk of Bias Assessment.

of this process can be found in Table 1 For outcomes with a P-value of less than 0.05, the analysis involved determining the number of events needed to increase the integer above the significance threshold. Conversely, for studies with outcomes having a P-value above 0.05, the number of events required to reduce it below 0.05 was calculated. The FI for each outcome was then defined as the number of events needed to reverse the significance of the outcome. The process of calculating the FI was applied to each outcome identified in the search, resulting in the determination of a median FI. Additionally, the FQ for each outcome was calculated by dividing the FI by the total sample size of each study, and the median FQ was also computed. The FI and FQ were further determined for the following subgroups: (1) primary vs secondary outcomes, (2) significant vs non-significant outcomes, (3) loss to follow up greater than FI, (4) studies published from 2000-2013, 2014-2018 and 2019-2022. Interquartile ranges (IQR) ranges for both FI and FQ were calculated. The IQR was the difference between 75th and the 25th percentiles. A Risk-of-bias assessment was also performed (Figure 2).

RESULTS

Out of the 7,844 studies screened, 46 studies fulfilled the search criteria, with 17 RCTs eventually included in the analysis (Figure 1 and Table 3). A total of 112 outcome events were identified, comprising 26 outcomes that were statistically significant ($p < 0.05$) and 85 outcomes that were not statistically significant ($p > 0.05$). Among the 26 significant outcomes, the median number of outcome events required to alter their significance was 4 (IQR, 2 to 7). (Table 2). The FQ for significant outcomes was 0.057 (IQR, 0.030 to 0.108). For the 85 outcomes that were reported as nonsignificant, the number of outcome events required to change significance was 7 (IQR, 5 to 10). The FQ for nonsignificant outcomes was 0.069 (IQR, 0.028 to 0.101). Of the 112 total outcomes, 27 (24.1%) were primary and 85 (75.9%) were secondary outcomes. No significant distinction was observed between primary and secondary outcomes regarding their FI. Both exhibited a median FI of 7, with IQR of 4 to 11 and 4 to 10, respectively. The associated FQ values for primary and secondary outcomes were 0.067 and 0.061, respectively.

Regarding outcomes where the FI < significance (LTF) (n = 9), the median FI was determined to be 8, with an IQR of 7 to 12. Conversely, for outcomes where the FI > LTF (n = 103), the median FI was calculated to be 7, with an IQR of 4 to 10. The corresponding median FQs for these two groups were 0.067 (IQR, 0.05 to 0.1135) and 0.069 (IQR, 0.028 to 0.106), respectively. Fragility sub analysis per year of publication identified a FI of 6.5(IQR 4 to 10) from 2000 to 2013, 7(IQR 4 to10) from 2014 to 2018 and 7.5 (IQR 5 to 10) from 2019 to 2022, thus demonstrating consistent statistical fragility over the 20-year period (Table 2). The final FI, incor-

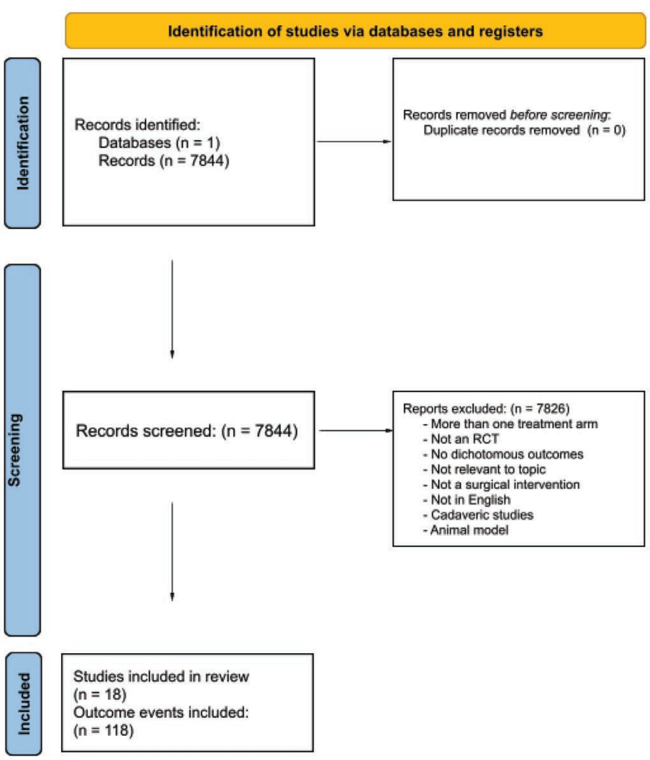

Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

Table 2. Overall Fragility Data and Analysis of Subgroups

	Events	FI	FQ
All Trials	112	7 (4-10)	0.067 (.029-.107)
Outcome Type			
Primary	27	7 (4-11)	.067 (.050-.117)
Secondary	85	7 (4-10)	.061 (.028-.0965)
Outcome Significance			
P < .05	26	4 (2-7)	.057 (.03-.108)
P > .05	86	7 (5-10)	.069 (.028-.101)
Comparing outcome FI to LTF			
FI < LTF	9	8 (7-12)	.067 (.05-.1135)
FI > LTF	103	7 (4-10)	.069 (.028-.106)
Year of Publication			
2000-2013	40	6.5 (4-10)	.028 (.017-.088)
2014-2018	40	7 (4-10)	.079 (.049-.108)
2019-2022	32	7.5 (5-10)	.070 (.047-.1115)

Table 3. RCTs Included in the Review

	Author et al.	Year	Journal	Total Events	P -Value	FI	Sample Size	FQ
1	Sihvonen et al.	2013	New England Journal of Medicine	7	0.50	8	146	0.05
2	Yin et al.	2013	The American journal of sports medicine	3	0.65	9	102	0.09
3	Kaminski et al.	2019	Journal of Arthroscopic & Related Research	3	0.00	7	40	0.17
4	Bryant et al.	2007	The American journal of sports medicine	1	0.92	11	100	0.11
5	Kise et al.	2015	Knee surgery, Sports traumatology, Arthroscopy	2	0.51	4	46	0.08
6	Spahn et al.	2010	Journal of Arthroscopic & Related Research	1	0.01	2	60	0.03
7	Alrosan et al.	2022	Georgia Medical News	11	<.005	6	66	0.09
8	Zaslav et al.	2021	Knee surgery, Sports traumatology, Arthroscopy	1	NS	16	116	0.14
9	Sihvonen et al.	2020	British Journal of Sports Medicine	9	0.61	8	142	0.06
10	Sihvonen et al.	2016	Annals of Rheumatic Disease	22	0.67	9	73	0.08
11	Kaminski et al.	2018	Biomed Research International	9	0.20	4	37	0.10
12	Järvelä et al.	2010	American Journal of Sports Medicine	8	NS	7	31	0.19
13	Katz et al.	2013	New England Journal of Medicine	20	0.68	7	351	0.02
14	Smith et al	2018	The Bone & Joint Journal	1	0.06	1	21	0.05
15	Bisson et al.	2021	Journal of Bone and Joint Surgery	2	0.69	8	189	0.05
16	Sihvonen et al.	2016	Annals of Internal Medicine	6	0.55	10	69	0.10
17	Berg et al.	2020	Osteoarthritis Cartilage	6	0.53	10	120	0.08

porating all 118 outcome events from the 18 RCTs was 7 (IQR, 4 to 10). The final FQ was 0.067 (IQR, 0.033 to 0.106), indicating that the reversal of 6.7 of 100 outcomes may change the study significance of the included RCTs.

DISCUSSION

The current high-level RCTs focusing on operative management of meniscal repairs demonstrate statistical fragility that is similar to what has been observed in the broader orthopaedic surgery literature. Statistically significant outcomes analyzed across 17 studies had a FI and FQ of 4 (IQR 2 to 7) and .057 (IQR 0.03 to 0.108), respectively. This means that a change of only 4 events was necessary to cause reversal of significance. The average reported number of patients lost to follow-up was 2. The systematic review found that the number needed to change the significance of the results was similar to number of patients lost to follow up. Suggesting, the use of FI and FQ alongside P-values can help ensure reliability of the results by considering the impact of missing data due to lost to follow up.

P-value analysis of RCTs involving meniscus repair is fragile and should therefore be interpreted with caution. Although clear fragility threshold values have yet to be determined, evaluation of several orthopaedic subspecialties has demonstrated similar degrees of fragility across literature. In a study examining the pediatric orthopedic literature, a median FI of 3 was identified.[27] Evanview et al. conducted an evaluation of the spine surgery literature and reported a median FI of 2.[17] In an analysis of the sports medicine literature, Parisien et al. evaluated 102 RCTs and non-RCTs and found a FI of only 5 across 339 outcomes.[23] McCormick et al. evaluated the shoulder arthroplasty literature and reported an FI of 6.[28] Additionally, Parisien et al. evaluated the fragility of dichotomous outcomes in cartilage restoration of the knee and reported a FI of 4.[29] In a review of primary outcomes within the sports medicine literature, Khan et al. found the overall FI to be 2.[22] Parisien et al. performed a review of 52 trials from the hip arthroscopy literature and identified a FI of 3.5.[30] In a review of the hand surgery literature Ruzbarsky et al. reported a FI of 3.[31] Furthermore, Parisien et al. reported a FI of 5in evaluation of the orhopaedic trauma literature.[24] Caroll et al. found a FI of 1 in review of proximal humeral fracture literature.[32] Doyle et al.'s review of achilles tendon injury literature found an overall FI of 4.[33] In their review of the rotator cuff literature, Parisien et al. demonstrated an overall FI of 4.[34] Furthermore, in a recent review of distal femur fracture literature, Megafu et al. reviewed 11 RCT with 98 outcomes and found a median FI of 5.[35] Similarly, Walsh et al., in a review of all RCTs from 2004 to 2010 found that 25% of studies had a FI of 3. The median FI of all RCTs was 8.[36] Checketts et al. in their study of 72 clinical trials that were cited by American Academy of Orthopedic Surgeons Clinical Guideline Practice as strong evidence, found a FI of 2. Additionally, utilization of a Fisher exact test in determination of the P-value nullified the significance of 16 studies, resulting in a FI of 0.[37] This suggests that the significance of some studies is reliant on a specific method of statistical analysis, leading to the presentation of fragile data. The current fragility analysis of the meniscus repair literature aligns closely with that of the studies cited above.

The focus of conducting evidence-based research is to provide unbiased and objective data that can guide the decision-making process of clinical care. Therefore, there is heavy reliance on statistical analysis as an objective tool. As seen in our analysis, and other cited studies, there is an opportunity for clinicians to better understand the context in which data is collected and analyzed.[17,22-24,27-33] The scientific community's current accepted practice in the reporting of statistical significance is through P-value analysis. However, P-value does not consider sample size, loss to follow up and can be malleable to study designs. Thus, there exists a possibility of an unintentional type I (alpha) error. Thus, the P-value should be supplemented with additional context to aid in interpretation and analysis of the data presented. Despite numerous studies reporting similar FI and FQ results, consensus on specific fragility threshold values remains elusive, largely due to the novelty of this research. One approach would to be to integrate additional statistical measures such as minimally clinically important difference, substantial clinical benefit, and patient acceptable symptomatic state with the suggested FI and FQ for statistically significant outcomes. However, this development is likely to take time to execute. In the meantime, inclusion of FI and FQ, along with P-value can provide clinicians with more comprehensive and accurate understanding of trial significance and reported significant outcomes.

LIMITATIONS

This study contained several strengths and limitations. A strength of this study was the variety of articles meeting inclusion criteria that were published in high impact medical and surgery journals. Articles were all published from 2013 to 2022, representing the most current management strategies for meniscal injuries. All the studies reviewed were RCTs, and we analyzed both primary and secondary outcome measures, as well as data on lost to follow up. This allowed for a thorough evaluation of the reliability of evidence concerning the management of meniscal injuries. Another strength of this study was the breath of dichotomous outcomes that were tabulated and analyzed across the 17 RCTs included in final analysis. This study was not without limitations. Calculation of fragility required utilization of dichotomous data with reported loss to follow up data and reported P-values. This led to multiple studies with non-dichotomous data (visual analog scales, patient reported outcome measurements, Likert scales) being excluded from analysis.

CONCLUSION

Further scrutinization of statistical data pertaining to the meniscus repair literature is necessary. Relying solely on P-value and failing to account for lost to follow up may constrain clinicians' ability to provide patients with optimal evidence-based treatment plans. Utilization of fragility methodology as an adjunct to current P-value analysis will serve to provide additional context to statistical findings, thus informing patient-centered shared clinical decision-making.

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ORTHOPEDIC SURGERY <50 DAYS FOLLOWING COVID-19 INFECTION IS NOT ASSOCIATED WITH INCREASED POSTOPERATIVE COMPLICATIONS

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ABSTRACT

Background: Recent literature indicates that COVID-19 infection is a negative predictor of good outcomes following elective orthopedic surgery. However, the ideal timing of surgery after infection is unclear. The purpose of this study was to compare the rates of post-operative complications between those who underwent elective orthopedic surgery <50 days and >50 days after COVID-19 infection.

Methods: This is a pilot study utilizing retrospective review of 28 adult subjects who underwent orthopedic surgery including 17 total-knee arthroplasties, seven total-hip arthroplasties, three posterior spinal fusions, and one common peroneal decompression. These subjects were indicated for an orthopedic surgery that was canceled due to positive pre-operative COVID-19 testing. The subjects were rescheduled for surgery between March 2020-December 2022.

There were two cohorts: those who underwent surgery <50 days after COVID-19 infection (n=14) and subjects who underwent surgery >50 days after COVID-19 infection (n=14). Demographics, preoperative comorbid conditions, and post-operative complications were recorded and compared.

Results: There were no significant demographic differences between the two cohorts with respect to age, body mass index, weight, and American Society of Anesthesiologists (ASA) grade. The two cohorts had no significant difference in pre-existing comorbid conditions with hypertension and peripheral vascular disease being the most common comorbidities overall. There were six postoperative complications involving four subjects within 90 days of surgery. One subject developed a postoperative pulmonary embolism (PE), and another subject developed a surgical-site infection, sepsis, and renal failure; both in the >50 days cohort. One patient in each cohort required reoperation. There was no difference in postoperative complications such as deep vein thrombosis (DVT), PE, sepsis, renal failure, and intensive care unit (ICU) admission between the two cohorts.

Conclusion: This pilot cohort study demonstrates that COVID-19 infection within 50 days of orthopedic surgery does not significantly increase the risk of postoperative complications such as DVT, PE, surgical site infection, renal failure, ICU admission, reoperation, or death. Further evaluation of the effects of COVID-19 on surgical outcomes in larger cohorts is warranted.

Level of Evidence: III

Keywords: COVID-19, orthopedic surgery, complications, comorbidities, reschedule, retrospective cohort

INTRODUCTION

The global impact of the COVID-19 pandemic and its persistent re-emergence has led to many precautions in healthcare, specifically requiring delays in surgery.[1-3] This has spurred further evaluation of post-infectious surgical complications within many surgical subspecialties, including orthopedics. Unexpected COVID-19 infection remains a clinical challenge as surgeons are required to answer several questions: Does a recent COVID-19 infection increase the risk of postoperative complications, and how are patients best optimized following infection?

Early in the pandemic, it was established that patients with active COVID-19 who undergo surgery are at a higher risk of developing postoperative complications, particularly venous thromboembolism (VTE), pneumonia, and death.[4-7] In 2020, the COVIDSurg Collaborative released a cohort study demonstrating that one-half of patients who underwent surgery with an active COVID-19 infection developed serious postoperative pulmonary complications.[4] There was a proposed reduction in surgical volume by many hospitals to decrease the spread of the virus due to the known increased risk of postoperative morbidity and mortality.[3,8-9]

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Following COVID-19 infection, this heightened risk likely persists for several weeks after infection. However, the duration of elevated risk, impact of infection severity, and influence of patient comorbid factors is unclear.[10-11] As a result, the optimal waiting time for rescheduling orthopedic surgery following COVID-19 infection remains uncertain. The multidisciplinary consensus statement released in 2021 by the Association of Anaesthetists (ASA), the Center for Perioperative Care, the Federation of Surgical Specialty Associations, and the Royal College of Anesthetists recommended that all elective surgery be delayed until seven weeks post COVID-19 infection.[12] This consensus statement was created based on early data of increased postoperative morbidity and mortality with recent COVID-19 infection but was also heavily geared towards protecting staff from becoming infected with the virus. Previous evaluations of postoperative comorbidities with active infection compared severe cases to non-infected individuals.[6] Now, the severity of cases is lessened with the distribution of vaccinations and developed immunity.[11,13]

From March 2020 through January 2022, patients testing positive for COVID-19 prior to elective orthopedic surgery at the study institution were rescheduled 50 days or more following infection. In January 2022, this waiting period was reduced to 28 days following test positivity. This study aims to evaluate the incidence of adverse events prior to and following the change in waiting time protocol. We hypothesize that there will be no difference in the incidence of venous thromboembolism, pneumonia, hospital readmission, or mortality between patients rescheduled for elective orthopedic surgery <50 days after COVID-19 positivity and those required to wait >50 days.

METHODS

This retrospective review was approved by the Study Institution's Institutional Review Board as a pilot study to investigate the impact of recent COVID-19 infection on postoperative complications following orthopedic surgery. In 2020, the institution adopted a global COVID-19 screening policy for all surgical patients. Patients were required to obtain a COVID-19 nasal swab sent for PCR testing within 72 hours of the scheduled surgical date. Patients who tested positively were rescheduled. The initial rescheduling timeline included >50 days since positive COVID-19 test regardless of symptom burden. The study institution modified the COVID-19 rescheduling protocol in October 2021 to reschedule surgery >28 days from positive COVID-19 testing.

Inclusion criteria for subject selection included: adults aged 18 or greater, confirmed positive pre-operative PCR COVID-19 test, and completion of the rescheduled procedure. All patients were from a single institution. Two cohorts were reviewed: those who underwent surgery within 50 days of positive COVID-19 testing (n=14) and those who had surgery more than 50 days after infection (n=14). All patients with an original surgical date between March 2020 and December 2022 who were rescheduled due to a COVID-19 test were collected.

The primary outcomes included rates of postoperative complications including deep venous thrombosis (DVT), pulmonary embolism (PE), surgical site infection, renal failure, readmission to the intensive care unit (ICU), reoperation, and death within 90 days of the rescheduled orthopedic surgery. To comprehensively assess potential risk factors, demographic data and pre-operative comorbid conditions such as asthma, chronic obstructive pulmonary disease (COPD), chronic heart failure (CHF), hypertension (HTN), peripheral vascular disease (PVD), and chronic kidney disease (CKD), and immunosuppression were recorded.

Standard statistical techniques, including paired t-tests were utilized to assess the difference in demographics of cohorts. An α level of 0.05 was utilized.

RESULTS

Demographics

28 adult subjects had their surgeries rescheduled during the study period. Surgeries included 17 total knee arthroplasties, seven total hip arthroplasties, three posterior spinal fusions, and one common peroneal decompression. A total of 14 male and 14 female subjects were included. The mean age was 63.29 years (range: 41-82), mean BMI was 33.30 kg/m^2 (range: 24-59 kg/m^2), and mean weight was 96.13 kg (range: 54-165 kg) (Table 1).

There were no significant differences in demographic characteristics between the two cohorts (Table 2). The shorter waiting period group (n=14) had a mean age of 61.9 years and mean BMI of 33.6 kg/m^2 compared to 64.7 years and 33.0 kg/m^2 (p=0.52, p=0.84), respectively in the longer waiting period group (n=14). ASA grade was similar between the two cohorts (p=0.67) indicating a similar pre-anesthesia risk between the groups.

Table 1. Combined Data – Subject Demographics

Quantitative Variables	No. of Patients	Range	Mean	SD	Median
Age (years)	28	41-82	63.29	9.36	63
BMI (kg/m^2)	28	24-59	33.30	8.19	31.50
Weight (kg)	28	54-165	96.13	22.62	96.75

Table 2. Shorter Post-COVID Positivity Waiting Period vs. Longer Waiting Period Data – Demographics

Variables	Cohort	No. of Patients per Group	Range	Mean	SD	Median	P-Value
Age (years)	Shorter Delay	14	41-82	61.86	11.02	61.50	0.52
	Longer Delay	14	52-76	64.71	7.50	66	
BMI (kg/m2)	Shorter Delay	14	24-53	33.61	7.11	32.50	0.84
	Longer Delay	14	24-59	33	9.41	29	
Weight (kg)	Shorter Delay	14	60-165	102.33	24.15	98.50	0.15
	Longer Delay	14	54-119	89.94	19.91	93.30	
ASA	Shorter Delay	14	1-3	2.33	0.65	2.5	0.67
	Longer Delay	14	2-3	2.31	0.50	2	
"Yes" Vaccinated against COVID-19 Preoperatively	Shorter Delay	11	-	-	-	-	-
	Longer Delay	11	-	-	-	-	

There were no significant differences between the pre-existing comorbidities of the two cohorts including diabetes, asthma, COPD, CHF, hypertension, history of myocardial infarction, peripheral vascular disease, immunosuppression, and CKD (Table 3). Notably, hypertension is prevalent (21 of 28 subjects) and balanced between the two cohorts. There were no current smokers in either cohort.

Complications

The overall complication rate was very low for both cohorts (Table 4). One subject in the longer waiting period cohort developed a venous thromboembolism. No subjects in either group suffered pulmonary complications. One subject in the greater wait period cohort developed a surgical site infection, sepsis, and renal failure. No subjects required readmission to the intensive care unit. Reoperation was necessary for two subjects and was equally divided between the shorter and longer wait time cohorts. Overall, there were few postoperative complications amongst all subjects and there was no difference in the incidence of complications between the shorter wait period cohort and the longer wait period cohort.

DISCUSSION

The impact of the COVID-19 pandemic on orthopedic surgery has been tremendous. Approximately 92% of orthopedic surgeons stopped all elective cases during the height of the pandemic.[14] Although elective orthopedic surgery has since resumed, COVID–19 infection still has a considerable influence over surgeons and patients – particularly regarding surgical timing and medical optimization. Uncertainty regarding the timing of elective arthroplasty procedures due to COVID-19 has been found to be one of the most anxiety producing factors in patients.[15]

The American Academy of Orthopaedic Surgeons recommends pre-operative testing either the day of or 72 hours before surgery.[16] COVID-19 infection was identified during the 72-hour pre-operative period in 10 of the patients in this study, with only 1 of those 10 demonstrating any symptoms. The other subjects were tested outside of the standard screening window, either by primary care physicians, urgent care centers or with at home tests for purposes outside of pre-operative preparation.

As of June of 2023, the American Society of Anesthesiologists recommends continued screening for COVID-19 for symptomatic patients prior to elective procedures.[17] They recommend that no elective surgery take place within two weeks of COVID-19 infection. Between 2-7 weeks after COVID-19 infection, a risk assessment is recommended based on age, comorbidities, functionality of the patient, complexity of the surgery, and severity of COVID-19 infection preoperatively.[17] These recommendations, although helpful, are based on limited data and remain surgeon dependent. Our understanding of the optimal timing of elective surgery after infection continues to evolve.

Forlenza et al. conducted a large database query, which demonstrated that total joint arthroplasty within 1 month of COVID-19 infection significantly increased

Table 3. Comorbidities Comparison Between Shorter and Longer Waiting Period Cohorts

Comorbidity	Total Count	Shorter Wait Period Count	Longer Waiting Period Count
Current Smoker	0	0	0
Diabetes	2	1	1
On home oxygen pre-operatively	0	0	0
Asthma/COPD	4	2	2
Chronic Heart Failure	2	2	0
Hypertension	21	11	10
History of Myocardial Infarction	2	2	0
Peripheral Vascular Disease	5	2	3
Immunosuppression	4	2	2
Chronic Kidney Disease	2	1	1

Table 4. Shorter Post-COVID Positivity Waiting Period vs. Longer Waiting Period Data – Complications

Variables	Total Count	Shorter Wait Period Count	Longer Waiting Period Count
DVT/PE	1	0	1
Pulmonary Complications	0	0	0
Surgical Site Infection	1	0	1
Sepsis	1	0	1
Renal Failure	1	0	1
ICU Admission	0	0	0
Reoperation	2	1	1
Death	0	0	0

the risk of thromboembolic events.[18] However, overall complication rates returned to baseline after 1 month.[18] Likewise, Mercier et al. examined post-operative complications in 740 patients with COVID-19 infection and found infected patients to have a higher risk of death, venous thromboembolism, and pneumonia within the 30-day post-operative period.[19] Meanwhile, Johnson et al. found 90-day rates of VTE, MI (Myocardial Infarction), pneumonia, and emergency room visits after elective orthopedic surgery to be significantly increased post SARs-CoV-2 infection.[20]

A systematic review performed by Khan et al. included 14 studies that report on complications associated with elective surgery after a COVID-19 infection.[21] They suggest that the best timeframe for surgical delay is based on the severity of infection: 4-8 weeks for asymptomatic patients, 6-8 weeks for mild/moderate disease, and a minimum of 12 weeks for severe disease. Although this study did not include a true determination of infection severity, most patients were asymptomatic or had mild/moderate disease, which may contribute to low incidence of complications regardless of time to surgery.

This study sought to help clarify the safe timing for elective surgery after COVID-19 infection. Our findings indicate that there is no significant increase in postoperative complications among patients undergoing elective orthopedic surgery within this period.

These results are particularly relevant in the context of the ongoing challenges posed by the pandemic. The fear of heightened complications after surgery in individuals recently infected with COVID-19 has led to a cautious approach in scheduling elective orthopedic procedures. However, this pilot data may alleviate some of these concerns, as it suggests that such surgeries can be performed safely within 50 days of COVID-19 infection in most patients.

It is essential to note that our findings do not diminish the overall importance of infection control measures and preoperative screening. While our data show no increased risk of complications within the 50-day window, adherence to robust preoperative protocols, including thorough screening for COVID-19 symptoms and testing,[22] remains crucial in ensuring the safety of both patients and healthcare professionals. Decisions regarding surgical timing should be made after carefully weighing patient specific factors and are beyond the scope of this investigation.

The limitations of this study include the small sample size and single institution nature of the data. Most of the subjects included were asymptomatic patients identified through routine pre-operative screening, or those with only mild disease. There is heterogeneity in the type of surgery performed, although all are considered major orthopedic surgeries. Overall, this is a pilot study aimed to explore the utility of larger cohort studies. Prospective studies with larger sample sizes and diverse patient cohorts would provide valuable insights to further validate our findings.

This research contributes to the evolving understanding of the relationship between recent COVID-19 infection and postoperative outcomes in orthopedic surgery. The absence of a significant association between surgery within 50 days of COVID-19 infection and increased complications suggests that, with appropriate precautions, orthopedic procedures can be safely performed in this timeframe. Although larger cohort studies are essential, this information can help guide clinicians in making informed decisions regarding surgical interventions during the ongoing pandemic.

CONCLUSION

This pilot cohort study suggests that undergoing orthopedic surgery within 50 days of a COVID-19 infection does not significantly elevate the risk of early postoperative complications. While these findings provide valuable initial insights, further exploration involving larger cohorts is essential to comprehensively understand the impact of COVID-19 on orthopedic surgical outcomes.

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STANDARDIZED MULTIMODAL PAIN PROTOCOL MINIMIZES INPATIENT OPIOID ADMINISTRATION IN PEDIATRIC ORTHOPEDIC SURGERY POPULATION

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ABSTRACT

Background: Optimal management of post-operative pain is a critical component of orthopedic surgical care. There is a heightened awareness of narcotic prescribing habits given the current "opioid epidemic." The lack of standardized protocols has led to increased errors, delayed access to prescribed medications, and excessive narcotic prescribing.

The purpose of this study is to assess the current trends in opioid use and document the prescribing patterns in the pediatric population before and after the implementation of a standardized protocol at our Institution.

Methods: A multimodal postoperative pain pathway was developed and implemented throughout a large, academic, pediatric orthopedic division. The pathway utilized opioid and non-opioid pain medications and educational handouts with descriptions of the different classes of pain medication and specific dosing regimens.

A query of electronic medical records was completed to identify all patients under the age of 18 that underwent inpatient orthopedic surgery from January 2016 to June 2018. Based on surgical dissection and anticipated postoperative pain, procedures were grouped into low complexity and high complexity. The average amount of opioids administered to the patients during their stay in the hospital was converted to morphine milligram equivalents (MME). The average MME was plotted, and the trends were analyzed.

Results: 455 inpatients met the inclusion criteria. Opioid pain medication administration was significantly higher in the high-complexity group compared to the low-complexity group. Implementing the multimodal pain pathway significantly reduces opioid administration in both groups without an increase in length of stay.

Conclusion: Implementation of a standardized, post-operative, multimodal pain regimen lead to a significant decrease in the amount of administered narcotics following inpatient orthopedic surgery without an increase in length of stay.

Level of Evidence: IV

Keywords: quality improvement, pain, length of stay, postoperative care, surgery

INTRODUCTION

Pain control following orthopedic surgical procedures is critical for expeditious recovery and accelerated rehabilitation. Therefore, responsible prescribing of controlled substances is equally essential. Ideally, adequate pain control can be achieved with minimal opioid use. However, throughout the literature, the ideal pain management approach in pediatric patients undergoing orthopedic surgery is unknown.[1] Suboptimal pain management in the pediatric population can lead to prolonged hospital stays, delayed mobility, poorly tolerated rehabilitation, low patient satisfaction, and overall poor outcomes.[2,3]

The perception of pain is the product of multiple intricate neurologic pathways. Pediatric pain control has historically focused solely on the mu pathway. However, management strategies utilizing multimodal pain pathways have become increasingly popular. In orthopedic surgery, employing multiple approaches to address post-surgical pain by recruiting multiple receptors through different medications accelerated the recovery process and decreased the need for opioids.[4] In children, it has been shown that nonsteroidal anti-inflammatories (NSAIDs) and acetaminophen are useful adjuvants.[5,6] Acetaminophen is the most common non-opioid analgesic used for pain management in the pediatric population, and intravenous administration has been found to be particularly efficacious.[3,7,8] Multiple studies have demonstrated the efficacy of NSAIDs in managing pediatric pain while demonstrating a low incidence of side effects.[9,10] However, NSAIDs are frequently avoided in fracture patients due to concerns for nonunion. Kay et al. demonstrated successful use of ketorolac with no increase in nonunion rate.[6]

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In addition to pharmacological management, other aspects of patient care, such as divisional protocols and patient/guardian educational tools, can help manage pain. Therefore, this study sought to investigate the effects of implementing a multimodal pain pathway protocol on prescribing habits within a tertiary care academic setting. The hypothesis is that implementing this protocol will lower post-operative prescribed morphine equivalents in our pediatric orthopedic inpatient population.

METHODS

This is a retrospective cohort study at a single, urban, academic healthcare institution. A query of institutional electronic health records was performed identifying 455 patients under 18 years of age who required inpatient, orthopedic pediatric surgery between January 2016 through June 2018. Exclusion criteria included, patients older than 18, patients not operated on by full-time faculty and patients discharged immediately from the post anesthesia care unit (PACU). Patient demographics (age, gender, race, body mass index [BMI], American Society of Anesthesiology [ASA] score, smoking, zip code and insurance type), admission data (surgery type, time of surgery, length of stay [LOS]), and inpatient opioid administration data (medication administration date-time, medication name, strength, dose, route and dose unit) were retrieved. The multimodal pain pathway was implemented on January 1, 2017. Patients operated on before this date comprised our comparison cohort. These patients were subsequently divided into two groups based on procedure type: low and high complexity procedures (Table 1).

Average opioid administration per day per surgical encounter was derived from the inpatient opioid administration record and converted to average morphine milligram equivalence (MME) per day per surgical encounter (MME/day/encounter). Conversions were calculated based on the Center for Disease Control and Prevention (CDC) guidelines, and supplemented with data from the American Pain Society and scientific literature.[11-14]

All data sets were queried using Microsoft SQL Server Management Studio 2017 (Redmond, WA), and imported into Microsoft Power BI (Redmond, WA) for merging, preliminary data modeling and transformation. This data was subsequently exported to MatLab 2018b (Mathworks, Natick, MA) for statistical analysis and data visualization. Descriptive statistics were performed. Continuous variables were calculated using Student's unpaired t-test, while categoricals were calculated using χ^2 tests. A $p < 0.05$ was deemed significant.

Patient/Public Involvement

Patients under 18 years old who underwent inpatient orthopedic surgery were not involved in formulating the research question or determining the outcome measures. However, they actively participated in the execution of the protocol. We aim to disseminate the study's primary findings to these patients and their families.

Table 1. Procedures Were Divided Into High and Low Complexity Procedures for Analysis and Listed Here

• Wrist fusion	• Soft tissue (tendon releases)
• ORIF lower extremity fractures	• Percutaneous fixation (Supracondylar fractures)
• Excision of accessory navicular	• Spica cast application
• Reconstruction foot, clubfoot, triple arthrodesis	• Procedures with no incisions
• Long bone osteotomies (Deformity correction, femoral and pelvic osteotomies)	• Distal radius and elbow fractures
• Excision of bony tumor	• Excision of soft tissue tumor / biopsy
• External fixator lower and upper extremities	• closed reduction of hip
• Arthroplasties lower and upper extremities	• ORIF fingers
• Fasciotomies	• Reconstruction finger
• Arthroscopy hip	• Fusion toe
• Arthroscopy shoulder with labral repair	• Arthroscopy except hip and shoulder with labral repair
• Ankle arthroscopy with OCD microfracture	• Correction of polydactyly foot and hand
• Core decompression hip	• Irrigation and debridement of any extremity
• ACL reconstruction	• Removal of hardware
• Arthroscopic ankle reconstruction	

Table 2. Demographics and Statistical Analysis

	Low Complexity Inpatient Pre-Protocol n=215	Low Complexity Inpatient New Protocol n=51	High Complexity Inpatient Pre-Protocol n=143	High Complexity Inpatient New Protocol n=46
Age	9.01±4.83	8.78±4.26	11.87±4.27	12.35±3.46
Gender				
Female	76 (35.35%)	22 (43.14%)	66 (46.15%)	18 (39.13%)
Male	139 (64.65%)	29 (56.86%)	77 (53.85%)	28 (60.87%)
BMI	4.83±20.09	4.26±21.24	23.12±8.33	23.78±7.69
ASA				
1	96 (44.65%)	24 (47.06%)	41 (28.67%)	14 (30.43%)
2	87 (40.47%)	20 (39.22%)	62 (43.36%)	22 (47.83%)
3	31 (14.42%)	7 (13.73%)	38 (26.57%)	10 (21.74%)
4	1 (0.47%)	0	2 (1.40%)	0
Median	2	2	2	2
Race				
African American (Black)	18 (8.37%)	4 (7.84%)	25 (17.48%)	10 (21.74%)
Asian	26 (12.09%)	6 (11.76%)	17 (11.89%)	2 (4.35%)
Caucasian	110 (51.16%)	25 (49.02%)	49 (34.27%)	17 (36.96%)
Other	61 (28.37%)	16 (31.37%)	52 (36.36%)	17 (36.96%)
Smoking				
Current Smoker	-	-	1 (0.70%)	0
Former Smoker	-	-	1 (0.70%)	0
Never Smoker	143 (66.51%)	35 (68.63%)	118 (82.52%)	38 (82.61%)
Never Assessed	72 (33.49%)	16 (31.37%)	23 (16.08%)	8 (17.39%)
Primary Payor				
Commercial	102 (47.44%)	18 (35.29%)	55 (38.46%)	16 (34.78%)
Medicaid	104 (48.37%)	32 (62.75%)	78 (54.55%)	25 (54.35%)
Child Health Plus	7 (3.26%)	0	1 (2.17%)	2 (1.40%)
Worker's Comp/No Fault	1 (0.47%)	0	1 (2.17%)	0
Other	1 (0.47%)	1 (1.96%)	-	-
Surgical Time	87.30±64.70	104.95±82.11	160.74±83.16	184.41±98.04
Length of Stay (Days)	2.05±3.38	2.33±3.31	2.67±4.14	2.65±2.66
MME/Day/Encounter	8.91±22.50^	3.21±5.66^	27.00±45.84*	12.43±12.64*

Notes the demographic distributions in our population categorized into low and high complexity procedures and statistical analysis of length of stay and MME/Day/Encounter amongst low vs high complexity procedures in the inpatient surgical setting. Average opioid administration for inpatients who underwent a low complexity procedure pre protocol was 8.91 vs 3.21 post protocol and this approached significance ($p = 0.083$)[^ denotes approaching significance]. Opioid consumption for inpatients who underwent a high complexity procedure pre protocol was 27 and 12.43 post protocol and this was statistically significant ($p<0.05$) [*].

RESULTS

455 patients met inclusion criteria, 358 patients were included in the control group and 97 in the experimental group. Complete demographic data is listed in Table 2. Procedures were divided into low and high complexity procedures. Low complexity procedures included soft tissue procedures, percutaneous reductions and most upper extremity surgeries. High complexity procedures included lower extremity fracture reductions, long bone osteotomies, and ACL reconstructions. The complete list of surgeries is listed in Table 1. 266 patients underwent low pain procedures while 189 underwent high pain procedures.

Overall, patients undergoing high complexity procedures received more opioid pain medication than those undergoing low complexity procedures 27.00 versus 8.91 MME/day/encounter, respectively (Table 1). Within the pre protocol group, 215 patients underwent low complexity procedures and 143 underwent high complexity procedure. Average opioid administration for inpatients who underwent a low complexity procedure pre protocol was 8.91 vs 3.21 MME/day/encounter post protocol and this approached significance (p= 0.083), table 2. Opioid consumption for inpatients who underwent a high complexity procedure pre protocol was 27 and 12.43 post protocol and this was statistically significant ($p<0.05$), table 2.

There was no statistical difference amongst patients in the low complexity and high complexity procedures based on demographics, ASA score, race, smoking status, insurance coverage or length of stay.

Additionally, when plotting opioid consumption over the two-year study period in both the high and low complexity procedures a steep decline in MME was noted in 2017, at the time of the implementation of the multimodal pain pathway protocol (Fig 2). Length of stay was not increased following protocol implementation.

DISCUSSION

The term "opioid epidemic" is used by the Center for Disease Control (CDC) to describe the recent rise in opioid-related deaths and over-prescription of narcotic medications. The current epidemic is a national problem where there is an increasing concern for pediatric orthopedic patients.[15] This received heightened attention after the publication reported opioid-related deaths as the second leading cause of accidental deaths in the US. Also noted was a 400% increase in admissions to substance abuse treatment between 1998-2008, with prescription analgesics being the second most prevalent type of abused medication after marijuana. These increases occurred when there was a tenfold increase in the medical use of opioids.[16] Since there has been a flurry of publications and legal proceedings related to opioid administration, this recent awareness led the FDA to create new guidelines for pharmaceuticals producing medication and physicians prescribing them. Even though they are appropriately prescribed, unconsumed opioids have become the gateway for the progression of opioid use disorders, primarily in the adolescent population.[17] While adequate pain control in the postoperative period is essential and often requires the administration of opioid pain medications, so too is the responsible and knowledgeable prescription of these medications. Despite efforts to minimize opioid mistreatment, little is known regarding the development of continuous opioid use following surgery among pediatric patients.[18]

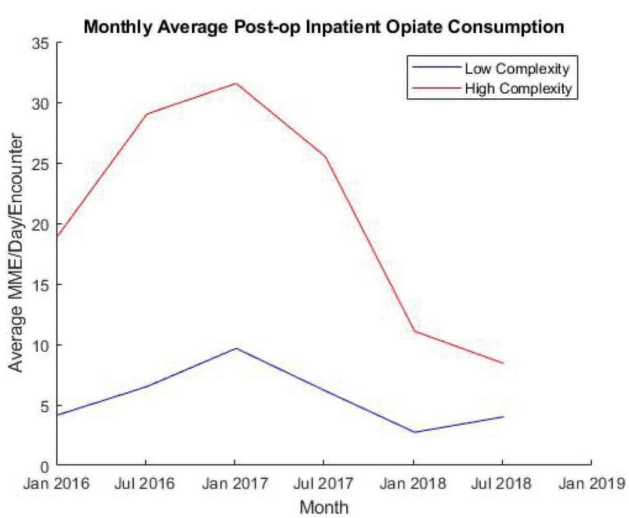

Figure 1. Demonstrates the trend of all inpatient's postoperative opioid consumption over a 2-year period in both the high and low complexity procedures. At the time of the implementation of the opioid sparing protocol in 2017 there was a steep decline.

This study sought to understand the impact of a standardized multimodal pain protocol on inpatient administration in a large healthcare center following pediatric orthopedic surgery implemented in 2017. Results demonstrated that adopting such a protocol can lead to significant reductions in the amount of administered opioid pain medication in the inpatient setting without an increase in length of stay. This was true for both high and low-complexity procedures.

While opioid administration was significantly reduced, opioids were not excluded from the protocol. Instead, a multimodal pain protocol including opioid and other non-opioids analgesic was designed to encourage thoughtful and responsible use of all post-operative analgesics. In addition, while direct patient-reported outcomes were not included in the present study, length of stay was used as a surrogate for pain control as poor pain control can lead to an increase in the length of stay of post-surgical patients.[4]

The length of stay was not increased following protocol implementation. In addition, educational handouts were created for caregivers detailing each medication and the appropriate dosing regimens to increase their knowledge and comfort with the prescribed medications. Multimodal pain pathways have demonstrated efficacy following adult surgery; however, literature is lacking within pediatric literature. Shah et al. reported on post-operative opioid use after inpatient supracondylar fractures treatment. They demonstrated surplus use of opioids in this population and stressed the importance of minimizing opioid use to safely monitor for complications, including compartment syndrome.[19] Rosenburg et al. showed that the addition of ketorolac or gamma aminobutyric acid analogues following pediatric spine surgery lead to less intravenous opioid exposure.[20] Eberson et al. demonstrated that patients who received ketorolac following foot or long bone osteotomies had less opioid consumption, fewer opioid-related gastrointestinal complications, and shorter length of stay.[21]

Significant limitations should be noted. Firstly, the current study did not include patient-reported outcomes and pain scores. Length of stay was used as a marker for adequate pain control. However, validated pain and outcome measures would be beneficial in further elucidating the impact of the protocol. In addition, the type of anesthesia administered during the operative procedure was not included. Regional anesthesia could significantly reduce post-operative pain. In addition, this is a retrospective study with inherent limitations associated with this type of study. Despite the limitations, the current study provides evidence that standardized, multimodal, post-operative pain protocols can significantly decrease administered opioid medications. Furthermore, implementing multimodal analgesia methods can decrease hospital costs and improve patient satisfaction and outcomes.[4]

Future studies should include prospective, randomized analysis with patient-recorded outcomes. The impact on outpatient pain consumption should also be investigated.

Implementing a standardized, multimodal, post-operative pain protocol led to significant reductions in inpatient administration of opioid medication following both high-pain and low-pain procedures. In addition, the length of stay was not affected by protocol implementation.

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DO PERCUTANEOUSLY APPLIED MEDIAL PROXIMAL TIBIA PLATES NEED TO GO BENEATH THE PES TENDONS?

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ABSTRACT

Background: Bicondylar tibial plateau fractures are often associated with significant soft tissue compromise making operative treatment challenging. Dual plating through a two-incision approach following temporary external fixation has been shown to improve complication rates although deep infection rates remain high.

The objective was to evaluate early outcomes following a novel technique of percutaneous application of the medial plate superficial to the pes anserinus tendons. Indications for a percutaneous medial plate included local soft tissue conditions, lack of or minimal involvement of medial articular surface with no displaced fragment requiring a posteromedial plate.

Methods: A retrospective chart review at a Level 1 Trauma Center identified twenty-four bicondylar tibial plateaus that were treated from 2015-2017 with standard lateral plate fixation and a medial plate that was percutaneously applied. Fractures were classified according to the AO/OTA classification. Demographic, injury characteristics, and co-morbidities were collected. The primary outcome was presence of a deep infection post-operatively. Secondary outcomes included secondary procedures, range of motion, and maintained radiographic alignment.

Results: The pre-dominant fracture pattern was AO/OTA 41-C3 (75%). The percutaneous medial plate was applied first (71%). The average follow-up was 427 days. Ninety-five percent achieved at least 90 degrees of flexion. All had satisfactory coronal alignment (≤5 degrees) and condylar width (<5mm). Satisfactory articular reductions (≤2mm) were noted in 76% and satisfactory sagittal alignment (≤5 degrees) in 94%. One patient had persistent wound drainage and underwent hardware removal after union. Another patient is pending hardware removal with concerns for deep infection five years post-surgery.

Conclusion: Early results demonstrate that it is safe to place the medial proximal tibia plate above the pes anserinus tendons percutaneously for select fracture patterns with maintained alignment and reduction. This technique may help to minimize deep infection rates.

Level of Evidence: IV

Keywords: trauma, tibial plateau, percutaneous

INTRODUCTION

Bicondylar tibial plateau fractures are often associated with significant soft tissue compromise making operative treatment challenging.[1-5] Treatment requires restoring the articular surface while also correcting alignment with options include dual plating, single lateral locking plate fixation, tensioned-wire fixation, and hybrid external fixation. Regardless of definitive fixation, significant complications are still reported. Historically, a single midline incision was used for dual plating. However, this was found to have unacceptably high deep infections and wound complications (73-87%).[6] Dual plating through a two-incision approach following temporary external fixation has been shown to improve complication rates although a recent study still demonstrated a 23.6% rate of deep infection.[2-5]

A single lateral locking plate has also been suggested as an alternative thus decreasing the need for a medial incision.[7] One biomechanical and clinical study reported good results with low rates of complications at lower loads of cyclic loading.[6,7] However, another biomechanical study demonstrated higher subsidence of the fracture fragments with a single lateral fixed-angle construct in comparison to dual plating.[8] Clinical data also reaffirms a concern for postoperative malalignment with one series reporting 30% malalignment including 8% varus malalignment.[9]

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We aim to describe a technique of dual plating for certain bicondylar fracture patterns using conventional open reduction and fixation of the lateral tibial plateau and a percutaneous plate application to the medial proximal tibia overlying the pes anserine tendons. This minimizes the soft tissue stripping on the medial proximal tibia while providing a medial buttress to help prevent postoperative malalignment. The goal of this study is to determine the complication rate following this novel technique and compare it to historic data with a standard two-incision approach. We hypothesize that the wound complication rates will be lower with this percutaneous technique with no compromise in alignment.

METHODS

An IRB-approved retrospective chart review was performed at a Level 1 Trauma Center. We identified 135 bicondylar tibial plateau fractures that were treated from 2015-2017 by two senior fellowship trained orthopaedic traumatologists. Twenty-four patients were treated with dual plating involving a standard lateral plate and a percutaneously applied medial plate. The indication for a percutaneous medial plate was under the discretion of the senior surgeon. Factors considered in this decision included local soft tissue conditions and pre-operative advanced imaging (lack of or minimal involvement of the medial plateau articular surface and no displaced posteromedial fragment requiring a posteromedial buttress plate).

All data was abstracted from the electronic medical record, operative notes, clinic visit notes, and radiographs. Patient demographics, injury characteristics, and co-morbidities were collected. Treatment variables including external fixation, timing of surgery, and compartment syndrome was recorded. Fractures were further classified according to the AO/OTA classification. The primary outcome was presence of a deep infection post-operatively within 90 days as defined by the Center for Disease Control (CDC) criteria. Secondary outcomes included range of motion and radiographic alignment in patients with a minimum of 90 days follow-up. Any secondary procedures including hardware removal were noted for patients with at least six months of follow-up.

Traveling traction external fixation or a femoral distractor was applied at the discretion of the treating surgeon. Percutaneous fixation of the medial column was typically performed first. (Figure 1). The patient is in the supine position and the injured lower extremity is allowed to externally rotate. The medial plate is localized under fluoroscopy in both the AP and lateral planes and a two centimeter longitudinal incision is made proximally. The plate is then slid distally in a subcutaneous fashion above the pes anserinus tendons and fascia. A cortical screw is placed distal to the fracture line through a percutaneous incision to buttress the fracture. A short screw is placed proximally to maintain alignment while not blocking any reduction required in the lateral condyle. An anterolateral approach is then made and standard reduction and fixation is performed. The remaining medial screws and shaft screws are then placed percutaneously (Figure 2).

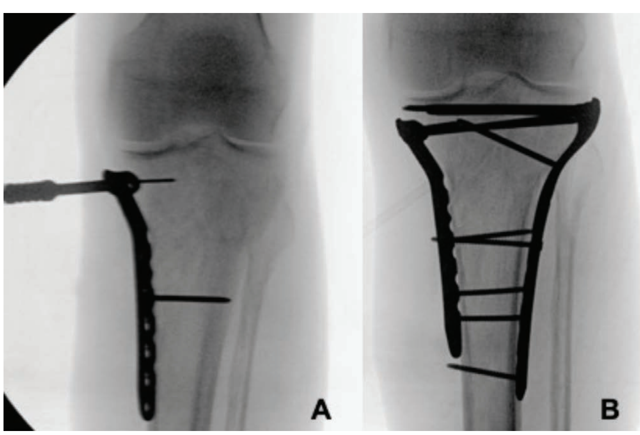

Figure 1A to 1B. (1A) Percutaneous fixation of the medial column is performed first. Plate is localized under fluoroscopy and 2 cm made proximally and then plate is slid in subcutaneous fashion. Cortical screw placed distal to fracture line and then short screw placed proximally. (1B) Standard reduction and fixation of lateral side. Remaining fixation medially is then placed.

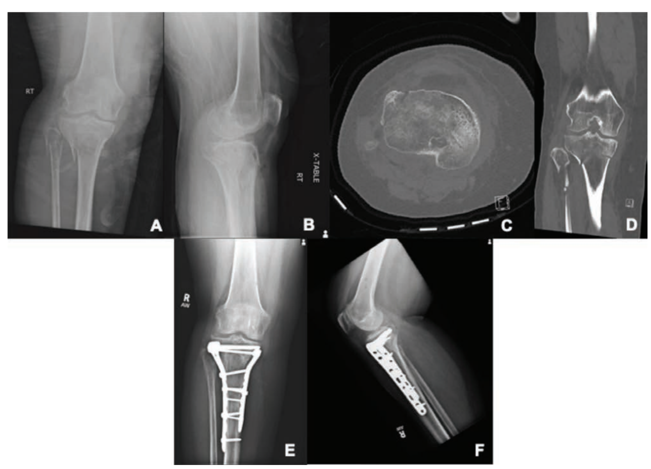

Figure 2A to 2F. (2A and 2B) 56 y/o female s/p motor vehicle collision with right bicondylar tibial plateau fracture. Plain radiograph injury films noted. (2C and 2D) No involvement of medial articular surface and no posteromedial fracture line identified on advanced imaging. (2E and 2F) Percutaneous medial plate placed and standard lateral fixation. Final plain radiographs demonstrated united fracture with excellent alignment.

RESULTS

Twenty-four patients with a mean age of 46 years (range, 26-64) were included in the study. There were fourteen male and 10 female patients. Mechanisms of injury included motorcycle/motor vehicle collision (n=12), fall from height (n=7), and low-energy fall (n=5). There was one open fracture. The pre-dominant fracture pattern was AO/OTA 41-C3 (75%). The average follow-up was 427 days. Nineteen patients (79%) of patients had at least 90 days of follow-up.

Seventeen patients were treated initially with an external fixator with definitive surgery taking on average 11.6 days later (range, 4-25 days). One patient required fasciotomies for compartment syndrome prior to definitive fixation. The percutaneous medial plate was applied prior to lateral plate insertion in 17 patients (71%). A pre-contoured 3.5 mm medial proximal tibia plate was used in all, but one patient.

Ninety-five percent (18/19 patients) had achieved at least ninety degrees of knee flexion at their last follow-up visit. Seventy-six percent of patients demonstrated satisfactory medial/lateral articular reductions (articular step or gap ≤2mm), all demonstrated satisfactory coronal alignment (medial proximal tibial angle of 87 ±5 degrees), 94% demonstrated satisfactory sagittal alignment (posterior proximal tibial angle of 9 ±5 degrees, and all demonstrated satisfactory condylar width (<5mm). Records were reviewed for patients requesting hardware removal due to medial soft tissue irritation or pes anserine irritation/bursitis. Of the 24 patients, none had clinical documentation of this in the retrospective record. One patient was noted to have chronic drainage that was initially treated with chronic suppressive antibiotics, but then subsequently underwent hardware removal at 16 months after union. Another patient who had fasciotomies and skin grafting after their initial injury developed drainage five years after their definitive surgery with concern for a deep infection and is pending hardware removal.

DISCUSSION

The high complication rates that are reported following open reduction internal fixation of bicondylar tibial plateau fractures with dual plating using a single mid-line incision has led surgeons to consider other treatment options. Limited articular internal fixation combined with external fixation decreases the rate of deep infections, but limits early joint motion. There are concerns with postoperative malalignment with a single lateral plate. Therefore, a dual-incision technique with an anterolateral and posteromedial approach is typically the standard of care. However, complication rates remain high, approaching 25% following high-energy mechanisms.[4-5] Therefore, we suggest that in some fracture patterns, percutaneous medial plate insertion may help minimize infectious complications.

Horwitz and colleagues in a biomechanical study demonstrated that in comparison to dual plating, single lateral buttress plating had significantly larger medial plateau subsidence with axial loading.[10] However, this was study was performed with a nonlocking plate. Fixed angle plates provided an opportunity for a more rigid construction with the potential to avoid further soft tissue dissection. Multiple biomechanical studies have not found any difference between subsidence with the use of the Less Invasive Stabilization System (LISS, Synthes) plate in comparison to dual plating.[11,12] On the other hand, Higgins et al. demonstrated in a biomechanical study that a fixed-angle plate did allow for significantly greater subsidence compared to dual plating.[9] A clinical study demonstrated that unilateral locked plating demonstrated significant malreduction in 24% of the patients and loss of reduction in 13%.[13]

This raises concerns with isolated lateral locked plating for bicondylar tibial plateau fractures and subsequent varus malalignment. Thus, the possibility for a less invasive application of a medial buttress plate could help prevent varus collapse while minimizing soft tissue complications associated with standard dual plating. Mashru et al. described a minimally invasive application of a medial distal tibia plate to the medial condyle.[14] Furthermore, this technique required dissection to elevate the pes anserinus to place the plate directly onto bone and thus was not truly percutaneous. In comparison, our technique requires little dissection and thus further minimizes any soft tissue compromise on the medial side. Over 90% of our patients achieved 90 degrees of flexion at twelve weeks and no patients required their hardware to be removed during our follow-up period. There were no deep infections noted.

In carefully selected patients, we feel that the percutaneous application of a medial buttress plate adds minimal additional surgical morbidity and little surgical time with the benefit of added stability to help prevent varus malalignment and medial fracture subsidence. This technique may not be appropriate with certain fracture patterns including those with a displaced posteromedial fragment that requires an open reduction and posteromedial buttress plate.

The limitations of this study include its retrospective design, small number of cases (n=24), short mean follow-up, and lack of comparative group. Furthermore, there was no need for any subsequent procedures for prominent hardware during early follow-up. Larger studies with longer follow-up are required to determine the true impact of percutaneous plating over the pes anserinus tendons as well as specific indications were percutaneous medial plating is acceptable.

In summary, this small series demonstrates initial successful percutaneous insertion of medial proximal tibia plates above the pes anserinus tendons for select bicondylar tibial plateau fractures. This dual plating technique allows for less soft tissue trauma and the ability to help prevent varus malalignment and medial fracture subsidence.

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EFFICACY OF INTRAOPERATIVE CELL SALVAGE ON PERIOPERATIVE BLOOD TRANSFUSION IN PELVIC AND ACETABULAR SURGERY: A MATCHED COHORT ANALYSIS

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ABSTRACT

Background: Pelvic fractures often result in traumatic and intraoperative blood loss. Cell salvage (CS) is a tool where autologous blood lost during surgery is collected and recycled with anticoagulation, centrifugation to separate red blood cells, and washing to be reinfused back to the patient. The purpose of this study was to investigate our experience with CS in pelvic and acetabular surgery and its relationship to perioperative transfusion requirements.

Methods: After institutional review board approval, adult patients who underwent pelvic ring or acetabular open reduction internal fixation between 01/2014-11/2021 at a tertiary care level-one trauma center were retrospectively reviewed. Perioperative outcomes including pre-/post-operative hemoglobin and hematocrit, estimated blood loss, use of CS, and perioperative blood transfusions were collected. Pooled two-sample t-tests were used to compare parametric populations while Fischer's exact test or Pearson's Chi squared test were used for nonparametric data.

Results: 402 patients were included (85 in the CS group and 317 in the non-CS group). Patients had a higher proportion of acetabular fractures. The use of CS was associated with longer operative time (366 mins vs. 269 mins, $p<0.0001$), EBL (911 mL vs. 473 mL, $p<0.0001$), and allogenic transfusion of RBC units intraoperatively (1.75 u vs. 1.28 u, $p=0.0442$) and postoperatively (1.38 u vs. 0.66 u, $p<0.0012$).

Conclusion: The use of CS was associated with higher total and postoperative allogenic units transfused. Future prospective randomized trials would help to further delineate the risks and benefits of CS utilization in surgical treatment of these fractures.

Level of Evidence: III

Keywords: cell salvage, transfusions, pelvis, acetabulum

INTRODUCTION

Pelvic and acetabular fractures often result in significant traumatic and intraoperative blood loss.[1] These patients are often polytraumatized and require frequent perioperative allogenic transfusion of blood or blood products. Administration of allogenic blood transfusions, particularly repeated transfusions, is not benign and is associated with known complications. Recipients of blood transfusions are at risk for surgical site infections, blood borne infections, and transfusion-related acute lung injury (TRALI).[2-5] Increased rates of surgical site infections after transfusion has been well documented in orthopaedic trauma,[6-8] joint arthroplasty,[9-11] and spine surgery.[12,13] The same risks of surgical site infection after transfusion during operative treatment of acetabular fractures has also been reported.[14,15] Allogenic blood product transfusion has also been shown to be an independent predictor of mortality in trauma patients, even after controlling for the shock severity.[16]

Cell salvage (CS) is an intraoperative tool where autologous blood lost during surgery is collected and recycled with anticoagulation, centrifugation to separate red blood cells, and washing to be reinfused back to the patient (17). Several studies demonstrating strategies for blood salvage techniques have been implemented in many subspecialties,[17] including cardiovascular,[18,19] vascular,[20,21] spine, and revision arthroplasty surgeries. While indicated for surgeries where large amount of blood loss is anticipated, routine use in orthopaedics has been limited to spine[22,23] and revision arthroplasty.[16] Few studies to date have investigated the routine use of CS in pelvic and acetabular surgery, and results have been inconclusive.[24] The purpose of this study was to investigate our institutional experience with CS in pelvic and acetabular surgery and whether there was a decrease in perioperative allogenic blood transfusion requirements.

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METHODS

Institutional Review Board Approval was obtained. Adult patients who underwent pelvic ring or acetabular fracture open reduction and internal fixation from January 2014 to November 2021 at a tertiary care level-one trauma center were retrospectively reviewed. Pelvic and acetabular fractures managed with external fixation, INFIX, or percutaneous screw fixation only were excluded as cell salvage was routinely not utilized and blood loss was typically low. In addition, bilateral acetabular fractures were excluded.

Patient demographics including age, gender, body mass index (BMI) were collected. Fractures were classified into the Letournel, Young Burgess, and Tile classifications for acetabular and pelvic fractures, respectively. Patients were further stratified by surgical approach and American Society of Anesthesiology (ASA) scores. Anterior approach commonly referred to an anterior intrapelvic (AIP) approach and posterior commonly referred to a Kocher-Langenbeck approach. Perioperative outcomes including length of stay, pre-/post-operative hemoglobin and hematocrit, OR time, estimated blood loss, use of CS, use of tranexamic acid (TXA), and perioperative allogenic blood transfusions were also collected. The use of CS and the CS volume transfused were recorded separately and were not part of the allogenic or total blood transfusion metrics. The pre-operative hemoglobin/hematocrit was the final lab value obtained before surgery. Conversely, the post-operative hemoglobin/hematocrit was the first lab value obtained immediately after surgery. The decision to transfuse blood products was shared between the anesthesia and surgical team intraoperatively and by the primary team postoperatively. In general, prophylactic anticoagulation, which typically consisted of unfractionated heparin or low molecular weight heparin (LMWH), was held before all cases.

To further stratify utilization of CS, matched comparisons were performed across Letournel patterns (Elementary vs. Associated) and surgical approach. A matched cohort sub-analysis by number of IV TXA doses was performed to minimize the confounding effects of TXA administration in reducing EBL. Pooled two-sample t-tests were used to compare parametric populations while Fischer's exact test or Pearson's Chi squared test were used for nonparametric data. Significance was defined as $p < 0.05$. Statistical analysis was performed in JMP Pro 16 (Cary, NC).

RESULTS

A total of 639 patients with pelvic ring or acetabulum fractures managed operatively were identified. After exclusion criteria were applied, 402 patients (283 male, 119 female) with age at time of injury ranging from 15 to 92 years were included for analysis. 85 patients were included in the CS group, while 317 did not receive any perioperative CS (Table 1). There were no significant differences in the sex, length of stay, time to OR, body mass index, or ASA class between the groups (Table 1). CS patients were slightly older at 44.8 years vs. 40.2 years (p=0.0268). There were a significantly higher proportion of acetabular fractures in the CS group vs. the non-CS group (78% vs. 57%, p=0.0001). There was a significantly higher proportion of associated acetabular fractures, particularly both column injuries, in the CS group (Table 2). No significant differences were found between the

Table 1. Baseline Cohort Characteristics

	Cell Saver	No Cell Saver	p-value
Number	85	317	
Age (years)	44.8	40.2	0.0268
Sex (M:F)	57:28	226:91	0.397 (Pearson)
LOS (days)	21.4	19.7	0.5831
Time to OR (days)	5.34	4.76	0.4136
BMI (kg/m2)	29.88	29.98	0.9535
ASA Class	2.44	2.39	0.6858
Injury Subtype			
Pelvic Injury (P)	6	106	0.0001 (Fischer's)
Acetabular Fracture (A)	67	183	
Both Injured (P & A)	12	28	

Table 2. Acetabular Fracture Classifications

	Cell Saver	No Cell Saver	p-value
Letournel Classification			
Anterior Column	1	2	<0.0001
Anterior Wall	0	1	
Posterior Column	2	0	
Posterior Wall	8	84	
Transverse	3	5	
T-Type	8	10	
Transverse and Posterior Wall	16	38	
Posterior Column and Posterior Wall	6	18	
Anterior and Posterior Hemi-transverse	7	13	
Both Column	28	38	
Associated	65	115	<0.0001
Elementary	14	92	

groups in pelvic ring fracture subtype classification using Young Burgess and Tile classification systems. The use of CS was associated with longer operative time (366 min vs. 269 mins, p<0.0001) and higher EBL (911 mL vs. 473 mL, p<0.0001) (Table 3). The rate of intraoperative (52.4% vs. 31.9%, p=0.0005) and postoperative (36.9% vs. 17.7%, p=0.0001) transfusion was higher in CS patients (Table 3). CS patients also had higher total (2.653 U vs. 1.672 U, p=0.0010), intraoperative (1.747 U vs. 1.275 U, p=0.0442), and postoperative (1.375 U vs 0.666 U, p=0.0012) units transfused (Table 3). A larger proportion of CS patients underwent combined approaches for fracture fixation (8.2% vs. 1.5%, p=0.0089). There were no differences in the mean number of IV TXA doses administered (Table 3).

Matched cohorts analysis for elementary and associated fracture patterns, surgical approaches, and doses of IV TXA administered did not reveal any significant differences between cohort characteristics. In elementary fracture patterns, the use of CS was associated with a smaller decrease in Hgb and Hct (Supplemental Table 1), though this did not translate to any differences in the transfusion rate or transfusion requirement. In associated acetabular fracture patterns and anterior approaches, CS patients had higher overall perioperative transfusion requirements and transfusion rates (Supplemental Tables 2 and 3). Postoperative transfusion rate was higher in CS patients undergoing posterior approach surgeries, while intraoperative transfusion rate was higher in CS patients undergoing combined approaches when compared with non-CS patients. No significant differences were found in number of units transfused to patients undergoing posterior or combined approaches (Supplemental Table 4 and 5). Even when eliminating the effect of IV TXA administration, CS patients maintained higher transfusion rate and units transfused. With one dose of IV TXA, CS patients had a smaller decrease in Hgb and Hct postoperatively. However, these patients received transfusion at a higher rate. No differences were found between CS and non-CS groups when two doses of IV TXA were administered (Supplemental Table 6). More patients in the CS group underwent a second stage surgery (20/85 vs. 21/335, p<0.0001) (Supplemental Table 7).

Table 3. Intraoperative Cohort Variables

	Cell Saver	No Cell Saver	p-value
OR Time (min)	366	269	<0.0001
EBL (mL)	911	473	<0.0001
Preoperative Hgb	10.02	10.73	0.0076
Preoperative Hct	30.29	32.66	0.0021
Postoperative Hgb	9.71	9.86	0.4353
Postoperative Hct	29.04	29.85	0.1711
ΔHgb	-0.294	-0.857	0.0117
ΔHct	-1.253	-2.80	0.0136
Intraoperative CS (mL)	344.42	0	<0.0001
Total Transfusion (U)	2.653	1.672	0.0010
Intraoperative Transfusion (U)	1.747	1.275	0.0442
Intraoperative Transfusion Rate	52.4%	31.9%	0.0005
Postoperative Transfusion (U)	1.375	0.666	0.0012
Postoperative Transfusion Rate	36.9%	17.7%	0.0001
Surgical Approach			
Anterior	40	147	0.0089 (Fisher's)
Posterior	38	165	
Combined	7	5	
Doses TXA Administered			
0	32	149	0.4586 (Fischer's)
1	38	123	
2	15	42	
>2	0	3	

Hgb – Hemoglobin, Hct – Hematocrit, TXA - Tranexamic acid.

Supplemental Table 1. Matched Cohorts Analysis – Elementary Acetabular Fracture Patterns

	Cell Saver	No Cell Saver	p-value
Number	14	92	
OR Time (min)	299	270	0.2792
EBL (mL)	664	451	0.0387
Preoperative Hgb	10.94	11.96	0.1159
Preoperative Hct	33.5	36.44	0.1310
Postoperative Hgb	10.41	10.46	0.9187
Postoperative Hct	31.46	31.65	0.8942
ΔHgb	-0.53	-1.51	0.0427
ΔHct	-2.06	-4.81	0.0466
Intraoperative CS (mL)	232	0	<0.0001
Total Transfusion (U)	1.18	1.28	0.8688
Intraoperative Transfusion (U)	0.9	1.0	0.8513
Intraoperative Transfusion Rate	21.4%	28.3%	0.5932
Postoperative Transfusion (U)	0.50	0.42	0.8480
Postoperative Transfusion Rate	28.6%	14.1%	0.1701

Hgb – Hemoglobin, Hct – Hematocrit.

Supplemental Table 2. Matched Cohorts Analysis – Associated Acetabular Fracture Patterns

	Cell Saver	No Cell Saver	p-value
Number	65	115	
OR Time (min)	382	287	<0.0001
EBL (mL)	960	627	0.0002
Preoperative Hgb	9.93	10.45	0.0791
Preoperative Hct	29.89	31.88	0.0246
Postoperative Hgb	9.63	9.62	0.9587
Postoperative Hct	28.71	29.22	0.4967
ΔHgb	-0.27	-0.81	0.0596
ΔHct	-1.18	-2.65	0.0713
Intraoperative CS (mL)	375	0	<0.0001
Total Transfusion (U)	2.98	2.00	0.0214
Intraoperative Transfusion (U)	1.97	1.49	0.1270
Intraoperative Transfusion Rate	56.3%	34.8%	0.0054
Postoperative Transfusion (U)	1.56	0.87	0.0388
Postoperative Transfusion Rate	36.0%	13.9%	0.0006

Hgb – Hemoglobin, Hct – Hematocrit.

Supplemental Table 3. Matched Cohorts Analysis – Anterior Approach

	Cell Saver	No Cell Saver	p-value
Number	40	147	
OR Time (min)	395.5	257.4	<0.0001
EBL (mL)	1021.4	455	<0.0001
Preoperative Hgb	9.45	10.03	0.0976
Preoperative Hct	28.49	30.56	0.0308
Postoperative Hgb	9.43	9.57	0.5548
Postoperative Hct	28.05	28.89	0.2483
ΔHgb	-0.04	-0.44	0.1787
ΔHct	-0.45	-1.61	0.1918
Intraoperative CS (mL)	408	0	<0.0001
Total Transfusion (U)	3.19	1.84	0.0030
Intraoperative Transfusion (U)	2.04	1.45	0.0986
Intraoperative Transfusion Rate	57.5%	35.4%	0.0114
Postoperative Transfusion (U)	1.75	0.68	0.0004
Postoperative Transfusion Rate	40.00%	21.77%	0.0193

Hgb – Hemoglobin, Hct – Hematocrit.

Supplemental Table 4. Matched Cohorts Analysis – Posterior Approach

	Cell Saver	No Cell Saver	p-value
Number	38	165	
OR Time (min)	332.2	274.12	0.0008
EBL (mL)	799	490	<0.0001
Preoperative Hgb	10.64	11.36	0.0661
Preoperative Hct	32.29	34.58	0.0525
Postoperative Hgb	9.98	10.12	0.6615
Postoperative Hct	30.05	30.73	0.4857
ΔHgb	-0.65	-1.23	0.0659
ΔHct	-2.25	-3.90	0.0703
Intraoperative CS (mL)	283	0	<0.0001
Total Transfusion (U)	2.2	1.43	0.0527
Intraoperative Transfusion (U)	1.43	1.02	0.1961
Intraoperative Transfusion Rate	42.11%	29.7%	0.1394
Postoperative Transfusion (U)	1.04	0.62	0.2150
Postoperative Transfusion Rate	34.21%	13.94%	0.0032

Hgb – Hemoglobin, Hct – Hematocrit.

Supplemental Table 5. Matched Cohorts Analysis – Combined Approach

	Cell Saver	No Cell Saver	p-value
Number	7	5	
OR Time (min)	378	423.8	0.3772
EBL (mL)	893	440	0.1179
Preoperative Hgb	9.8	10.34	0.6795
Preoperative Hct	29.63	31.02	0.7293
Postoperative Hgb	9.81	9.68	0.8433
Postoperative Hct	29.21	29.12	0.9603
ΔHgb	0.014	-0.66	0.5912
ΔHct	-0.414	-1.90	0.6762
Intraoperative CS (mL)	315.07	0	<0.0001
Total Transfusion (U)	1.67	3.67	0.2402
Intraoperative Transfusion (U)	1.60	4.00	0.1134
Intraoperative Transfusion Rate	83.33%	0%	0.0057
Postoperative Transfusion (U)	0.667	1.50	0.2394
Postoperative Transfusion Rate	33.33%	20%	0.6210

Hgb – Hemoglobin, Hct – Hematocrit.

Supplemental Table 6. Matched Cohorts Analysis – Effect of Tranexamic Acid

	Doses TXA = 0			Doses TXA = 1			Doses TXA = 2		
	Cell Saver	No Cell Saver	p-value	Cell Saver	No Cell Saver	p-value	Cell Saver	No Cell Saver	p-value
Number	32	149		38	123		15	42	
OR Time (min)	328	242.5	<0.0001	399	290	<0.0001	359	295	0.0325
EBL (mL)	970	396.56	<0.0001	929	569	0.0004	742	464	0.0154
Preoperative Hgb	9.97	10.68	0.0894	9.98	10.65	0.1149	10.17	11.06	0.1552
Preoperative Hct	30.00	32.34	0.0540	30.12	32.60	0.0392	31.32	33.82	0.1644
Postoperative Hgb	9.57	9.81	0.4498	9.87	9.84	0.9166	9.57	10.15	0.2321
Postoperative Hct	28.59	29.71	0.2299	29.35	29.75	0.6641	29.2	30.79	0.2604
*Δ*Hgb	-0.36	0.85	0.2008	-0.12	-0.82	0.0347	-0.60	-0.92	0.4943
*Δ*Hct	-1.41	-2.58	0.2724	-0.78	-2.88	0.0203	-2.12	-3.02	0.4947
Intraoperative CS (mL)	342.8	0	<0.0001	364.8	0	<0.0001	296.3	0	<0.0001
Total Transfusion (U)	2.29	1.41	0.0238	2.99	2.10	0.1020	2.82	1.63	0.1737
Intraoperative Transfusion (U)	1.34	1.13	0.5134	2.07	1.57	0.1972	2.13	1.2	0.1896
Intraoperative Transfusion Rate	56.25%	32.9%	0.0130	51.35%	31.7%	0.0293	46.67%	28.6%	0.2019
Postoperative Transfusion (U)	1.03	0.39	0.0023	1.78	1.10	0.1300	1.75	1.00	0.4654
Postoperative Transfusion Rate	40.63%	18.8%	0.0074	40.54%	16.3%	0.0017	20%	16.7%	0.7708

Hgb – Hemoglobin, Hct – Hematocrit, TXA - Tranexamic acid.

Supplemental Table 7. Second (Staged) ORIF

	Cell Saver	No Cell Saver	p-value
Second ORIF	20/85 (23.53%)	21/335 (6.62%)	<0.0001
OR Time (min)	285	328	0.2873
EBL (mL)	677	658	0.9190
Preoperative Hgb	8.95	9.51	0.1831
Preoperative Hct	27.16	29.37	0.0725
Postoperative Hgb	8.49	9.49	0.0297
Postoperative Hct	25.70	29.05	0.0152
*Δ*Hgb	-0.46	-0.035	0.3316
*Δ*Hct	-1.465	-0.448	0.3858
Cell Salvage Use	7/20 (33.33%)	5/21 (23.81%)	0.5055 (Fischer's)
Total Transfusion (U)	1.53	1.95	0.4530
Intraoperative Transfusion (U)	1.53	2.10	0.3272
Postoperative Transfusion (U)	0.68	0.65	0.9072
Surgical Approach			
Anterior	9	9	1.0000 (Fischer's)
Posterior	9	10	
Combined	2	2	
Doses TXA Administered			
0	11	10	0.0266 (Fischer's)
1	3	10	
2	6	1	

Hgb – Hemoglobin, Hct – Hematocrit, TXA - Tranexamic acid.

DISCUSSION

Pelvic and acetabular fractures are significant injuries, often occurring in the setting of polytrauma. Acute management of these fractures often requires critical measures to stabilize patients by halting ongoing hemorrhage and administering resuscitative fluids and blood products. During surgical treatment, utilization of intraoperative cell salvage techniques (CS) is an option to minimize blood loss by recycling and transfusing autologous blood in favor of allogenic transfusion. As previous studies have demonstrated, allogenic blood transfusion is an identifiable risk factor for postoperative infection and mortality.[2,16] To our knowledge, this is the largest study, comprising 402 patients, investigating the effects of CS on perioperative transfusion in pelvic and acetabular surgeries. The data presented demonstrates no clear intra-operative or post-operative benefit of CS utilization in limiting allogenic transfusion requirements, even after matching for potential confounding factors such as surgical approach, doses of IV TXA, and fracture patterns.

While better studied in other orthopaedic subspecialties, routine usage of CS in pelvic and acetabular surgery is not conclusive and is continuously debated in the literature. In a similar retrospective study, Scannell et al. analyzed 186 patients with acetabular fractures and found that the utilization of cell salvage did not affect allogenic transfusion rates.[25] Similar results have been found in more recent studies by Firoozabadi et al.[26] and Jawad et al.[27] However, Firoozabadi et al. did find that CS may be useful in specifically fractures requiring an anterior approach, which often has more intraoperative blood. Our findings were consistent with those of Jawad et al. as we found no benefit of CS even when controlling for different surgical approaches. In anterior approaches, CS continued to demonstrate higher transfusions rates and units transfused.

Contrasting studies have recommend routine use of CS in pelvic and acetabular fracture surgery. Bigsby et al. found that CS was cost effective during surgical treatment of associated acetabular fracture patterns in 80 consecutive patients.[28] In a retrospective study, Odak et al. showed that the expected post-operative hemoglobin decrease was lower due to intraoperative cell salvage use, and that overall fewer blood transfusions were required.[29]

While our cohort had largely similar demographics and baseline characteristics including fracture patterns, the proportion of acetabular fractures and fractures requiring staged surgery were significantly higher in the CS group (Table 1, Table 3). We postulate that the CS group may be comprised of more medically and surgically complicated, polytraumatized patients. We considered using a metric to gauge the severity of injury, such as the injury severity score (ISS). However, the ISS, which approximates the overall severity of trauma, does not adequately represent multiple injuries to the same anatomic region, and therefore was not helpful. The increased complexity of these cases may have led to a higher overall perioperative transfusion requirement that was not sufficiently compensated by the use of CS. On average, 344 cc of autologous blood was transfused via CS intraoperatively. This corresponds to roughly 1 unit of PRBCs. Volume of CS transfused intraoperatively was separately tabulated from allogenic blood transfusions. Matched cohort analysis attempted to reduce the number of confounding factors in our comparisons. This sub-analysis corroborated no clear benefit of CS even when patients were matched based on associated fracture patterns, anterior approach, and zero doses of IV TXA. Elementary fracture patterns and one dose of IV TXA did demonstrate a lower change in Hgb and Hct, but there was no difference in the transfusion rate or requirement. Similarly, in a randomized control study of 47 patients by Spitler et al., the use of TXA did not influence intra-or post- operative transfusion rates).[30] Other matching groups did not find any difference in perioperative transfusion between groups.

This study is limited by the lack of a dedicated treatment protocol and use-case guidelines for CS. At our institution, CS and IV TXA were utilized at the discretion of the individual surgeon and anesthesiologist. In addition, the threshold to transfuse is not perfectly uniform. Generally, as an institution, transfusion thresholds are a Hgb of 7 g/dL in non-cardiac patients or 8 g/dL in cardiac patients, however this decision was ultimately left to the anesthesia and critical care teams to make based on clinical judgement. There may be some inherent selection bias regarding the use of CS – it was typically selected for more complicated surgeries and anterior cases, where more operative time and blood loss were anticipated. Another limitation that was not studied here is the influence of preoperative DVT prophylaxis type (low molecular weight heparin, vs. unfractionated heparin) and timing of cessation prior to pelvic and acetabular surgery. Standardization of chemoprophylaxis and review of timing of last dose is logistically difficult. At our institution, surgery was not generally performed if patients received a morning dose of chemoprophylaxis. Additionally, the retrospective nature of the study introduces inherent variability in groups. Despite these limitations, our large patient cohort and matched cohort analysis help substantiate the role of CS in pelvic and acetabular fracture surgery. In conclusion, our results do not show a clear benefit to intraoperative CS use in reducing allogenic blood transfusion requirements. Future direction includes further investigation of this focus area with a single or multi center prospective randomized trial to more specifically elucidate the effects of cell salvage in pelvic and acetabular surgery and minimize potential confounding factors.

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THE IMPACT OF ADDITIONAL FRACTURES AND POLYTRAUMA ON COMPLICATIONS IN PATIENTS UNDERGOING FEMORAL NECK FRACTURE FIXATION

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ABSTRACT

Background: While there have been significant advancements in recent years, complications following fixation for femoral neck fractures remain a concern. This retrospective cohort study aimed to investigate the influence of polytrauma and additional fractures on the occurrence of complications in patients who underwent surgical fixation for femoral neck fractures. The study focused on analyzing patient demographics, comorbidities, fracture classifications, fixation methods, and the likelihood of experiencing post-operative complications, with a specific emphasis on the impact of polytrauma and additional fractures.

Methods: This retrospective cohort study analyzed data from medical records and radiographs of patients who underwent surgical fixation for femoral neck fractures at a tertiary care center between 2007 and 2020. A total of 58 patients met inclusion criteria and were assessed based on their medical history, comorbidities, fracture classification, fixation method, and the occurrence of complications such as osteonecrosis, non-union, limb length discrepancy, and conversion to Total Hip Arthroplasty (THA). Among the patients, 36 received Cancellous Screw (CS) fixation, 12 underwent Sliding Hip Screw (SHS) fixation, while the remaining 10 patients who underwent different fixation methods were excluded from the analysis due to the heterogeneity of the group.

Results: Demographic characteristics and comorbidities were similar between the CS and SHS fixation groups. The overall complication rate for CS fixation was 16.7% (6/36 patients), while the rate for SHS fixation was 33.3% (4/12 patients). However, when considering the presence of polytrauma and additional fractures, a significant association with increased complication rates was observed. Cox proportional regression analysis revealed that the absence of polytrauma/additional fractures significantly reduced the complication rates by more than 90% (Hazard ratio (HRpolytrauma)=0.01, P value = 0.01). This highlights the substantial impact of polytrauma and additional fractures on complications in femoral neck fracture fixation surgeries.

Conclusion: This study emphasizes the need for thorough evaluation and tailored management strategies for patients with femoral neck fractures associated with polytrauma or additional fractures to minimize the complications of femoral neck fracture surgery. Further research is warranted to explore potential preventive measures and optimized treatment approaches for this high-risk patient subset of the femoral neck fracture population.

Level of Evidence: III

Keywords: femoral neck fracture, polytrauma, hip fracture, sliding hip screw, cancellous screw, complications, orthopedic surgery, fixation

INTRODUCTION

Femoral neck fractures occur at the junction between the femoral head and shaft and are associated with significant morbidity, mortality, and functional impairment. It is a challenging injury that most commonly affects older adults and can lead to severe disability.[1] Femoral neck fractures account for about 3% of all hip fractures with an incidence rate of five in 10,000 per year.[2] These injuries are much less common in younger adults and children but place a significant burden on these patients when they do occur.[3,4] Younger patients often have additional injuries such as ipsilateral femoral shaft fractures and acetabular factures which often complicates reduction and fixation.[5] The incidence of femoral neck fractures in the population aged < 50 years is only 2%, the etiology of which is mainly trauma.[6]

Typically, femoral neck fractures are repaired using screw fixation, Sliding Hip Screw (SHS), or arthroplasty. Arthroplasty is more common in older, less active populations while internal fixation is, in general, preferential

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for younger patients.[7] Cancellous screw (CS) fixation is a surgical technique in which wide, self-tapping screws are inserted into the femoral head and neck. This provides stability by engaging the trabecular bone of the femoral head and neck, thereby promoting healing and fracture alignment. Screws are typically placed in an inverted triangle orientation, crossing the fracture line to increase stability.[8] Sliding hip screw (SHS) fixation is another commonly used technique for femoral neck fractures. The hip screw assembly consists of a large lag screw and side plate with a sliding mechanism. The screw inserts into the femoral head, and the side plate attaches to the lateral aspect of the femoral shaft.[9] The sliding mechanism allows controlled dynamic compression across the fracture site. When a weight is applied, the screw slides within the barrel, providing stability and promoting healing.[8]

The management of femoral neck fractures depends on a variety of factors including displacement classification, fracture location and orientation, surgeon preference, and implant availability.[10,11] Multiple cannulated screws are typically preferred for nondisplaced fractures, while both CS and SHS are frequently used for the fixation of displaced fractures.[4] Systematic reviews have shown very little difference in surgical outcomes and complication rates when comparing CS and SHS fixation.[1,12,13] Despite many advancements and apparent improvements in surgical outcomes, complications following femoral neck fracture surgery remain a significant concern.[14,15] Complications such as nonunion, avascular necrosis (AVN), implant failure, and infection can lead to poor surgical outcomes, increased costs, and decreased quality of life. Reoperation rates hover around 20% in the younger population of patients 60 years and younger, while a significant proportion of these patients develop AVN (14.3%), implant failure (9.7%), nonunion (9.3%), malunion (7.1%), and surgical site infection (5.1%).[15] Physiologically young adults with femoral neck fractures are often the result of high-velocity mechanisms, such as motor vehicle accidents or falls. These types of injuries are associated with higher incidences of AVN and nonunion than the intracapsular femoral neck fractures more common in the aged population.[16,17,18] Many factors can influence the risk of complications in femoral neck fracture surgery, including patient demographics, medical comorbidities, fracture characteristics, and fixation methods.[19] While a patient's medical condition, metabolic bone quality and fracture classification are variables that a surgeon has minimal control over, operative factors to achieve positive outcomes include leveraging an appropriate surgical approach that conserves supply to the femoral head and achieving an anatomical reduction and stable fixation in a timely manner.[20,21] It is worth noting the importance of timeliness has been somewhat disputed in the literature.[22,23] A successful fixation minimizes the need for a potential re-operation or salvage procedure, such as an arthroplasty.[24] Femoral neck fractures in the younger population are often the result of high-energy trauma with the potential for additional fractures (multiple long bone fractures)/polytrauma; however, few studies have explored the role of additional fractures/polytrauma in the surgical outcomes of femoral neck fracture fixation. This study focused on analyzing patient demographics, comorbidities, fracture classifications, fixation methods, and the likelihood of postoperative complications, with a specific emphasis on the impact of polytrauma and additional fractures among patients aged < 60 years who underwent femoral neck fracture surgery.

METHODS

Data Collection

This retrospective cohort study analyzed data from the medical records and radiographs of patients who underwent surgical fixation for femoral neck fractures at a tertiary care center between 2007 and 2020. The inclusion criteria for the study were intracapsular femoral neck fractures (Subcapital, Transcervical, and Basicervical fractures) and age less than 60 years. The exclusion criteria were extracapsular fractures (trochanteric, intertrochanteric, and subtrochanteric fractures) and age greater than 60 years. The study participants were followed up retrospectively for 10 years. The radiographic images were reviewed by a resident and a fellow who participated in the project.

Data Description

A total of 58 patients met the inclusion criteria and were assessed based on their medical history, comorbidities such as diabetes and hypertension, fracture classification, fixation methods (cancellous screws (CS), sliding hip screws (SHS), and other fixation methods such as Total Hip Arthroplasty or Hemiarthroplasty), and the occurrence of complications. Other comorbidities included medical conditions such as hypothyroidism, osteoporosis, obstructive pulmonary disease, depression, vitamin D deficiency, chronic kidney disease, malnutrition, and other conditions that may affect bone health. Complications that were considered and grouped as "Any Complication" included osteonecrosis, nonunion, limb length discrepancy, and conversion to Total Hip Arthroplasty (THA). The development of any complication represented a failure - or decreased "survival" - in this analysis.

Table 1. General Characteristics of Patient Population

Characteristics	Frequency (%) N = 58
Age (years), Mean (SD)	44.1 ± 15.5
Sex	
Male	35 (60.3)
Female	23 (39.7)
BMI (kg/m2), Mean (SD)	25.4 ± 5.7
Hypertension	
Yes	19 (32.8)
No	39 (67.2)
Diabetes	
Yes	10 (17.2)
No	48 (82.8)
Presence of other comorbidities	
Yes	39 (67.2)
No	19 (32.8)
Current Smoking	
Yes	18 (31.0)
No	40 (69.0)
Previous surgery	
Yes	33 (56.9)
No	25 (43.1)
Length of follow up (years), Mean (SD)	2.53 ± 3.0
Surgery Implant	
Cancellous screw (CS)	36 (62.1)
Sliding hip screw (SHS)	12 (20.7)
Others	10 (17.2)
Days to Surgery	
≤ 24 hours	43 (74.1)
> 24 hours	15 (25.9)
Additional fractures at Surgery	
Yes	11 (19)
No	47 (81)
Fracture Classification	
Subcapital	11 (19.0)
Transcervical	34 (58.6)
Basicervical	13 (22.4)
Fracture Displacement	
Yes	44 (81.5)
No	10 (18.5)
Complications	10 (17.2)
Osteonecrosis (AVN)	3 (5.2)
Non-union	5 (8.6)
Limb length discrepancy	1 (1.7)
Conversion to THA	6 (10.3)

Statistical Analysis

Descriptive statistics were used to show the distribution of the study variables. Complication rates and Cox-proportional-regression-generated hazard rates of failure for Any Complication among patients in the treatment groups were calculated. Statistical analyses were performed using SAS version 9.2 (SAS Institute, Cary, North, USA).[25]

RESULTS

Demographic characteristics and comorbidities were similar in the CS and SHS fixation groupsI. The patient population was young, with a mean age of 44.1 years, consisting of more males (60.3%) than females. The majority of the fractures were transcervical (58.6%) and displaced. Conversion to THA (10.3%), non-union (8.6%), and osteonecrosis (5.2%) were the most common complications. Approximately 19% of the study population had additional fractures/polytrauma at the time of the injury. The mean follow-up period was 2.53 years. (Table 1)

The overall complication rate for CS fixation was 16.7% (6/36 patients), whereas that for SHS fixation was 33.3% (4/12 patients) (Table 2). Most fractures were fixed within 24 h, and the majority of fractures in both fixation groups (CS, 61.1%; SHS, 41.7%) were transcervical (Table 2). In the absence of polytrauma and additional fractures, a statistically significant reduction in hazard ratio (HR) was observed (β = -3.25; HR = 0.01; p = 0.01). In addition, the absence of hypertension precluded the risk of complications by more than 90 % (p = 0.03), whereas there was no statistically significant difference in either fixation method in relation to the risk of developing postoperative complications (p = 0.77) (Table 3). The directed adjusted survival curve showed that there was no difference between the survival probabilities (complication free probabilities) of patients who underwent both fixation methods (CS and SHS) after 10 years of follow-up (Figure 1). In contrast, the curve showed a statistically significant difference between the survival probabilities of those who had additional fractures or polytrauma and those who did not. At 4 years follow up period, the survival probability of those who had additional fractures or polytrauma was approximately 30%, whereas that of those who did not was more than 80% (Figure 2). (Table 3).

DISCUSSION

This study examined the impact of polytrauma and additional fractures in patients aged < 60 years who underwent femoral neck fracture surgery. The study showed that the absence of additional fractures or polytrauma significantly reduced the rate of postoperative complications by > 90%. This highlights the substantial impact of

Table 2. Demographics and Rate of Complications by Fixation Method

Variables	Cancellous screw (%) N = 36	Sliding Hip Screw (%) N = 12	P value
Age, Years	42.4 ± 17.2	40.4 ± 12.7	0.667
Sex			0.300
Male	25 (69.4)	6 (50)	
Female	11 (30.6)	6 (50)	
BMI, Kg/m2	24.8 ± 4.3	26.9 ± 7.1	0.395
Hypertension	10 (27.8)	4 (33.3)	0.726
Diabetes	8 (22.2)	0 (0)	0.174
Presence of other comorbidities	23 (63.9)	8 (66.7)	1
Current Smoking	12 (33.3)	4 (33.3)	1
Previous surgery	20 (55.6)	7 (58.3)	1
Length of follow up (years), Mean (SD)	2.3 ± 2.9	3.4 ± 3.4	0.308
Days to Surgery			0.002
≤ 24 hours	32 (88.9)	5 (41.7)	
> 24 hours	4 (11.1)	7 (58.3)	
Additional fractures at Surgery	6 (16.7)	4 (33.3)	0.241
Fracture Classification			0.042
Subcapital	9 (25)	1 (8.3)	
Transcervical	22 (61.1)	5 (41.7)	
Basicervical	5 (13.9)	6 (50)	
Fracture Displacement			0.692
Yes	26 (78.8)	8 (72.7)	
Any Complication	6 (16.7)	4 (33.3)	0.241
Osteonecrosis	3 (0)	0 (0)	0.563
Non-union	2 (5.6)	3 (25)	0.092
Limb length discrepancy	1 (2.8)	0 (0)	1
Conversion to THA	3 (8.3)	3 (8.3)	0.156

Fisher exact P values are reported in the table.

Table 3. Cox Proportional Regression Showing Hazard Rate of Failure (Any Complication) Among Patients

Variable	β coefficient	Hazard Ratio	Confidence Interval	P-value
Age	-0.06	0.95	0.880 – 1.015	0.12
Additional Fractures at surgery				
Yes	-3.25	Ref		0.01
No		0.01	0.003 – 0.467	
Hypertension				
Yes	-3.39	Ref		0.03
No		0.02	0.002 – 0.562	
Fixation Method				
SHS	-0.22	Ref		0.77
CS		0.76	0.191 – 3.387	

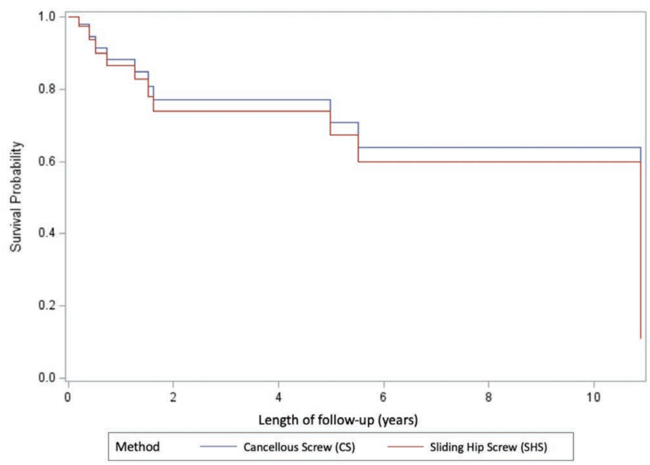

Figure 1. Impact of Fixation Method (CS or SHS) on Survival. Direct adjusted survival curve depicting comparison in the development of any complication in patients undergoing femoral neck fracture fixation with cancellous screw fixation and with sliding hip screw fixation.

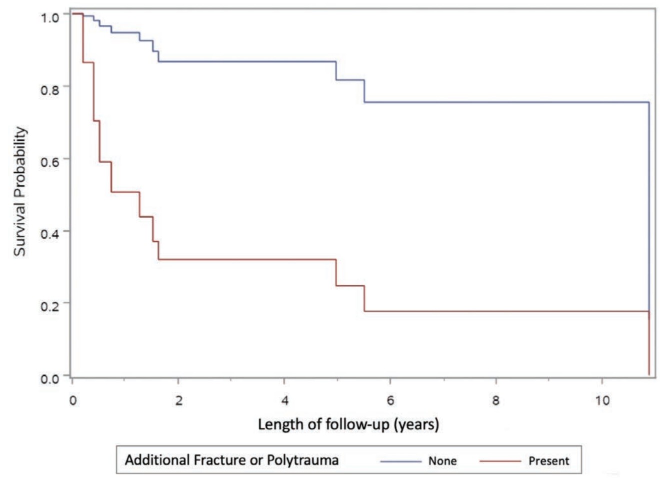

Figure 2. Impact of Presence of Additional Fracture/Polytrauma on Survival after Fixation. Direct adjusted survival curve depicting comparison in the development of any complication in patients undergoing femoral neck fracture fixation with and without polytrauma/additional fractures at time of surgery.

polytrauma and additional fractures as significant risk factors for complications in young patients undergoing surgical fixation of femoral neck fractures. Although no significant differences were observed between CS and SHS fixation methods, the presence of polytrauma or additional fractures substantially increased the risk of postoperative complications. Patients with femoral neck fractures who have additional fractures or polytrauma experience higher rates of postoperative complications like nonunion and avascular necrosis after femoral neck fracture fixation. This may be attributed to a more pronounced systemic inflammatory response induced by polytrauma. Patients with multiple traumatic injuries undergo physiological stress that disrupts the balance between the systemic inflammatory response and compensatory anti-inflammatory response.[26] Specifically, serum levels of the inflammatory cytokine interleukin-6 (IL-6) are significantly elevated in polytrauma patients compared to isolated injuries.[27] Higher IL-6 levels correlate with injury severity score (ISS), incidence of organ dysfunction, acute respiratory syndrome (ARDS) and poor postoperative outcomes.[28]

Polytrauma patients may face other challenges such as increased surgical complexity, vascular and soft tissue damage, heightened infection risks from additional wounds, compromised rehabilitation, and medical complications like fat embolism and deep vein thrombosis.[15] The combined impact of amplified systemic inflammation, greater surgical stress, and medical complications may contribute to a higher risk of adverse outcomes after femoral neck fracture fixation in the setting of polytrauma. Moreover, patients with additional fractures or polytrauma may experience nutritional challenges owing to metabolic dysregulation during the early postoperative period. While baseline malnutrition has been shown to increase the risk of poor clinical outcomes, the quality of evidence supporting the importance of nutrition in polytrauma patients is sparse.[29] However, the nutritional status of patients with polytrauma should be monitored, and management should be individualized.

The findings from this study contribute significantly to the current literature, as few studies have comprehensively evaluated the impact of additional fractures or polytrauma on the complication rates following femoral neck fracture fixation. The findings of our study, which showed no significant difference between fixation methods, were similar to those of Shehata et al. (2019), a systematic review and meta-analysis that pooled data from 10 randomized controlled trials. Most randomized controlled trials comparing complication rates between both fixation methods have a maximum follow-up period of four years, and the only reasonable inexpensive way to have a much longer follow-up period is through retrospective cohort analysis, as in this study.

This study has some limitations. First, the small sample size may have limited the generalizability of this study. For instance, the confidence interval of the additional fracture hazard ratio in Table 3 is wide and introduces considerable uncertainty in the estimated hazard ratio. However, the overall findings of an increased risk of polytrauma or additional fractures are medically sound and have been supported by other studies. [30,31] Second, the retrospective nature of this study may have introduced censoring bias due to the limited follow-up data, because some participants were lost to follow-up at some point earlier in the study. In addition, reliance on existing data that may be incomplete or inaccurate may introduce some measurement errors, and the available data for the participants may not truly represent the general population. Finally, there may be additional unmeasured confounders not accounted for in this study, and the retrospective survival analysis approach of this study does not prove causality between additional fractures or polytrauma and femoral neck fracture fixation failure or complications.

CONCLUSION

This study emphasizes the need for thorough evaluation and tailored management strategies for patients with femoral neck fractures associated with polytrauma or additional fractures to minimize the complications of femoral neck fracture surgery. Potential pre-, intra-, and postoperative interventions should be explored by care teams to best follow at-risk patient groups with the goal of optimizing functional outcomes, vitality, and longevity following fixation. Further research is warranted to explore potential preventive measures and optimized treatment approaches for this high-risk patient subset of the femoral neck fracture population.

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