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Public Notice of Corrections

1. Volkmar AJ, Day MA, Fleury IG, Lawler EA, Seering M, Caldwell LS. Safety and Efficacy of Forearm Tourniquet Compared to Upper Arm Tourniquet for Local Intravenous Regional Anesthesia in Hand Surgery: A Randomized Clinical Trial. Iowa Orthop J. 2021;41(1):177-181. PMID: 34552422; PMCID: PMC8259182.

   This corrects Table 2 with appropriate Trademarking.

Table 2. The Iowa Satisfaction with Anesthesia Scale (Dexter, et al.) 3 = Agree very much

Statements	Response choices
I threw up or felt like throwing up	-3 = Disagree very much
I would want to have the same anesthetic again	-2 = Disagree moderately
I itched	-1 = Disagree slightly
I felt relaxed	1 = Agree slightly
I felt pain	2 = Agree moderatel
I felt safe	3 = Agree very much
I was too cold or hot	
I was satisfied with my anesthetic care	
I felt pain during surgery	
I felt good	
I hurt	

The Iowa Satisfaction with Anesthesia Scale is copyrighted, franklin Dexter and the University of Iowa Research Foundation. Permission to use the questionnaire may be obtained at https://www.franklindexter.net.
The 11 statements that make up the Iowa Satisfaction with Anesthesia Scale alternate between "negative" and "positive" statements. Responses to statements are given an individual score ranging from -3 to +3, the scores for the "negative" statements are multiplied by -1, and the cumulative scores are averaged to determine a final composite score. A final score of +3 represents the most satisfied a patient can be with their anesthesia experience, while a final score of -3 represents the least satisfied a patient can be with their anesthesia experience.[13]

2. Baron JE, Shamrock AG, Volkmar AJ, Westermann RW. Haemophilus Parainfluenzae Septic Arthritis Following Primary All-Inside Meniscus Repair: A Case Report and Review of the Literature. Iowa Orthop J. 2020;40(1):111-114. PMID: 32742217; PMCID: PMC7368514. of the Literature.

   This corrects the author: Volkmar AJ

INSTRUCTIONS FOR AUTHORS, 2022 EDITION

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BRACHIAL ARTERY THROMBOSIS IN A COVID-19 POSITIVE PATIENT WITH THORACIC OUTLET SYNDROME

Nathan Heineman, MD[1]; Daniel Koehler, MD[1]

ABSTRACT

Severe coronavirus disease 2019 (COVID-19) has been complicated by coagulopathy and thrombotic events including venous thromboembolism, pulmonary embolism, and arterial thrombus at a rate higher than has traditionally been seen with sepsis-induced coagulopathy or disseminated intravascular coagulation leading most centers to treat hospitalized patients with prophylactic anticoagulation. We present a case of a patient with thoracic outlet syndrome who presents with brachial artery thrombosis in the setting of infection with COVID-19. Both thoracic outlet syndrome and COVID-19 infection are independently associated with increased risk of thrombotic events. The induced hypercoagulable state from COVID-19 infection may result in acute arterial thrombosis in patients with predisposing anatomic differences consistent with thoracic outlet syndrome.

Level of Evidence: V

Keywords: compartment syndrome, COVID-19, hypercoagulable, thoracic outlet syndrome, thrombus

INTRODUCTION

Since the COVID-19 pandemic began there have been reports from multiple sites of a high rate of thrombotic complications particularly among critically ill patients.[1,2,3] The majority of these have manifested as pulmonary embolism, stroke, or myocardial infarction. However, there have also been reports of acute limb ischemia from peripheral arterial thrombosis.[2] Infection with COVID-19 is believed to induce a hypercoagulable state secondary to a combination of direct and indirect mechanisms. While factors such as immobilization, dehydration, and an acute inflammatory state are common to systemic infections, the rate of thrombotic complications appears to be higher among patients with COVID-19. One proposed explanation is endothelial cell damage secondary to the virus binding to the ACE2 receptor.[4] COVID-19 infection has been associated with high D-dimer levels and relatively normal platelet counts in contrast to the consumptive thrombocytopenia traditionally seen with disseminated intravascular coagulation. The D-dimer level has been found to directly correlate with severity of illness and mortality.[5]

Thoracic outlet syndrome (TOS) is a second condition associated with arterial thrombosis. TOS can involve either neurologic compression of the brachial plexus, or much less commonly, vascular compression of the subclavian or axillary vessels. While arterial thoracic outlet syndrome is much less common than neurogenic or venous thoracic outlet syndrome, it may be more common than initially believed with as many as 80% of patients with bony cervico-thoracic abnormalities found to have some form of arterial pathology.[6]

In the present study, we report a case of a patient with an anomalous cervical rib and arterial TOS who presented with an occlusive thrombus to the brachial artery in the setting of COVID-19 infection.

CASE REPORT

A 44-year-old male presented to the emergency department with six days of intermittent, aching, right upper extremity pain extending from his biceps into his hand with a strong exertional component and mild persistence at rest. He denied any past medical history and is a lifetime non-smoker. There was no previous endorsement of ischemia, paresthesias, cold sensitivity, or distal limb pain either at rest or with changes in upper extremity position/activity. He acknowledged associated pallor during episodes of pain and diffuse tingling over the palm of his right hand without bias towards any peripheral nerve or cervical dermatome. No loss of motor function or strength was observed. He denied any significant precipitating trauma.

Physical examination revealed 5 out of 5 strength throughout the distal limb. The patient was able to demonstrate well preserved discriminatory sensibility to both pin prick and light touch despite the subjective paresthesias. Neither the radial nor ulnar pulse was pal-

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Statement of Informed Consent: Informed consent was obtained from the patient for case report publication.

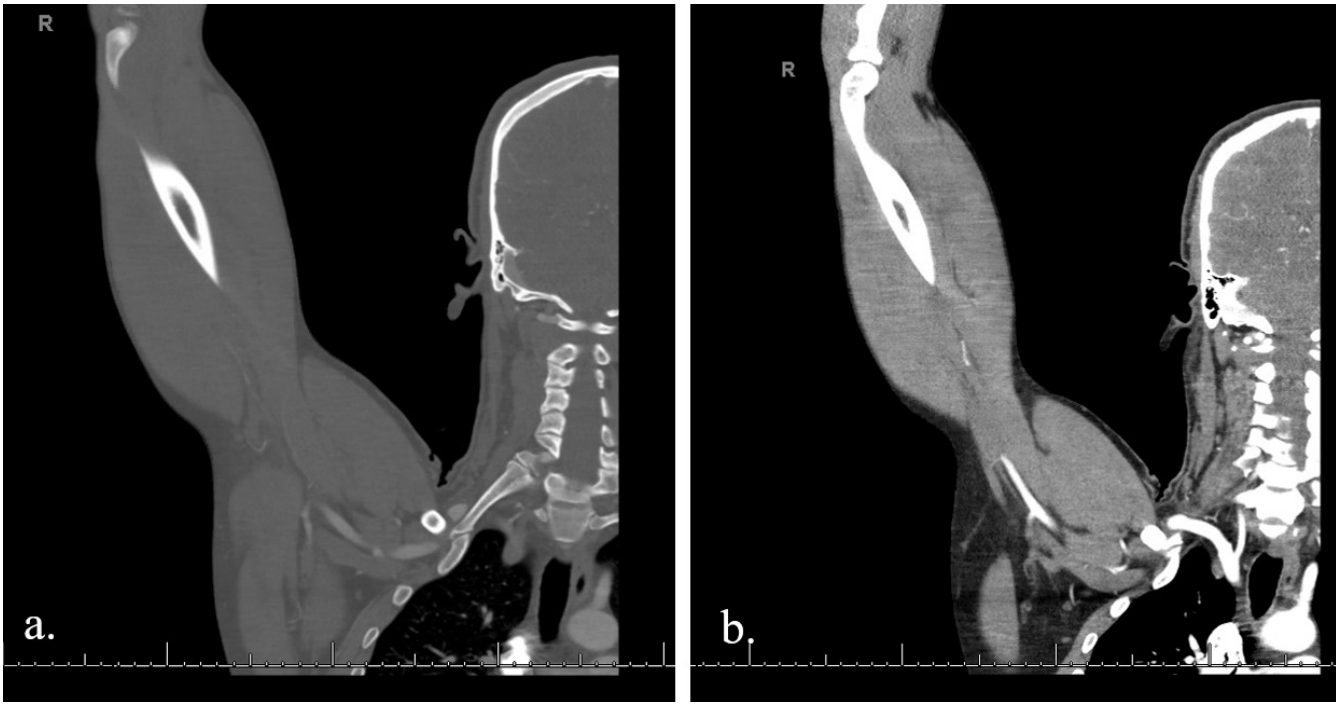

Figure 1. Coronal cuts from computed tomography angiography demonstrating right accessory cervical rib leading to narrowing of the thoracic outlet (a) and thrombosis leading to complete occlusion of the proximal right brachial artery (b).

pable. Faint Doppler signals were obtained at the radial artery and ulnar artery without a detectable superficial palmar arch signal. Distally the digits remained pink and perfused via collateral circuits with three second capillary refill.

Computed tomography angiography of the right upper extremity was significant for an accessory right cervical rib with narrowing of the thoracic outlet (Figure 1a) and an associated subclavian artery aneurysm leading to complete occlusion of the proximal brachial artery (Figure 1b). There was complete occlusion of the proximal right brachial artery with distal reconstitution of the ulnar artery, and poor opacification of the right radial artery. Doppler studies were notable for partial occlusion of the right subclavian and axillary arteries, near occlusive thrombus of the proximal brachial artery, completely occlusive thrombus of the proximal and distal right radial artery with collateralization of the mid segment, and near complete occlusion of the ulnar artery. Tri-phasic waveforms were preserved in the subclavian and axillary arteries. Peak systolic velocity of the proximal, mid, and distal segments of the brachial artery were 20 cm/second, 0 cm/second, and 0 cm/second, respectively. Bilateral lower extremity vein mapping was completed in order to prepare for the possibility of brachial arterial bypass if needed.

Urgent vascular surgery consultation was obtained and the patient was initiated on a therapeutic heparin drip. Surgical intervention was discussed in the form of cervical rib resection, subclavian artery bypass with anticipated employment of the deep femoral vein, brachial artery thrombectomy with possible requirement for brachial artery bypass, and anticipated forearm compartment releases. Per institutional policy, testing for COVID-19 was obtained with a positive PCR test and the patient was subsequently admitted to the COVID-19 unit. The patient denied any recent travel, sick contacts, fevers, chills, or infectious symptoms, and he remained asymptomatic as it pertains to viral symptoms throughout his hospital course. The decision was made to proceed with urgent revascularization only with the intention to defer the definitive management of his TOS until he cleared his COVID infection status. An informed consent process was completed with the acknowledgement of a delayed secondary procedure to address the cervical rib and subclavian artery aneurysm pathology.

On hospital day two, the patient was taken for brachial artery thrombectomy with planned intra-operative angiography. Enhanced precautions were employed to prevent exposure of the surgical teams to the virus. Initial dissection was carried down to the distal brachial artery immediately proximal to the level of the bifurcation. The vessel was pulseless with visible thrombus. With control of the distal vasculature an arteriotomy was created and extensive thrombus burden was retrieved from the brachial artery continuing proximal to the subclavian with sequential employment of Fogarty catheters until brisk pulsatile bleeding was obtained. An equally significant

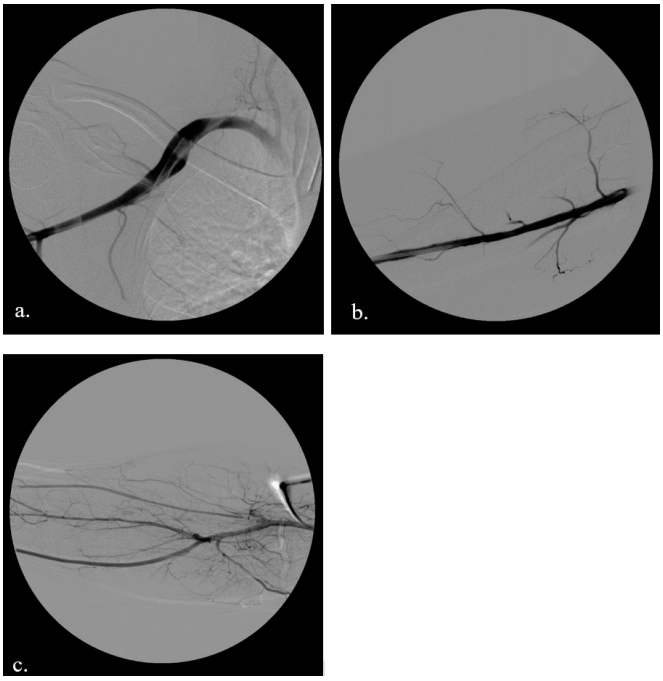

Figure 2. Intraoperative angiography demonstrating post-stenotic subclavian artery aneurysm (a), reperfusion of the brachial artery (b), and forearm vasculature notable for diminutive radial artery with proximal stenosis (c).

volume of thrombus was removed from the ulnar artery distally with an embolectomy balloon. The radial artery was noted to be chronically stenosed and the catheter was unable to be passed. Following closure of the arteriotomies a palpable ulnar pulse was restored. Subsequent intra-operative angiography demonstrated widely patent subclavian and axillary arteries with demonstration of the post-stenotic subclavian artery aneurysm (Figure 2a). The brachial artery demonstrated complete reperfusion (Figure 2b). The ulnar artery provided the dominant flow to the hand with global perfusion to all digital vessels. The interosseous vessels remained patent and the radial artery was reconstituted distally via collateral flow (Figure 2c).

Progressive tenseness and swelling were identified in the ipsilateral forearm musculature following reperfusion. The hand surgery team was consulted intraoperatively and completed forearm fasciotomies of all three compartments with extension distally into an open carpal tunnel release. The forearm musculature was uniformly identified to be contractile, healthy, and well-perfused following the surgical releases. Skin incisions were able to be loosely opposed in a primary fashion and the patient retained a strongly palpable ulnar pulse at the conclusion of the case (Figure 3). An internal Doppler probe was further placed at the ulnar artery just distal to its origin for post-operative monitoring. A robust tri-phasic signal was identified.

Post-operatively, the patient was anticoagulated with an intravenous heparin infusion. Excellent clinical perfusion was maintained throughout the limb without further compromise as evidenced by improved capillary refill time and continuous monitoring with internal brachial artery doppler. The patient subjectively did not endorse any further ischemia pain. Hematology was consulted with recommendations to initiate a Lovenox bridge to warfarin with a goal INR of 2-3 for a minimum of 3 months. Occupational hand therapy was initiated for management of residual distal limb swelling and stiffness. His hospital course was complicated by development of an extravascular hematoma in the volar forearm compartment. This was managed with hematoma evacuation via opening of the forearm fasciotomy incisions. There was no further

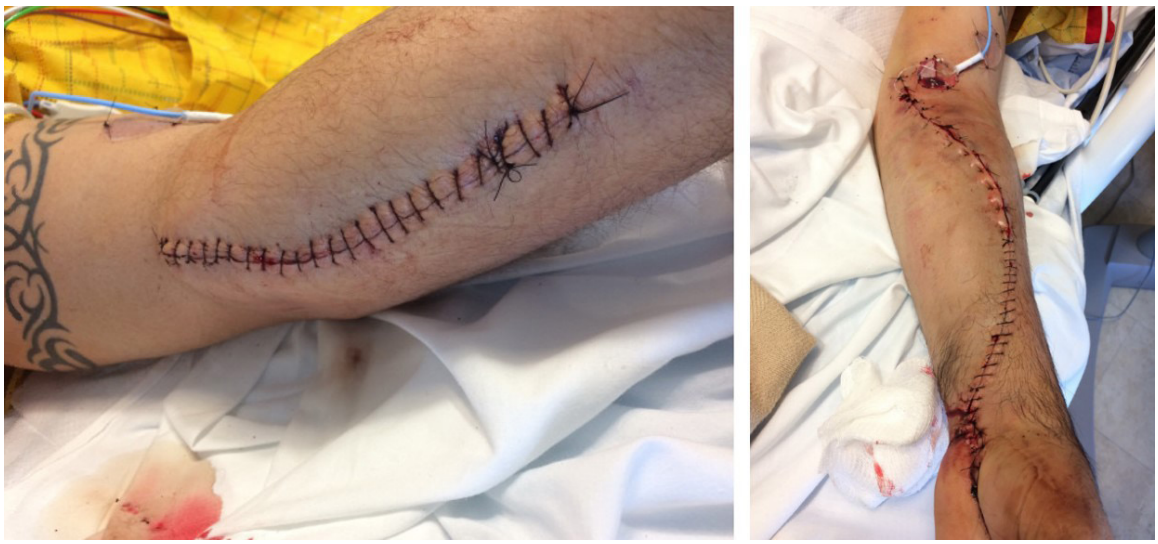

Figure 3. Post-operative images of the primary closure of dorsal and volar incisions used for forearm fasciotomies of all three compartments with extension distally into an open carpal tunnel release.

demonstration of active bleeding or extravasation. The two incisional sites were left open to decompress with local wound care measures and packing. Delayed secondary closure of the volar forearm fasciotomy wound was completed in the operating room over a drain with split thickness skin grafting to the dorsal forearm fasciotomy wound. Definitive management of the TOS pathology was completed by the vascular surgery team as a tertiary staged procedure with first thoracic and cervical rib resections and subclavian to axillary artery bypass with a Dacron graft without complication.

DISCUSSION

While hypercoagulability and thrombotic complications have been strongly associated with more severe manifestations of COVID-19, this case raises the possibility of COVID-19 infection contributing to a hypercoagulable state in an asymptomatic patient. This patient had both structural manifestations consistent with arterial TOS as well as an infectious disease process which may have combined in a synergistic fashion to produce his pattern of critical limb ischemia and brachial artery thrombosis.

TOS may manifest with primary compression of neurogenic, venous, or arterial structures. Three points of classic compression have been defined including the scalene triangle, the costoclavicular space, and the subcoracoid space. The most common derivative of TOS is a neurogenic etiology with compression of the brachial plexus producing both local and radiating neurologic symptoms. Venous TOS most commonly presents as swelling at rest or with activity with a sensation of heaviness and discoloration of the affected limb. Arterial TOS is the least common of the three pathologic states with an estimated incidence representing only 1% of all cases.[7]

Compression of the subclavian artery produces luminal stenosis with turbulent flow resulting in post-stenotic dilation and eventual aneurysm formation which predisposes to formation of thrombus.[8] While this process progresses slowly and may be reversible in the early stages, it is rarely diagnosed early as symptoms are vague and may have significant overlap with neurogenic TOS. Early symptoms may include a dull ache, numbness, cyanosis or pallor, and easy fatigability with exertion.[8] The most common clinical presentations of arterial TOS are acute limb ischemia or evidence of chronic ischemia from emboli in the form of hand or digital ulceration.[6] Patients may also present with a discrepancy in blood pressure between the upper extremities and loss of the distal pulse with elevation of the arm at the shoulder although this finding is nonspecific. There is a strong association between arterial TOS and bony abnormalities including cervical ribs, elongated C7 transverse processes, abnormal first thoracic rib anatomy, and acquired or congenital soft tissue abnormalities.[8] Treatment consists of thrombectomy for acute ischemia with eventual decompression and repair or bypass of the injured segment of the artery with consistently excellent outcomes.[8,9]

COVID-19 has been strongly associated with a hypercoagulable state. An autopsy study of 80 consecutive cases in Hamburg found 21% to have pulmonary emboli and 40% to have DVTs.[1] Among 3,334 consecutive hospitalized patients in New York City thrombotic events occurred in 16% (6.2% venous, 11.1% arterial).[3] A group out of Spain reported 4 cases of acute limb ischemia in critically ill COVID-19 patients.[2] This hypercoagulability is hypothesized to be due to a combination of factors inherent to any critical illness (dehydration, immobilization, and acute inflammation) and others unique to COVID-19 which targets the ACE2 receptor potentially leading to endothelial damage leading to a pro-thrombotic state.[4] Prophylactic anticoagulation has been shown to decrease mortality in the most critically ill COVID-19 patients and those with signs of sepsis induced coagulopathy or significantly elevated D-dimer, further supporting the hypothesis that the novel coronavirus produces a systemically hypercoagulable state.[10]

CONCLUSION

In the present case, while the patient did have anomalous cervical anatomy consistent with known arterial TOS pathology, the degree of subclavian arterial stenosis was quantitatively determined to be mild and there was no evidence of significant post-stenotic dilation indicating long-standing pathology. His concomitant infection with COVID-19 raises the question as to whether an induced hypercoagulable state as a product of his viral infection may have contributed to his presentation with acute upper extremity ischemia due to arterial thrombosis. While COVID-19 testing is now widely available and routinely performed prior to any procedural intervention, consideration may be given to monitoring similar patients who present with acute arterial thrombosis and distal limb ischemia for the presence of COVID-19 infection to further discern this clinical relationship.

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RESECTION OF TARSAL COALITION IN 27 CHILDREN WITH 2 YEARS FOLLOW-UP – PATIENT-REPORTED OUTCOMES USING THE VALIDATED OXFORD ANKLE FOOT QUESTIONNAIRE

Ahmed Abdul-Hussein Abood, MD, PhD[1]; Bjarne Møller-Madsen, MD, DMSc[1]; Jan Duedal Rölfing, MD, PhD[1]; Alexios Iliadis, MD, FRCS[2]; Manoj Ramachandran, MD, FRCS[2]; Ole Rahbek, MD, PhD[3]

ABSTRACT

Background: Patient Reported Outcome Measures (PROM) after resection of tarsal coalitions are sparse. This cross-sectional study evaluates the outcome after resection of tarsal coalitions in children using the validated Oxford Foot and Ankle Questionnaire (OxAFQ).

Methods: Tarsal coalition patients between 5-16 years of age from Aarhus University Hospital (Denmark) and The Royal London Hospital (United Kingdom) were included. The patients were identified using patient and theatre register. All patients and proxies filled in the PROM: OxAFQ-C and OxAFQ-proxy respectively. The scores were calculated within each domain and reported as means (95% confidence intervals). Talocalcaneal coalitions were compared to calcaneonavicular coalition with regard to OxAFQ score and re-operation rate.

Results: 27 patients and their proxies returned 54 questionnaires in total regarding 36 feet. Mean time from surgery to filling of the questionnaire was 25 (21-30) months. The relative mean OxAFQ score was higher in the School and Play and Emotional domain than the Physical domain, p = 0.007. The OxAFQ scores and re-operation rates were similar for both coalitions, p=0.63.

Conclusion: The OxAFQ PROM showed more encouraging results in playing or emotional health status than the physical health status. The outcome for both types of coalitions is similar.

Level of Evidence: IV

Keywords: coalitio, oxafq, prom

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Sources of Funding: No sources of funding declared.

INTRODUCTION

Tarsal coalitions can cause pain and stiffness in the foot due to the bridge formation between the calcaneus and the navicular bone or talar bone.[1] Several surgical options have been explored. Although studies have indicated a positive outcome using arthrodesis,[2] recent studies show improved outcome with resection of the coalition and interposition of a biologic material, such as fat or muscle tissue, to prevent bridge relapse.[3–10] Consequently, arthrodesis should only be performed as salvage procedure, i.e., after failed resection of a tarsal coalition or in case of osteoarthritis in the transverse tarsal joint.[4,11,12]

Outcome after coalition-resection have been widely described. However, the literature seems to lack validated and standardized reports on patient-reported outcome measures (PROM), leaving a gap for investigation.[9,10,13–15] Hence, much uncertainty remains regarding the long-term effect of treatment with resection of tarsal coalitions. The aim of this study was to report PROM data of the validated Oxford Foot and Ankle Questionnaire (OxAFQ) from the children and their proxies after resection of tarsal coalition and correlate the data gathered from the children to the data from their proxies.

METHODS

The study was carried out in a cross-sectional retrospective design. Patients in this study were included at Aarhus University Hospital, Denmark AUH and The Royal London Hospital, United Kingdom RLH (Figure 1).

The Danish study population was identified by the Danish medical database using the International Classification of Disease 10 (ICD-10) diagnosis code for tarsal coalition (DQ668A). Patients with confirmed diagnosis and treated at AUH from 2006 until 2014 were included. Additionally, codes were used to identify patients with a tarsal coalition registered under a different diagnosis.

The British study population was identified using the orthopedic theatre lists from 2011-2014 at RLH.

First physician contact was defined as the first contact to an orthopedic specialist with the patient complaining from a symptomatic foot.

Data regarding type of coalition, operation date, applied imaging modalities, post-operative complications, additional surgery, co-existing disorders, age and sex

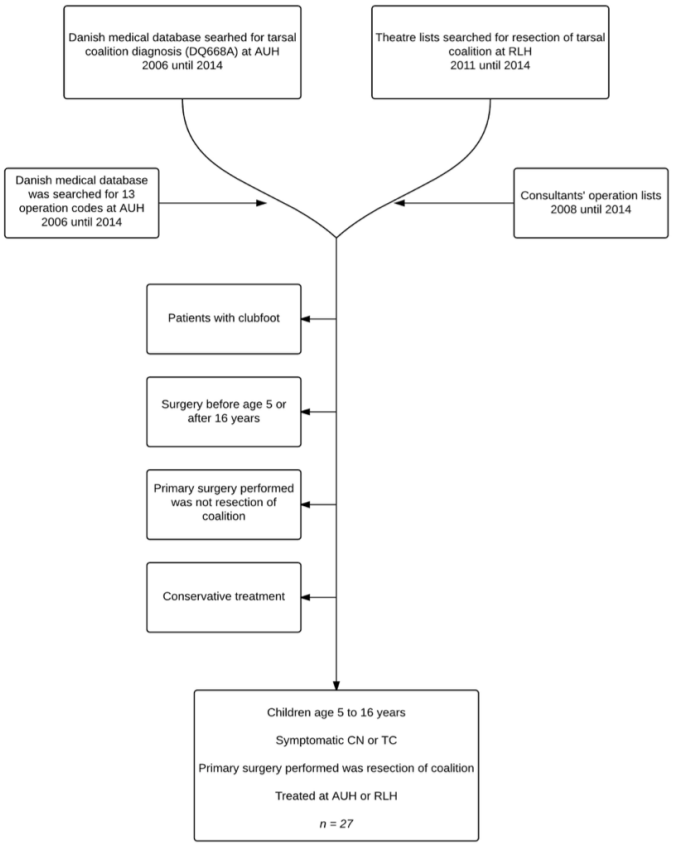

Figure 1. Flowchart over inclusion. Inclusion and exclusion criteria as listed.

were obtained by reviewing the patient charts.

Inclusion criteria were at least one symptomatic TC or CN coalition and surgical intervention with resection of the coalition performed between age 5 and 16 years at AUH or RLH. Exclusion criteria were presence of other foot and ankle disorders and learning disability that may impair the ability to respond to the PROM. All British participants received the child specific OxAFQ-C.[16] The Danish population received a translated and validated version of the PROM.[17] Both the child and their primary caregiver or proxy were asked to respond to the questionnaire. Contact with the patients was made through the phone. Patients with bilateral coalitions were asked to report data regarding the most symptomatic operated foot.

There are four domains in the OxAFQ: physical domain with a possible score of 0 to 24; school and play domain with a possible score of 0 to 16; emotional domain with a possible score of 0 to 16; final-item domain with possible score of 0 to 4. Higher scores are equivalent to better functional outcomes.

The outcome measures were the respective OxAFQ scores within each domain in the questionnaire, the number of additional surgical procedures performed, such as resection of relapsed bridge (RRB) or triple arthrodesis (TA) and the time from first physician contact to primary surgery.

Ethical consideration

The study was performed in accordance with the Declaration of Helsinki and was reviewed and approved by an internal review board and the regional ethical committee.

Statistics

Re-operation rate was calculated based on a total of 36 feet. The OxAFQ scores were calculated for each patient, based on the most symptomatic foot.

Both continuous and binary data were analyzed. Continuous data were time from surgery to PROM (OxAFQ) (months), age (years) and the individual OxAFQ score for children and their proxy (points). Binary data included were coalition type (CN or TC), the need for additional surgery due to unsatisfactory results from primary resection (yes or no), gender and observational period after initial physician contact to primary surgery (less than or more than 6 months). Values are reported as mean (95% confidence intervals). Fischer's exact test was performed to test for significance in binary data. Pearson correlation analysis was performed for QxAFQ-C and OxAFQ-proxy.

All analyses were performed using STATA 13 (StataCorp. 2013 Stata Statistical Software: Release 13. College Station, TX: StataCorp Lp.).

RESULTS

Thirty-six feet in 27 patients having a tarsal coalition (17 CN, 10 TC) were identified and included in the study (12 males, 15 females). All identified patients completed the OxAFQ-C and proxy. Patient characteristics and applied image modalities to diagnose the coalitions are given in Table 1.

The relative child and proxy OxAFQ-scores within the domains were highest in the School and Play and Emotional Domain, $p < 0.1$ (Table 2).

The collected child-questionnaires gave a mean OxAFQ-C-score of approximately 70% of the possible maximum score for all four domains for the TC coalitions. For the CN coalitions, the mean OxAFQ-C-score was 81% for all domains. The combined OxAFQ-C and Proxy score was similar for both TC and CN coalitions (Table 2). OxAFQ scores did not increase with time from surgery to completing the questionnaire for both TC and CN coalitions, r = -0.27; -0.02 (Figure 2).

The collected proxy-questionnaires demonstrated a similar mean OxAFQ-proxy-score within each domain compared to the OxAFQ-C with a strong correlation, r = 0.68 – 0.89 (Figure 3). The mean TC OxAFQ-proxy-score was 66% for all domains, and 75% for the CN coalitions.

Table 1. Patient Characteristics and Imaging Modalities for Talocalcaneal and Calcaneonavicular Coalitions

	TC (n = 10, feet = 13)	CN (n = 17, feet = 23)	In Total (n = 27, feet = 36)
Patient characteristics			
Males	4 (40%)	8 (47%)	12 (44%)
Females	6 (60%)	9 (53%)	15 (56%)
Mean age at surgery [years]	11.8 (10.5 – 13.0)	12.0 (10.5 – 13.7)	11.9 (11.0 – 12.8)
Mean time from 1st visit to surgery [months]	6.3 (4.3 – 8.3)	7.4 (4.2 – 10.6)	7.0 (4.9 – 9.1)
Mean time from surgery to OxFAQ [months]	25.1 (15.6 – 34.6)	25.2 (19.6 – 30.9)	25.2 (20.6 – 29.8)
Imaging modality			
X-ray	1 (10%)	10 (59%)	11 (41%)
CT	5 (50%)	4 (23%)	9 (33%)
MRI	4 (40%)	3 (18%)	7 (26%)

Values are reported as mean (95% confidence intervals) or n (%).

The re-operation rate was 19% and similar for both types of coalitions, p=0.63. No significant difference was observed in the OxAFQ scores between the re-operated and primary resected coalitions.

The mean time from surgery to filling in the questionnaire was also similar for both coalitions (Table 1).

DISCUSSION

Most studies on outcome after resection of tarsal coalitions have reported clinical outcomes rather than patient reported outcomes.[5–8,13,18,19] Although a few recent studies have dealt with this issue using PROMS,[9,10,14] no studies have utilized a validated child-specific questionnaire. In this study we have quantified the obstacles and their influence on daily life using the validated child-specific OxAFQ-C. The OxAFQ scores were similar for both coalitions and highest within the School and Play and Emotional domain. Previous studies have advocated a more favorable outcome for CN coalitions,[18,20] however the PROM scores were similar between the two coalitions in our study, which also reflects with recent other reports.[4,10,14,21,22] The higher relative scores within the School and Play and Emotional domains (maximum of 16 points) indicate that the children are not impaired in the daily play or affected emotionally despite the lack of satisfaction of the physical outcome. Data collected from the children seems to be in accordance with the parental observations as shown in Figure 3. The strong correlation between the data collected from the children and proxies suggests it is reliable to gather the information from the proxy. A possible bias in the col-

Table 2. Mean Child and Proxy OxAFQ-Scores (95% CI) and the Number of Additional Surgeries Needed in Talocalcaneal and Calcaneonavicular Coalitions

	TC (n = 10)	CN (n = 17)	In Total (n = 27)
OxAFQ-C			
Physical domain	15.5 (11.1-20.0)	17.6 (14.3-21.1)	16.9 (14.3-19.4)
School & play domain	11.3 (8.0-14.56)	13.8 (11.9-15.8)	12.9 (11.2-14.6)
Emotional domain	12.6 (10.4-14.8)	14.6 (12.9-16.3)	14 (12.6-15.2)
Final item domain	2.3 (1.6-3.0)	2.6 (1.8-3.4)	2.5 (2.0-3.0)
All domains	41.7 (32.8-50.6)	48.6 (41.4-55.9)	46.1 (40.6-51.5)
OxAFQ-proxy			
Physical domain	13.5 (8.11-18.9)	16.6 (13.4-19.9)	15.5 (11.5-19.5)
School & play domain	11.5 (8.0-15.0)	12.6 (10.5-14.8)	12.2 (9.6-14.9)
Emotional domain	12.6 (9.4-15.8)	13.3 (11.3-15.3)	13.0 (10.6-15.5)
Final item domain	2.1 (0.9-3.3)	2.3 (1.6-3.0)	2.2 (1.3-3.1)
All domains	39.7 (27.6-51.9)	44.9 (37.4-52.4)	43.0 (36.9-49.0)
Surgery			
Additional surgery	2 (20 %)	3 (18 %)	5 (19 %)

Values are reported as mean (95% confidence interval).

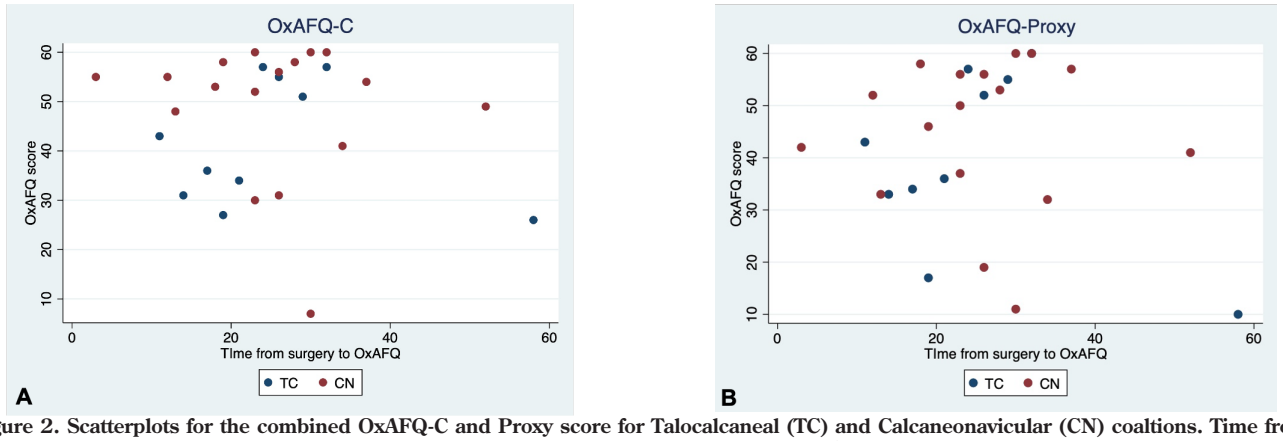

Figure 2. Scatterplots for the combined OxAFQ-C and Proxy score for Talocalcaneal (TC) and Calcaneonavicular (CN) coaltions. Time from surgery to completing the questionnaire is represented on the x-axis and the combined OxAFQ score for all domains is showed on the y-axis.

A: Pearson's coefficient = -0.14 (CN), Pearson's coefficient = -0.07 (TC)
B: Pearson's coefficient = -0.02 (TC), Pearson's coefficient = -0.27 (TC)

lected data may be the time from surgery to completing the questionnaire. However, as seen in Figure 2, there does not seem to be any correlation between the type of coalition, the time from surgery to questionnaire and the OxAFQ for both proxies and children. In fact, the Pearson's correlation coefficient between -0.27 and -0.02 suggests a negligible correlation.

Despite the overall positive outcome upon resection in recent studies, some patients continue to have a symptomatic foot. This raises the issue of need for additional management as the outcome for conservative treatment options differs somewhat with studies reporting a success rate of 25-30% on the short term whilst the long term outcome after 5 years was 74% using conservative treatment.[23,24] An estimation of 25% of all coalitions are symptomatic, leaving the vast majority to be a random non-symptomatic find.[25,26] A prospective study with OxAFQ scores pre- and post-operatively can be performed to clarify this important issue and the improvement or worsening of the condition of the patients after resection of tarsal coalition.

Limitation to this study is the retrospective cross-sectional design. First, no pre-operative data exists.

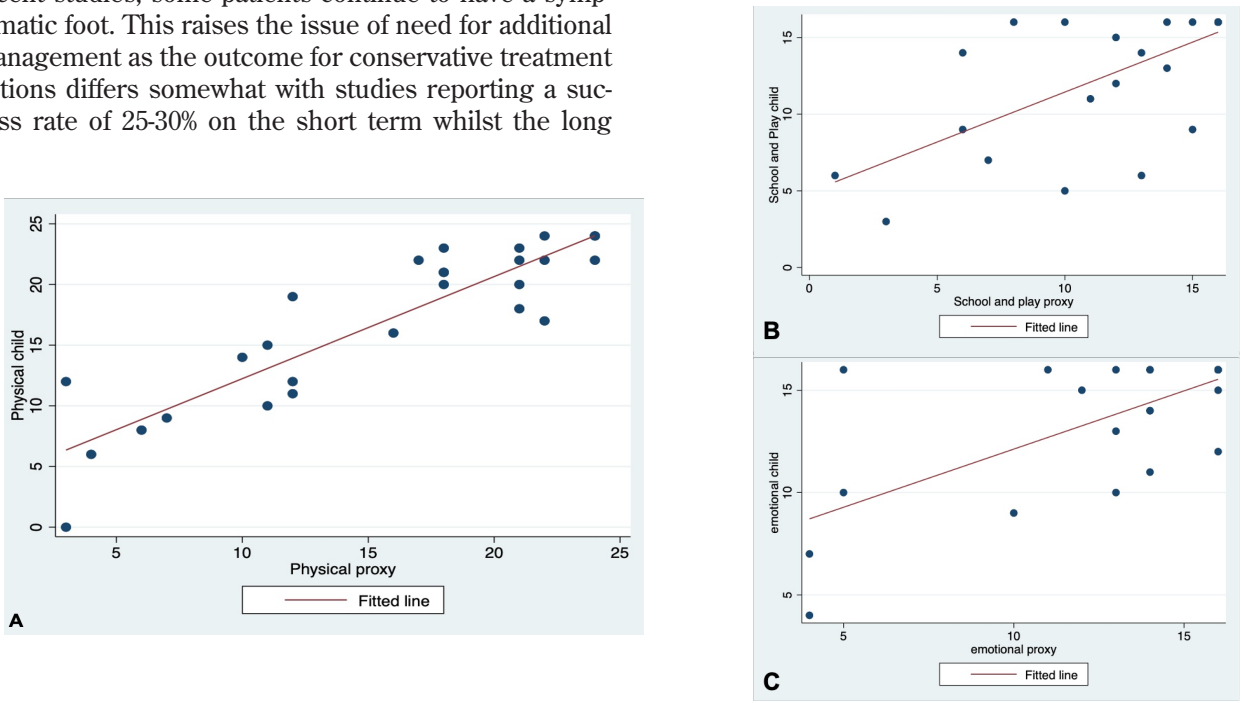

Figure 3. Scatterplots for the Physical, School and Play and Emotional Domain. The OxAFQ score for proxies appears on the x-axis with the matched OxAFQ score for children on the y-axis. Linear regressions have been performed accordingly.

A: Physical domain. Pearson coefficient = 0.89
B: School and Play domain. Person's coefficient = 0.69
C: Emotional domain. Pearson's coefficient = 0.68

Despite the focus of this study being to report data from a validated PROM postoperatively, it could have been advantageous to correlate these data with pre-operative PROM data to investigate improvement or worsening of the condition. Moreover, several bilaterally resected coalitions are present in this study, whilst only the most affected foot was reported in the OxAFQ-C and proxy. This may suggest the presence of a slightly higher OxAFQ-core if a questionnaire was completed for each foot, especially in the physical domain, which scored lower than the two other main domains in relative score. Another limitation is the study population. To achieve a large study population, patients from AUH in Denmark and RLH in the United Kingdom were enrolled. The registration procedure of patients at RLH differed from AUH. Therefore, no search could be done using the ICD-10 code. Instead, a manual search of the theatre lists was performed. This approach of manually identifying patients retrospectively, is more likely to miss some cases than the Danish counterpart, where we were able to search for diagnosis and operation codes. In an attempt to locate some of the possibly missing patients, personal operation lists provided by the consultants were also applied.

In conclusion, children and proxies can receive valid and specific information about the patient reported outcome after surgical resection, with no difference being detected between TC and CN coalitions. Despite the persistent physical affection, the children are less affected emotionally and in their daily play. Notably, OxAFQ-C and proxy were coherent and independent from the time from surgery to completing the questionnaire.

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LOCAL INFILTRATIVE ANALGESIA IS EQUIVALENT TO FASCIA ILIACA BLOCK FOR PERIOPERATIVE PAIN MANAGEMENT FOR PROPHYLACTIC CEPHALOMEDULLARY NAIL FIXATION

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ABSTRACT

Background: Impending pathologic fractures of the femur due to metastatic bone disease are treated with prophylactic internal fixation to prevent fracture, maintain independence, and improve quality of life. There is limited data to support an optimal perioperative pain regimen.

Methods: A proof of concept comparative cohort analysis was performed: 21 patients who received a preoperative fascia iliacus nerve block (FIB) were analyzed retrospectively while 9 patients treated with local infiltrative analgesia (LIA) were analyzed prospectively. Primary outcomes included: visual analog scale (VAS) pain scores, narcotic requirements and hospital length of stay. Patient cohorts were compared via two-sample t-tests and Fischer's exact tests. Differences in VAS pain scores, length of stay and morphine milligram equivalents (MME) were assessed with Wilcoxon rank sum.

Results: The LIA group had more patients treated with preoperative narcotics (p=0.042). There were no significant differences between the FIB and LIA groups in MME utilized intraoperatively (30.0 vs 37.5, p=0.79), on POD 0 (38.0 vs 30.0, p=0.93), POD 1 (46.0 vs 55.5, p=0.95) or POD 2 (40.0 vs 60.0 p=0.73). There were no significant differences in analog pain scale at any time point or in hospital length of stay (78 vs 102 hours, p=0.86).

Conclusion: Despite an increased number of patients being on preoperative narcotics in the LIA group, use of LIA compared with FIB is not associated with an increase in VAS pain scores, morphine milligram equivalents (MME), or length of hospital stay in patients undergoing prophylactic internal fixation of impending pathologic femur fractures.

Level of Evidence: III

Keywords: metastasis, pain

INTRODUCTION

Metastatic carcinoma to bone often requires stabilization to treat or prevent pathologic fracture. Intramedullary nailing is commonly employed to maintain quality of life, provide pain relief, and permit full weight bearing immediately after the operation. Poorly controlled pain following surgery may delay recovery and rehabilitation, and overall, negatively affect the patient outcome.[1]

A nerve block in the fascia iliaca compartment at the pelvic brim is commonly utilized as an analgesia adjunct for this procedure. The block affects the femoral nerve and lateral femoral cutaneous nerve. Blockade of the femoral nerve results in anesthesia of the anterior and medial thigh and knee, as well as the periosteum of the femur. Blockade of the lateral femoral cutaneous nerve confers anesthesia to the anterolateral thigh. However, it does not have efficacy in the path for nail insertion.

Local infiltration analgesia is a form of post-operative pain control which distributes an anesthetic solution directly to the surgical site during the procedure. The solution is typically a long-acting local anesthetic combined with other adjuvants (e.g., epinephrine, ketorolac, opioids)[1-5] that targets nociception and inflammation at its origin. The local blockade of pain, administered by the surgeon, decreases the need for systemic postoperative narcotics. This technique has gained popularity and has been adopted for post-operative analgesia following a range of surgical procedures (orthopedic, general, gynecological, and breast surgeries).[1,6,7] Local infiltration analgesia (LIA) has been shown to be an effective pain treatment modality compared to regional nerve blocks in the adult reconstruction literature.[2,4,5,7] Additionally, it may reduce the risk of peripheral nerve block complications due to injury to the nerve and nerve plexus, as well as rebound neurogenic pain and paresthesia.[8]

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Optimizing pain control has important implications for increasing patient satisfaction, decreasing length of stay, decreasing narcotic consumption, and decreasing rates of post-operative complications by encouraging early mobility.[2] Specific to prophylactic cephalomedullary nailing for impending pathologic femur fractures, there is concern that no regional block predictably covers the area at maximal risk for pain following the procedure--the proximal lateral buttock. While there is evidence supporting LIA in total hip and total knee arthroplasty, no studies to date examine the effects of local or regional anesthesia following prophylactic intramedullary nailing of impending femur fractures. The purpose of this study is to compare infiltration analgesia (LIA) versus fascia iliac block (FIB) as pain control modalities in patients with prophylactic cephalomedullary nailing for metastatic disease.

METHODS

This comparative cohort analysis was approved by an Institutional Review Board and included a retrospective and a prospective cohort. The retrospective cohort was treated with a fascia iliaca block (FIB) and the prospective cohort was treated with local infiltrative anesthesia (LIA).

A retrospective review was performed of patients whose chart contained common procedural terminology (CPT) codes 27187 and 27495 (prophylactic treatment of the proximal femur, and prophylactic treatment of the femur, respectively) between January 1, 2013 and December 31, 2015. Patients were excluded if they did not receive a FIB performed by the anesthesia team prior to surgery. In both retrospective and prospective groups, the exclusion criteria included American Society of Anesthesiologists (ASA) physical status class IV, history of opioid abuse, preexisting lower extremity neurologic impairment, and known hepatic or renal impairment restricting pain control options.

Patients were enrolled prospectively between January 1, 2016 and May 31, 2017 with informed consent if they were scheduled to undergo prophylactic treatment of femoral metastasis with intramedullary nailing along with LIA as their adjunctive anesthetic option. All patients were treated by a single surgeon with prophylactic cephalomedullary fixation of an impending pathologic femur fracture, with or without biopsy of the femur. Patients received general or spinal anesthesia in addition to the adjunctive pain modality associated with their cohort. In all cases, the plan for perioperative pain management was discussed with the regional anesthesia team. The retrospective cohort had a fascia iliaca block in the preoperative holding area or operating room prior to their surgery. In the prospective cohort, once final implant positioning was confirmed and all wounds were irrigated, the surgeon administered the LIA, which included: 30 mL Ropivacaine 0.5% (5mg/ml), 0.25mL Epinephrine 1:1000 (1mg/ml), 1mL Morphine 10mg/ml, 1mL Depo-Medrol 40mg/ml, 1mL Ketorolac 30mg/ml, and NS 0.9% qs to a total volume of 60 mL. This cocktail in a 60mL syringe is in the pharmacy formulary at the institution where the study was conducted as it is employed by surgeons in the adult reconstruction division. Ketorolac was excluded in renal impaired patients, Depo-Medrol was excluded in patients with diabetes mellitus, Epinephrine was excluded in patients with coronary artery disease or cardiac arrhythmias and Morphine was excluded in patients >70.

The injection was delivered around the proximal and middle incisions (consistent with the locations needed to appropriately insert the nail and helical blade through the proximal femur, respectively). The small (~1 cm) distal incisions where cross-lock bolts were placed were not treated. There were no changes to the surgical procedure or implant models during the study. In all cases, the deep dermal layer was closed with inverted interrupted 2-0 monofilament, and the skin was closed with staples.

Postoperatively, patients were admitted through identical order sets. All patients received an order to start physical therapy and occupational therapy once medically stable and a licensed therapist was available. Each patient had plain radiographs of the operative extremity within 24 hours of the procedure to confirm implant positioning. All patients had a hospitalist on staff during hospitalization directing medical management.

Patients were ordered scheduled acetaminophen 650mg q6 hours if no contraindication. Patients were ordered hydrocodone 10mg – acetaminophen 325mg q4 hours prn for severe pain and hydrocodone 5mg – acetaminophen 325 mg q4 hours for mild pain. All were ordered morphine 2mg iv push q3h prn for first 24 hours. Patients had a standardized anticoagulation regimen following surgery in the form of low molecular weight heparin for two weeks followed by oral aspirin for two weeks, unless the patient was on a personalized anticoagulation regimen prior to surgery.

Patient demographic information was collected including body mass index, race, gender, smoking status, preoperative narcotic requirement, and age. Visual analog scale (VAS) pain scores in the preoperative holding area, immediately following surgery in the recovery room, and during the inpatient hospital course were recorded. VAS pain scores were also collected at the 2 and 6 week follow up appointments. Other variables studied included the narcotic pain requirement converted to the morphine milligram equivalent (MME) dose as calculated based

Table 1. Patient Characteristics

	Overall n=30	Fascia Iliaca Block 21 (70%)	Local Anesthesia 9 (30%)	p-value
Age, mean (SD)	60.1 (11.6)	61.3 (10.0)	57.3 (14.9)	0.39
Female, n (%)	18 (60.0)	14 (66.7)	4 (44.4)	0.42
Race, n (%)				
White	25 (83.3)	18 (85.7)	7 (77.8)	0.28
Black	3 (10.0)	1 (4.8)	2 (22.2)	
Hispanic	2 (6.7)	2 (9.5)	0 (0.0)	
BMI kg/m^2, mean (SD)	30.5 (7.7)	31.0 (8.7)	29.4 (4.4)	0.52
Smoker, n (%)	3 (10.0)	2 (9.5)	1 (11.1)	0.99
Pre-op narcotics, n (%)	17 (56.7)	9 (42.9)	8 (88.9)	0.042

BMI-body mass index

on previously accepted methods in the literature, adverse events, and hospital length of stay.[9-12]

Patient characteristics were described as means and standard deviations or counts and percentages by anesthetic type. In our original IRB, we elected to include all available patients who meet inclusion/exclusion criteria in our retrospective analysis, and thus, did not require power calculations. Based on the results of the retrospective aim, power calculations were conducted for the prospective cohort. Comparisons were made via two-sample t-tests or Fisher's exact tests, respectively. Medians and interquartile ranges for VAS pain scores, length of stay, and morphine equivalents were calculated. Statistical significance of differences between the cohorts were assessed with Wilcoxon rank sum tests. Rates of narcotic use at two and six weeks post-operatively were compared with Fisher's exact tests.

RESULTS

Of the thirty patients in the study (Table 1), 18 were female (60%) and 12 were male (40%). The average age of the study participants was 60 (+/- 11.6 years). The majority of the patients were white (83.3%). The LIA group has significantly more patients taking preoperative narcotics (8/9 vs 9/21, p=0.042). The average BMI was 30.5 (+/- 7.7) and 3 patients (10%) were smokers.

There were no significant differences in narcotic use in MME, VAS pain scores, length of hospital stay, reported pain levels at post-operative visits, or narcotic refills between the LIA and FIB groups. (Table 2)

In the FIB group the median MME utilization was 30 MME (IQR 15-39) intraoperatively, 38.0 (23.5-81.0 IQR) on POD 0, 46 (IQR 25-87.5) on POD 1, and 40 (IQR 10-80) on POD 2. VAS scores at POD 0 ranged from minimum of 2 (IQR 0-3) to maximum of 7 (IQR 6-9). POD 1 ranged from 3 (IQR 2-3) to 6 (IQR 6-9). Similarly, POD 2 VAS score ranged from minimum of 3 (IQR 3-4) to maximum of 6 (IQR 6-7). The median length of hospital stay was 78 hours (IQR 52-104). Refills of narcotics were required in 6 patients at the 2 week follow up visit and 8 patients at the 6 weeks follow up orthopedic visit or after telephone encounter to orthopedic team regarding postsurgical pain (Table 2). Narcotic refills or new narcotic prescriptions from other multidisciplinary clinics without clear reference to the surgical procedure were not considered.

Patients in the LIA group required a median MME dose of 37.5 (15.0 – 37.5) intraoperative, 30.0 (IQR 22.5 – 50.0) on POD 0, 55.5 (IQR 30.0 – 66.0) on POD 1, and 60 (IQR 10.0 – 80.0) on POD 2. VAS pain scores ranged from 1 (IQR 0-3) to 8 (IQR 5-9) on POD 0, 3 (IQR 2-3) to 7 (IQR 6-8) on POD 1, and 3 (IQR 2-4) to 7 (IQR 6-8) on POD 2. The average length of hospital stay was 102 (IQR 46 – 147) hours. Refills of narcotics were required in 4 patients at the 2 week follow up visit and 2 patients at the 6 weeks follow up visit. (Table 2)

DISCUSSION

This study examines LIA vs. FIB in patients undergoing prophylactic cephalomedullary fixation for metastatic disease. We determined no significant differences in narcotic use in MME, VAS pain scores, length of hospital stay, reported pain levels at post-operative visits, or narcotic refills between the LIA and FIB groups. This is the first study to examine the efficacy of LIA to regional anesthesia in patients undergoing prophylactic fixation of metastatic disease to bone. As the incidence of metastatic bone disease continues to rise, the need for prophylactic surgical stabilization with intramedullary nail fixation is likely to increase.[13-15] The goal of prophylactic stabilization surgery is adequate pain control permitting early mobility to decrease the risk of perioperative pulmonary complications or venous thromboembolism.[18-19] While this procedure has been shown to impact length of survival, the experience of postoperative pain and potential delayed recovery in an already physiologically compromised patient population remains a concern.[16-17] This study did not demonstrate a difference between LIA

Table 2. Anesthetic Type and Outcomes

	n	Fascia Iliaca Block 21 (70%)	Local Anesthesia 9 (30%)	p-value
Morphine equivalent, median (IQR)				
Intra-op	30	30.0 (15.0-39.0)	37.5 (15.0-37.5)	0.79
Postoperative day 0	30	38.0 (23.5-81.0)	30.0 (22.5-50.0)	0.93
Postoperative day 1	30	46 (25.0-87.5)	55.5 (30.0-66.0)	0.95
Postoperative day 2	30	40.0 (10.0-80.0)	60.0 (10.0-80.0)	0.73
Visual analog scale, median (IQR)				
Postoperative day 0 minimum	30	2 (0-3)	1 (0-3)	0.67
Postoperative day 0 maximum	30	7 (6-9)	8 (5-9)	0.99
Postoperative day 1 minimum	30	3 (2-3)	3 (2-3)	0.87
Postoperative day 1 maximum	30	6 (6-9)	7 (6-8)	0.98
Postoperative day 2 minimum	24	3 (3-4)	3 (2-4)	0.74
Postoperative day 2 maximum	24	6 (6-7)	7 (6-8)	0.56
2 weeks	18	1 (0-4)	1.5 (0-6)	0.81
6 weeks	12	0 (0-0)	3 (2-6)	0.061
No pain at 2 weeks, n (%)	18	6 (50.0)	3 (50.0)	0.99
No pain at 6 weeks, n (%)	12	6 (85.7)	1 (20.0)	0.072
Length of stay (hours), median (IQR)	30	78 (52-104)	102 (46-147)	0.86
Refills of narcotics, n (%)				
2 weeks	25	6 (33.3)	4 (57.1)	0.38
6 weeks	20	8 (57.1)	2 (33.3)	0.63

IQR-interquartile range

and FIB with regard to narcotic requirements in MME, postoperative pain scores or length of stay.

The conventional criticism of LIA is the effects are too short acting to allow for effective pain control and thus negatively impacts recovery. However, a systemic review and meta-analysis of twenty-eight studies of patients undergoing total knee arthroplasty demonstrated lower mean differences in 24- and 48-hour VAS scores with lower probability of postoperative nausea and vomiting in the LIA group compared to no injection or placebo.[20] In addition, prospective randomized clinical trials in the lower extremity reconstruction and trauma setting have evaluated the efficacy of LIA. Spangehl et al.[21] compared pain control related outcomes in patients following primary total knee arthroplasty who received a periarticular injection or a combined femoral and sciatic nerve block. Their study found comparable pain scores in both groups and a decreased length of stay in the group who received periarticular analgesia. Parvateneni et al.[22] performed a level one study demonstrating LIA improved both functional and pain relief measures after total hip and total knee arthroplasty. Beyond arthroplasty, Koehler et al. found that patients with femoral fractures treated with operative intervention and intraoperative surgical site injection of local anesthetic had lower VAS scores throughout the first postoperative day and decreased MME compared to the control group.[23] The use of LIA for treatment of postoperative pain in patients undergoing prophylactic surgery for impending pathologic fracturs has not been reported. The current study parallels these previously published reports demonstrating that LIA offers adequate pain relief leading to active rehabilitation and timely discharge.[1,22,24-26]

Peripheral nerve blocks are technically challenging and dependent on provider accuracy with the ultrasound.[27-28] Vascular puncture, transient paresthesia, and permanent nerve damage are rare but reported complications with this procedure.[8,29,30] Additionally, even if the blockade is planned for sensory nerves, there may be limited efficacy secondary to mismatch between the area of anatomic coverage and structures manipulated during the operation, and there exists potential for the analgesia to spread to motor nerves which act as a fall risk.[31] LIA directly targets the areas of surgical manipulation and can be tailored to capture areas of particular concern.

There are several limitations to this study. The cohorts were reliant on accurate documentation of pain scores; however, this was routine practice on the orthopedic ward with near immediate electronic entry by nursing. The surgeon was not blinded to the treatment in the prospective group which may create inherent bias during the procedure. However, while the variables pertaining to anesthesia and perioperative analgesia were not strictly controlled, both groups had the inpatient

pain medication algorithm originated from a standard electronic template. Additional as needed doses for pain relief were not controlled, but the ordering providers were blinded to the study. It should also be noted that filling an opioid prescription is not a direct corollary of actual patient consumption and that additional opioid prescriptions may have occurred outside the health system. Finally, interpretations from this study are limited by its small cohorts which increases the fragility index of the data. However, this was designed to be a pilot study; future studies with broader data collection and more adequate power are necessary to expand upon these initial findings.

To put these results in a broader context, there is interest among multiple orthopaedic subspecialties, notably hand and adult reconstruction, to optimize postoperative pain protocols to reduce opioid consumption in the midst of an opioid epidemic.[32-35] Higher preoperative opioid use usually leads to increased use postoperatively.[36-38] However, despite the LIA group showing significantly increased usage of preoperative narcotics, there was no difference in narcotic use in the hospital or narcotic refills in the outpatient setting after surgery, signaling that the local infiltrate of analgesics was as effective as the nerve block at managing the immediate postoperative pain.

The ideal perioperative and postoperative anesthesia should be easy to perform, have a rapid onset, allow for early mobilization, and have minimal side effects. This is the first comparative cohort study of prophylactic femoral nailing demonstrating LIA versus FIB is not associated with an increase in narcotic requirement, pain scores, or length of hospital stay. Further investigation in larger numbers is warranted to verify these findings.

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NOVEL SCORING CRITERIA FOR PREOPERATIVE PREDICTION OF NEOADJUVANT CHEMOTHERAPY RESPONSE IN OSTEOSARCOMA

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ABSTRACT

Background: The extent of tumor necrosis after neoadjuvant chemotherapy is an important predictive factor of survival in osteosarcoma. However, the response to chemotherapy is not known until after the definitive resection and limits the utility of this information for operative planning. Our study questions include: 1) Are there clinical and radiographic factors following neoadjuvant chemotherapy, but prior to the tumor resection, that may aid in predicting response to treatment? 2) Can we combine these criteria into a predictive composite score that can identify good and poor responders to chemotherapy?

Methods: We identified consecutive patients diagnosed with osteosarcoma and managed with neoadjuvant chemotherapy prior to surgical resection. We assessed post-chemotherapy tumor ossification, tumor size and growth, and the presence of pain to devise a scoring criteria to predict the percent necrosis on the final histologic specimen. Bivariate analyses were done, and a receiver operating characteristic curve was constructed to determine predictive capacity.

Results: Out of the 40 patients included in this study, 15 (38%) had a good response (≥ 90% necrosis) to treatment and ten patients (25%) had a poor response with ≤ 50% necrosis. Tumor size, growth and increase in ossification were significantly associated with a good response to treatment. For good responders, a composite score of 6 was seen to attain the highest sensitivity and specificity, 100% and 84%, respectively. Tumor size, no change in ossification, and post-chemotherapy pain were significantly associated with a poor response to treatment. For poor responders, a composite score of 7 was seen to have the highest sensitivity and specificity, 100% and 63%, respectively.

Conclusion: Compared to the use of one single factor, our combined scoring criteria demonstrated a far improved accuracy in identifying good responders to neoadjuvant chemotherapy, where a score of 6 or less is predictive of a good response. However, the specificity of this scoring criteria to predict poor responders was low, indicating that this criterion may not be the most accurate method to identify poor responders. The utility of this score has implications regarding pre-operative counseling of the patient and operative planning.

Level of Evidence: III

Keywords: orthopaedic surgery, osteosarcoma, neoadjuvant chemotherapy, predictive factor

INTRODUCTION

In the past, osteosarcoma was treated with surgery alone, and more specifically, amputation. The five-year survival rate at that time was abysmally low at approximately 22%.[1] The addition of chemotherapy significantly improved the prognosis of patients with osteosarcoma and also contributed to limb-salvage surgery being an effective treatment. Now, five-year survival rates have increased to 60%.[1,2] Despite these initial advancements in treatment, local recurrence and metastatic spread of osteosarcoma continues to be a significant problem and subsequent attempts to improve survival rates have been disappointing. It is well accepted that the extent of tumor necrosis after neoadjuvant chemotherapy is an important predictive factor of local recurrence and survival in osteosarcoma.[3-8] In most of these studies, tumor necrosis of 90% or greater was considered "good" and less than 90% was defined as "poor" response.[3-10]

Recent attempts have investigated the predictive value of radiological response to neoadjuvant chemotherapy in osteosarcoma patients.[11-15] However, to date there is not an easily determined and accurate scoring system using clinical and radiograph factors to predict response to neoadjuvant chemotherapy. From the perspective of the surgeon, assurance of a good response to chemotherapy will comfortably allow for a closer margin (within one-two mm of important structures) and a limb sparing surgery, while a poor response may make a plan for wider mar-

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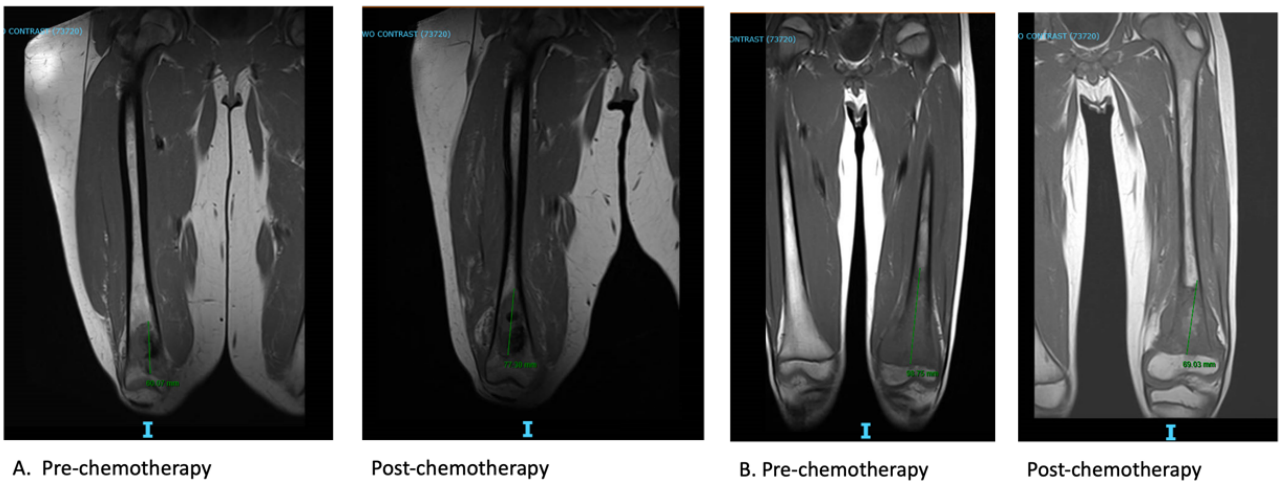

Figure 1. Measurements of tumor size in greatest dimension on MRI of femur of two patients. (A) MRI shows an increase in the greatest dimension of the tumor after neoadjuvant chemotherapy. (B) MRI shows a decrease in the greatest dimension of the tumor after neoadjuvant chemotherapy.

gins, or possibly an alteration in plan to an amputation, more advisable. The difficulty in this clinically is that the response to chemotherapy is not known until days after the surgery has been completed, compromising the surgeon's ability to make the most appropriate operative decision. Accurately predicting the response to chemotherapy would have the potential to improve outcomes by allowing the surgeon to make adjustments in the treatment plan, including surgery and surveillance, prior to the operative encounter.

Our goals are to (1) identify clinical and radiographic factors following neoadjuvant chemotherapy, but prior to the tumor resection, that may aid in predicting a good or poor response to treatment; and (2) create a composite score that will identify good and poor responders to chemotherapy.

METHODS

This study was an institutional review board-approved single-institution retrospective chart review of patients who had osteosarcoma from an ongoing cohort of extremity sarcoma patients from September 2010 to February 2020. Our population of interest included patients diagnosed with osteosarcoma and managed with multi-agent neoadjuvant chemotherapy, followed by tumor excision. We included all histologic subtypes of high-grade osteosarcoma, as well as localized or metastatic disease at diagnosis. We excluded cases of recurrent osteosarcoma, patients who were not treated with neoadjuvant chemotherapy or did not undergo tumor removal and patients with incomplete medical records.

Patient records, including clinic notes, pathology reports, and radiology reports, were reviewed to determine

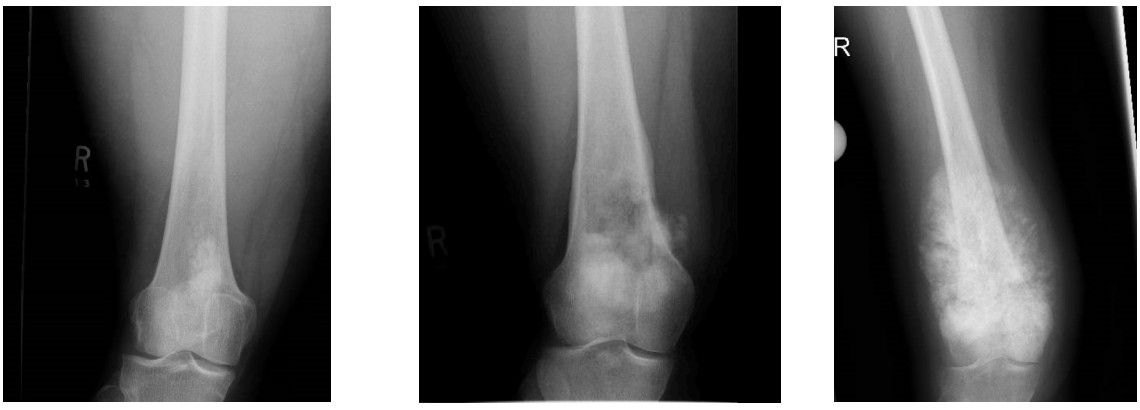

Figure 2. Examples of tumor ossification on plain radiographs AP view of distal femur of three different patients. (A) Minimal ossification of the tumor was demonstrated in this plain radiograph. (B) Moderate ossification of the tumor was demonstrated in this plain radiograph. (C) Extensive ossification was demonstrated in this plain radiograph.

Table 1. The Proposed Scoring System (The Larger the Score, The Worse the Outcome)

	Score		
Variable	1	2	3
Change in Size	Smaller	No Change	Larger
Post-Chemo Size (cm)	≤ 10 cm		> 10 cm
Post-Chemo Pain	No		Yes
Ossification Change	Increase		No Increase

underlying patient and tumor characteristics. From the medical records, we identified potential predictive factors including presence of pain, tumor size and growth on MRI, and tumor ossification on plain radiographs.

Presence of pain was measured using the 10-point Visual Analog Scale (VAS). VAS score ranges of 1-3, 4-6, and 7-10 were minimal, moderate, and severe pain, respectively. The VAS score at the pre-chemotherapy visit was recorded as the baseline pain while the VAS score after completion of chemotherapy, just prior to surgery, was recorded as the post-chemotherapy pain.

Tumor size in the greatest dimension and growth was recorded using the MRI radiology reports before and after chemotherapy. The term "No change" in tumor size was reported if there was ≤ five mm size change. MRI imaging review by the authors was used if the radiology report was unclear in its description (Figure 1). Post-chemotherapy tumor size and overall change in size was utilized in the composite score.

Tumor ossification was assessed on plain radiographs by two separate observers. Pre-chemotherapy and post-chemotherapy radiographs were viewed side by side, where ossification was graded as none, minimal, moderate, or extensive. There were no pre-set criteria to classify the ossification, hence this was done subjectively by both observers prior to independent review (Figure 2). We determined a patient to have an overall increase in ossification if the post-chemotherapy ossification was graded higher than the pre-chemotherapy ossification. A second assessment of radiographs were then done by both observers together at a later date. Kappa statistics were utilized to measure the degree of agreement between each observer.

Our primary outcome was percent tumor necrosis on final histopathology report, which was categorized based off the Huvos four-grade system.[16] For the analysis, we defined a good response as necrosis ≥ 90% and a poor response when necrosis is ≤ 50% on the final histologic specimen.

Bivariate methods (Fisher's exact testing) were used to investigate the association of identified clinical and radiographic factors with percent tumor necrosis. With these identified clinical and radiographic factors, we

Table 2. Patients' Characteristics and Tumors and Treatment Factors Between the 2 Groups which are Based on Tumor Necrosis at 90% and 50% Cutoff

Demographics	Total patients (n=40)	≥ 90% Necrosis (%) (n=15)	< 90% Necrosis (%) (n=25)	> 50% Necrosis (%) (n=30)	≤ 50% Necrosis (%) (n=10)
Age					
< 20	20	11 (74)	9 (36)	18 (60)	2 (20)
20-40	8	2 (13)	6 (24)	4 (13)	4 (40)
> 40	12	2 (13)	10 (40)	8 (27)	4 (40)
Sex					
Male	22	9 (60)	13 (52)	17 (57)	5 (50)
Female	18	6 (40)	12 (48)	13 (43)	5 (50)
Location					
Lower Limb	32	10 (67)	22 (88)	23 (77)	9 (90)
Upper Limb	7	4 (27)	3 (12)	6 (20)	1 (10)
Pelvis	1	1 (6)	0 (0)	1 (3)	0 (0)
Histological subtype					
Conventional	34	13 (87)	21 (84)	24 (80)	10 (100)
Telangiectatic	3	2 (13)	1 (4)	3 (10)	0 (0)
Parosteal	1	0 (0)	1 (4)	1 (3)	0 (0)
Periosteal	1	0 (0)	1 (4)	1 (3)	0 (0)
Giant cell rich	1	0 (0)	1 (4)	1 (3)	0 (0)
Metastasis at Diagnosis					
Yes	7	3 (20)	4 (16)	5 (17)	2 (20)
No	33	12 (80)	21 (84)	25 (83)	8 (80)

Table 3. Probability of a Good Response to Treatment "Tumor Necrosis ≥ 90%"

Score	Good Response ≥ 90%	Not Good Response <90%	% Good	% Not Good
4	6	1	86%	14%
5	4	1	80%	20%
6	5	2	71%	29%
7	0	7	0%	100%
8	0	5	0%	100%
9	0	3	0%	100%
10	0	3	0%	100%
11	0	3	0%	100%

devised scoring criteria to predict good (≥ 90%) or poor (≤ 50%) responders to neoadjuvant chemotherapy (Table 1). With the devised scoring criteria, we scored all 40 patients and conducted sensitivity and specificity analyses to test the statistical validity of the scoring criteria. We also constructed a receiver operating characteristic (ROC) curve to determine predictive capacity of the composite score we created.

RESULTS

Out of the 630 extremity sarcoma patients, a total of 40 patients met the study criteria with a median age of 20 years (range, 8-70 years) (Figure 3). There were 22 male patients and 18 female patients. Seven patients presented with metastases at diagnosis, while 33 did not. Lower extremity (32) osteosarcomas were the most frequent, followed by upper extremity (7) and pelvic (1) osteosarcomas. The most common histologic subtype of osteosarcoma was conventional (34), followed by telangiectatic (3) and then one each of giant cell rich, periosteal, and parosteal with a high-grade component. Of the conventional subtypes of osteosarcoma, 16 cases were unspecified, 10 were chondroblastic, 6 were osteoblastic and 2 were of the fibroblastic variant (Table 2).

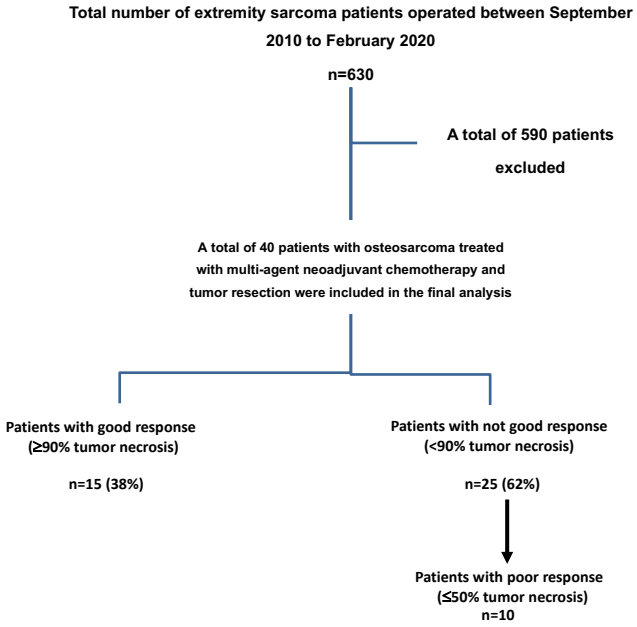

Figure 3. Patients' participation status flowchart.

Overall, of the 40 patients included in this study, 15 (38%) had a good response to treatment, with four of those patients having complete tumor necrosis. Ten patients (25%) had a poor response to treatment with ≤ 50% necrosis. All 40 patients were scored using the criteria, with all patient scores ranging from 4 to 11.

In the good responders' group, scores ranged from 4 to 6, while in those without a good response, scores ranged from 4 to 11. The data indicated that 86% of patients (6 of 7) with a score of 4, 80% of patients (4 of 5) with a score of 5, and 71% of patients (5 of 7) with a score of 6 were good responders. There were no good responders with a score greater than 6. (Table 3). The sensitivity and specificity of each score were plotted on the ROC curve, where a score of 6 is seen to attain the highest sensitivity and specificity: 100% and 84%, respectively. Thus, a score of 6 reflects a cutoff point for

Table 4. Probability of a Poor Response to Treatment "Tumor Necrosis ≤ 50%"

Score	*Poor Response ≤ 50%*	*Not Poor Response >50%*	*% Poor*	*% Not Poor*
4	*0*	*7*	*0%*	*100%*
5	*0*	*5*	*0%*	*100%*
6	*0*	*7*	*0%*	*100%*
7	*4*	*3*	*57%*	*43%*
8	*2*	*3*	*40%*	*60%*
9	*0*	*3*	*0%*	*100%*
10	*1*	*2*	*33%*	*67%*
11	*3*	*0*	*100%*	*0%*

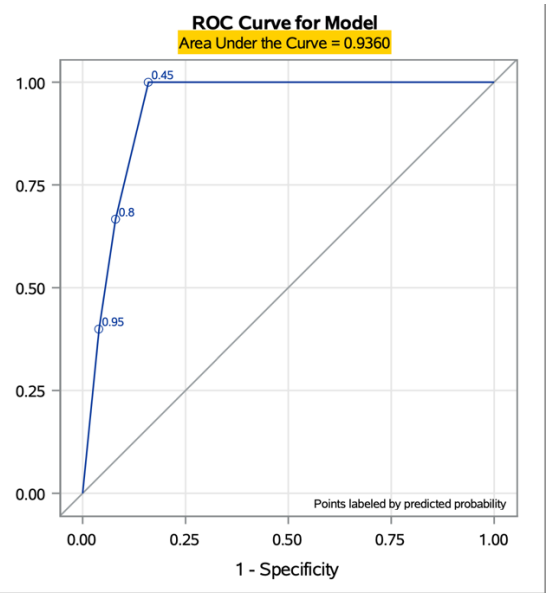

Figure 4. ROC Curve for good responders. A score of 6 is seen to attain the highest sensitivity and specificity, 100% and 84% respectively; this reflects the cutoff score for predicting a good response to treatment.

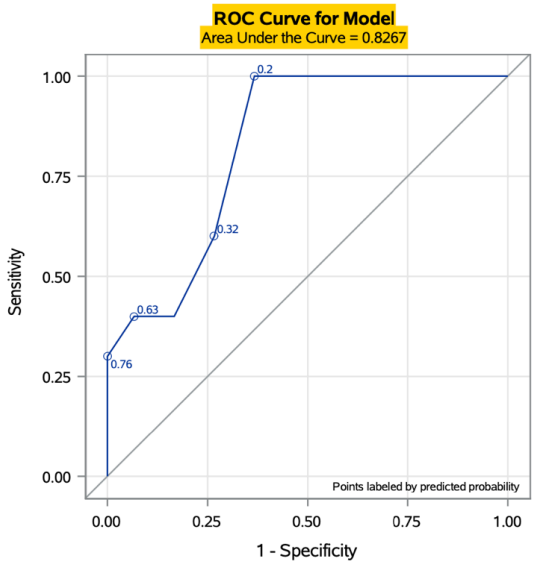

Figure 5. ROC Curve for poor responders. A score of 7 is seen to attain the highest sensitivity and specificity, 100% and 63% respectively; this reflects the cutoff score for predicting a poor response to treatment.

predicting a good response to neoadjuvant chemotherapy (Figure 4). Our criterion was able to attain a positive predictive value of 79%, a negative predictive value of 100%, and accuracy of 90%.

We used this same scoring criteria to predict the poor responders to treatment, ≤ 50% tumor necrosis after neoadjuvant chemotherapy. Patient scores in this group ranged from 7 to 11, while all other patients with a tumor necrosis of > 50% had scores ranging from 4 to 11. The data indicated that 57% of patients (4 of 7) with a score of 7, 40% of patients (2 of 5) with a score of 8, 0 of 3 patients with a score of 9, 33% of patients (1 of 3) with a score of 10, and 100% of patients (3 of 3) with a score of 11 were considered to be poor responders to treatment (Table 4). Again, the sensitivity and specificity of each score were plotted on the ROC curve, where it is shown that a cutoff score of 7 is seen to have the highest sensitivity and specificity: 100% and 63%, respectively (Figure 5).

Bivariate analyses of each predictive factor utilized in our proposed scoring criteria was done to assess whether any individual factor was as effective as the scoring criteria to predict treatment response, and to

Table 5. Predictive Factors for Tumor Necrosis in Osteosarcoma at 90% Cutoff

Predictive Factors	≥90% Necrosis (%) (n=15)	< 90% Necrosis (%) (n=25)	p value
Tumor change in size			p < 0.01*
Larger	0 (0)	9 (36)	
Smaller	11 (73)	2 (8)	
No change	4 (27)	14 (56)	
Post-chemo tumor size			p < 0.01*
> 10 cm	1 (7)	13 (52)	
≤ 10 cm	14 (93)	12 (48)	
Post-chemo pain			p = 0.32
Yes	4 (27)	12 (48)	
No	11 (73)	13 (52)	
Post-chemo ossification			p = 0.02*
Increase	15 (100)	16(64)	
No Increase	0 (0)	9 (36)	

*Proportions between the two groups are compared using Chi-square test or Fischer exact, p value of ≤ 0.05 is significant.

Table 6. Predictive Factors for Tumor Necrosis in Osteosarcoma at 50% Cutoff

Predictive Factors	> 50% Necrosis (%) (n=30)	≤ 50% Necrosis (%) (n=10)	p value
Tumor change in size			p = 0.03*
Larger	6 (20)	3 (30)	
Smaller	13 (43)	0 (0)	
No change	11 (37)	7 (70)	
Post-chemo tumor size			p = 0.72
> 10 cm	10 (33)	4 (40)	
≤ 10 cm	20 (67)	6 (60)	
Post-chemo pain			p < 0.01*
Yes	8 (27)	8 (80)	
No	22 (73)	2 (20)	
Post-chemo ossification			p = 0.03*
Increase	26 (87)	5 (50)	
No Increase	4 (13)	5 (50)	

*Proportions between the two groups are compared using Chi-square test or Fischer exact, p value of ≤ 0.05 is significant.

justify its inclusion in the overall scoring criteria. There was a strong association between the tumor's growth response to treatment and tumor necrosis. Among the 15 good responders; the tumor decreased in size in 11 (73%) patients and had no change in size in four (27%) patients ($p < 0.01$) (Table 5.) In addition, 14 (93%) of the good responders had a post-treatment tumor size of ≤10 cm, compared to only one patient who had a tumor size of >10 cm ($p < 0.01$). There was also an association between change in tumor size and ≤ 50% tumor necrosis. Among the poor responders; the tumor grew larger in three (30%) patients and had no change in size in seven (70%) patients ($p = 0.03$) (Table 6).

After chemotherapy, 16 patients had residual pain while 24 patients reported being pain free. While there was no strong association among the good responders, we did find that eight (80%) of the poor responders had residual post-chemotherapy pain, compared to only two (20%) who did not have any pain ($p < 0.01$).

After evaluating the data, a high degree of agreement on evaluation of ossification existed between each observer, with a kappa score of .73, indicating 90% agreement. In context, a kappa score of 1 implies perfect agreement, while a kappa score of .61-.80 corresponds to substantial agreement (Table 7). There was a significant association with an overall increase in tumor ossification and a good response to treatment. All 15 good responders had an increase in post-chemotherapy tumor ossification compared to pre-chemotherapy ($p = 0.02$).

We found a significant association with an overall no change in tumor ossification and a poor response to treatment, where 55% of patients with no change (5 of 9) in ossification, compared to 16% of patients who had an increase (5 of 31) were poor responders to treatment ($p = 0.03$).

Table 7. Inter-observer Reliability of Evaluation of Tumor Ossification

Observer	Total (n =40)	≥ 90% Necrosis (n=15)	≤ 50% Necrosis (n=10)
A			
Increase in ossification	29	14	4
No increase	11	1	6
B			
Increase in ossification	31	15	5
No increase	9	0	5

Inter-observer reliability measured by Cohen's Kappa, with k=0.73 indicating 90% agreement.

DISCUSSION

Patients diagnosed with osteosarcoma will typically be managed with a course of neoadjuvant chemotherapy, followed by tumor resection. Many studies have shown that the final histologic response to neoadjuvant chemotherapy is an important predictive factor for overall outcome in osteosarcoma. Unfortunately, this knowledge is not known until days after the surgery has been completed. Based on the patient's progression of pain, tumor growth, or other factors, a physician may have some idea of how well a patient is responding to chemotherapy during their treatment. However, to date, there has been no definitive clinical tool utilizing the association of clinical findings with response to chemotherapy. Therefore, the main purpose of our study was to create a scoring criterion that will accurately predict how a patient has responded to neoadjuvant chemotherapy based upon predictive clinical and radiographic factors prior to the tumor resection.

Studies by Miwa et al. evaluated various radiologic factors, including sclerotic change on plain radiographs and percent reduction of the maximal diameter of the mass on MRI. They used these imaging modalities and findings to create a combined radiological scoring system and found a high correlation with histologic response to neoadjuvant chemotherapy.[12,13] Our study included similar radiologic factors of tumor ossification and tumor change in size, along with the final tumor size itself in our scoring criteria to evaluate the likelihood of having a good response to treatment. We found a significant association between these individual factors and a good response to treatment. Several other studies have also shown that increased ossification of the tumor could be a sign of chemotherapeutic response.[17-20] While these factors individually demonstrated high sensitivity in predicting a good response, we found that specificity was low. Only 54% (14 of 26) of patients with a final

tumor size of ≤ 10 cm actually had a good response to treatment. In addition, 48% (15 of 31) of patients with an increase in post-chemo ossification had a good response to treatment. This suggests that these factors, while sensitive, are not adequate by themselves to predict a good response to neoadjuvant chemotherapy.

A similar study by Amit et al. looked at the association of pain with histologic response to chemotherapy and found that resolved pain with a great VAS score reduction was predictive of a good histologic response with a positive predictive value of 66.67%. They also reported that persistence of pain with minimal reduction predicted a poor response, with a negative predictive value of 87.5%.[21] Our cohort did not show the same association between pain and a good response to treatment. However, our data did show that presence of pain does seem to predict the likelihood of being classified as a poor responder to treatment, where 50% (8 of 16) of patients with persistent pain had a poor response. Since the clinical evaluation of pain can be subjective, our scoring criteria simplifies this issue by classifying pain as either absent or present after treatment.

Our approach to this study was similar to Mirels in intent, where he evaluated the predictive value of known risk factors of an impending pathologic fracture in a long bone affected by metastases and then compared the accuracy with a proposed scoring system comprised of those risk factors. In his study, the weighted scoring system demonstrated the highest accuracy, where a score of 9 or greater highly indicated prophylactic fixation of the lesion.[22] Our study was able to demonstrate that our proposed scoring criteria was more accurate in predicting a good histologic response to treatment compared to any single identified clinical or radiographic factor. The results of our ROC curve were promising, as it demonstrated that our proposed criterion was able to achieve a high sensitivity and specificity of predicting a good response to neoadjuvant chemotherapy at the cutoff score of 6. At the end of a patient's course of neoadjuvant chemotherapy, the attending physician can assess the patient's response to treatment by utilizing this criterion. With a patient having a score of 6 or less, the attending physician can conclude that there is a high likelihood of the patient responding well to treatment and can carry on with their typical surgical management. On the other hand, a score of greater than 6 suggests that the patient has not had an optimal response to treatment and may warrant heightened awareness of the intended surgical margins in the preoperative plan to ensure they will be widely free of tumor. To take a hypothetical example, in osteosarcoma involving the proximal fibula, the surgeon must decide whether to preserve the peroneal nerve. In cases with a composite score ≤ 6, the decision may be justified as the tumor is likely diffusely necrotic and a periosteal margin will be adequate and negative. However, if there are clinical or radiographic features that are concerning and result in a score of 7 or greater, the surgeon may consider sacrificing the nerve to ensure margins clear of viable tumor and decrease the risk of local recurrence. The utility of this score has implications regarding pre-operative counseling of the patient, surgical margins, borderline limb salvageable presentations, and functional preservation. In our study, all the poor responders of ≤ 50% necrosis had a score of 7 or more. However, the specificity of this scoring criteria to predict the poor responders was very low at 63%, indicating that this criterion may not be the most accurate method to identify poor responders.

There are limitations to this study that merit mention. First, our numbers are small, and this is preliminary data from which no clinical decisions should be drawn at this stage. Validation studies of different populations of many more patients will be required to confirm or improve upon these suggested values and predictive variables. Next, we lacked objective criteria supported by literature that could be used to measure the degree of tumor ossification. However, our study did demonstrate significant inter-observer reliability in independently reviewing ossification with our determined subjective criteria. This indicates that our methodology in grading the change in ossification is reliable and accurate. Still, with the lack of objective criteria, other observers may have difficulty in reproducing identical results and this will be important to note on validation studies. Further, our study did not investigate overall survival and notable events such as local recurrence. These outcomes are very important in the management of osteosarcoma, and further investigation must still be done to demonstrate the utility and importance of a predictive criteria. Necrosis of the specimen is well known as an important factor that predicts survival, so we believe we are justified to use this as our surrogate measure for later oncologic events.

In conclusion, our study supports the accuracy of our proposed criteria and has the potential to be an effective tool in assessing and managing cases of osteosarcoma, in particular by predicting good responders to neoadjuvant chemotherapy. In our evaluation of identified factors, we found that a decrease in tumor size, the tumor size itself, and an increase in tumor ossification is significantly associated with a good response to multi-agent neoadjuvant chemotherapy. While we also did not find an association between pain and a good response to treatment, we still found some relation regarding a poor response to chemotherapy. The inclusion of all four of these factors in a combined scoring criteria shows a far improved accuracy in identifying good responders to neoadjuvant

chemotherapy compared to the use of one single factor, or any other combination of the four factors. However, since our study is small, we propose further investigation of our criteria by assessing and scoring a larger sample size to ensure similar levels of sensitivity and specificity.

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ACCURACY OF X-RAY AND MAGNETIC RESONANCE IMAGING IN DEFINING THE TUMOR MARGIN IN PRIMARY BONE SARCOMA

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ABSTRACT

Background: Limb-salvage surgery for primary bone sarcomas are preceded by X-ray and MRI for surgical planning. However, the accuracy of X-ray and MRI predicted margins are not well described. Our study examined these questions: (1) How accurately do X-ray and MRI margin measurements reflect the true margin on pathology reports? (2) Do X-ray or MRI margin measurements have smaller differences compared to pathology reports? (3) How many X-ray or MRI margin measurement differences were greater than 1 cm, 2 cm, and 3 cm from pathology reports? (4) Is there an X-ray or MRI view that consistently results in a smaller difference from pathology reports?

Methods: This retrospective chart review examined patients with primary bone sarcoma treated with limb-salvage surgery. Reviewers used electronic measurement tools to determine margins from X-ray or MRI based on the resection length of the pathologic specimen. Mean differences of margin measurements to pathology reports were calculated. We determined outliers of imaging margin measurements at 1 cm, 2 cm, and 3 cm differences to pathology reports.

Results: In the total cohort of 39 patients, the mean difference of X-ray and MRI margins compared to pathology reports were 1.09 cm (st dev 0.79 cm) and 0.71 cm (st dev 0.70 cm), respectively. MRI margin measurements had smaller differences compared to pathology reports than X-ray in 32 of 38 cases (84%) with complete imaging. X-ray outliers at 1 cm, 2 cm, and 3 cm differences were 36, 14 and 2 respectively for 70 margin measurements and MRI outliers at 1 cm, 2 cm, and 3 cm differences were 17, 6, and 0 respectively for 66 margin measurements. The views with the smallest difference were anterior-posterior X-rays and MRI views with the closest predicted margin.

Conclusion: Electronic MRI margin measurements with the closest predicted margin provided the smallest differences with pathology reports and are therefore the most accurate for preoperative planning. When there is adequate residual diaphysis for reconstructive fixation, surgeons should plan for a 3 cm bone margin using MRI measurements to ensure complete removal of the intramedullary extent of sarcoma.

Level of Evidence: IV

Keywords: bone, tumor, surgery, salvage, limb, margin, mri, x-ray, osteosarcoma

INTRODUCTION

Primary bone sarcomas account for 3-6% of childhood cancers and less than 1% of cancers in adults.[1,2,3,4] There is a bimodal distribution of primary bone sarcomas with a first peak incidence at 15 years of age and the second peak incidence in elderly over 65 years of age.[2,4,5] Primary bone sarcomas typically originate near the ends of long bones such as the femur or tibia.[5,6,7] In the past, treatment relied heavily on limb amputation.[8] Fortunately, advances in preoperative imaging, surgical technique, reconstructive options, and systemic therapy have allowed treatment to shift to limb-salvage surgery.[8,9,10,11,12] Prior to surgical resection, patients with primary bone sarcomas undergo diagnostic X-ray and magnetic resonance imaging (MRI).[12,13] The X-ray provides information about the tumor-bone interface, periosteal reaction, mineralization, and an estimate of the tumor extent.[13] MRI is used to obtain a more detailed picture of the tumor when sarcoma is suspected.[12,13,14] Specifically, MRI provides additional details about the involvement of the joint or growth plate, relationship to nearby neurovascular bundles, and the extension of the tumor into surrounding soft tissue or medullary canal.[12] The ability of MRI to determine the extent of intramedullary extension is one of the factors that makes limb-salvage surgeries possible and remains a critical clinical tool in operative planning.[12]

Rationale

One critical decision that the surgeon must make is where to perform the corticotomy to ensure that all of

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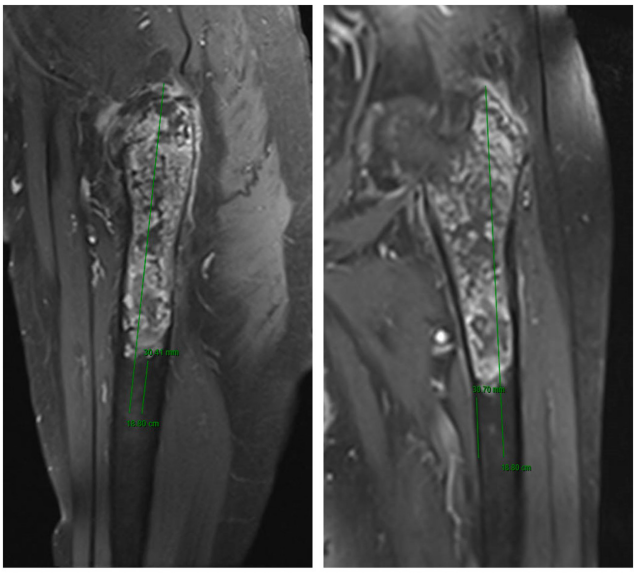

Figure 1. Representative electronic measurement method on MRI. T1 weighted fat-suppressed MRI of a chondrosarcoma of the left proximal femur in a sagittal plane (left) and coronal plane (right). The resected length of bone in this patient was 18.8 cm indicated by the longer green line in each panel.

the intramedullary extension of the tumor is removed. If an inappropriately close margin is planned, the surgical resection may fail to completely remove the tumor, resulting in an increased risk of local recurrence and a worse prognosis.[12,15] Alternatively, removal of an excessive amount of normal tissue with an unnecessarily large margin may limit reconstructive options and compromise function, thus impacting the quality of life. Therefore, the goal is for a safe and adequate surgical margin that allows for an optimal reconstruction and functional outcome.[12,15] X-ray and MRI are the primary clinical tools surgeons have to plan the surgical margin that will be executed during the operation.[16] Although MRI and X-ray are universally used to plan the surgical margins of primary bone sarcoma, the accuracy of electronic margin measurements are not well described.[16] Developing a better understanding of the accuracy of X-ray and MRI will help ensure that operations are planned to minimize the risk of an unanticipated positive intramedullary margin.

Study Questions

1. How accurately do X-ray and MRI margin measurements reflect the true margin distance on pathology reports?

2. Do X-ray or MRI margin measurements have smaller differences compared to pathology reports?How many X-ray or MRI margin measurement differences were greater than 1 cm, 2 cm, and 3 cm from pathology reports?

3. Is there an X-ray or MRI view that consistently results in a smaller difference from pathology reports?

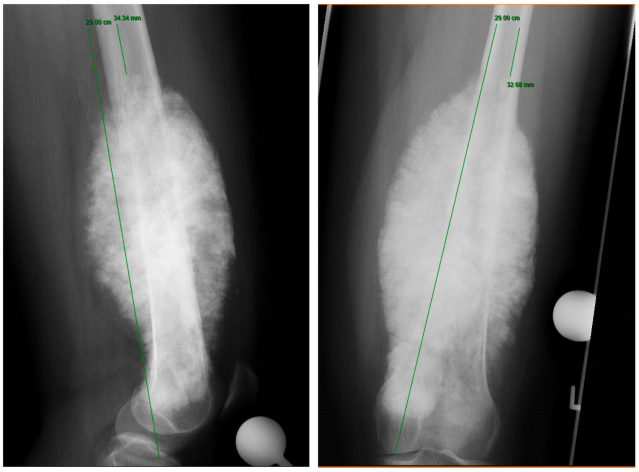

Figure 2. Representative electronic measurement method on X-ray. Plain film of a distal femur with osteosarcoma in a lateral view (left) and anterior-posterior view (right). The resected length of bone in this patient was 29.0 cm indicated by the longer green line in each panel.

METHODS

Study design and setting

This study was a retrospective chart review of patients with a primary bone sarcoma in a long bone treated with limb-sparing surgery between March 2011 and May 2020. Two non-blinded reviewers collected margin measurements with the Carestream Vue Motion™ version v12.2.1.3 measurement tool software on selected X-ray and MRI images in our electronic medical record.

Participants/study subjects

Inclusion criteria were resections involving one joint only, a complete pathology report describing the dimensions of the tumor and bony specimen, and complete imaging of the tumor on X-ray or MRI. Exclusion criteria were resections of the entire long bone, incomplete pathology reports, intercalary resections, and amputations. From an initial cohort of 52 patients, three patients were excluded because the resection was extra-articular and the distance from the joint of the affected bone was not reported, three were excluded because the resection was an amputation, and seven cases were excluded because the pathology reports did not describe the margin sufficiently. This study analyzed 39 cases total, of these cases, three were missing complete X-ray imaging, and one case had incomplete MRI data. Analysis was still conducted on these cases for the imaging that was available. The diagnoses of the 39 patients were: 27 osteosarcomas, 10 chondrosarcomas, 1 leiomyosarcoma, and 1 peripheral nerve sheath tumor.

Description of study

Preoperative X-ray and MRI images were collected from the electronic medical record of the selected patients. We first obtained the total bony resection length

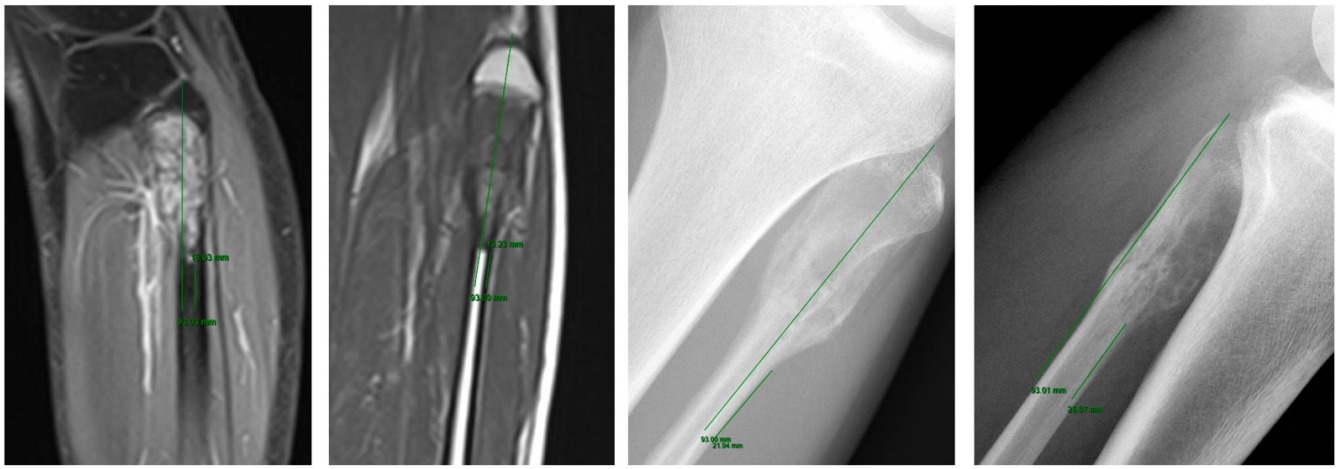

Figure 3. This figure demonstrates the margin measurements on a fibula with osteosarcoma from a sagittal T1 fat-suppressed MRI, coronal TSE T1 MRI, A-P plain film X-ray, and a lateral plain film X-ray respectively from left to right. The bony resection was 9.3 cm as indicated by the long green line in each image, and the pathology reported a margin of 1.6 cm. The margins measured from each image in the figure and the respective differences from the pathology value is tabulated in Table 1.

and final reported intramedullary margin distance from the pathology report. This length was then measured on the imaging from the most proximal or most distal portion of the resected articular surface towards the opposite end of the long bone where the bone cut occurred. This line was made parallel with the longest dimension of the bone. The two non-blinded reviewers (TK, OH) then measured from the end of the visible tumor on the imaging study to the end of the resection. This measured margin distance was then compared to the reported margin distance from the pathology report (Figures 1, 2).

Variables, outcome measures, data sources, and bias

The primary variable of interest was the absolute difference between the margin measurement on X-ray or MRI imaging and the margin from the pathology report. The measurements on X-ray images were made on anterior-posterior and lateral plain films. MRI measurements were made initially on coronal and sagittal T1 images; when T1 images were unavailable or difficult to interpret, T1 fat-suppressed or short tau inversion recovery (STIR) was used. Although both imaging techniques are valid, STIR has been shown to slightly overestimate the tumor size more than T1 weighted imaging.[17] To minimize this T1 images were used in all cases in which T1 images were available for a given view. Due to the possibility of interobserver variability the study utilized two observers who each measured the margin on an image independently. The observers then compared margin measurements and agreed upon one value based on further discussion and imaging review. This electronic margin measurement was compared to the margin in the pathology report and the absolute difference of the two values was obtained (Figure 3, Table 1). The two reviewers were non-blinded; it is possible knowledge of the pathology reported margin biased margin measurements on images. This bias was minimized by utilization of two observers and careful comparison of the margin measurements on imaging.

Study size and analysis

The number of patient cases analyzed in this study was determined by collecting consecutive patients in our electronic medical record database between March 2011 and May of 2020. The 52 patient cases initially selected was reduced to 39 due after applying the inclusion and exclusion criteria. For each case with complete X-ray imaging, a value was obtained for the anterior-posterior view margin measurement and the lateral view margin measurement. For each case with complete MRI imaging, a value was obtained for the coronal view margin measurement and the sagittal margin measurement.

Table 1. An Example Calculation of the Margin Measurements from the Imaging of the Fibula with Osteosarcoma in Figure 3

Pathology reported margin = 1.6 cm	Bone resection length = 9.3 cm	
Imaging	**Margin**	**Margin Difference**
Coronal MRI margin	1.32 cm	0.28 cm
Sagittal MRI margin	1.80 cm	0.20 cm
Average MRI margin	1.56 cm	0.04 cm
Closest MRI margin	Coronal (1.32 cm)	Coronal (0.28 cm)
Anterior-Posterior X-ray margin	2.19 cm	0.59 cm
Lateral X-ray margin	2.61 cm	1.01 cm
Average X-ray margin	2.40 cm	0.80 cm
Closest X-ray margin	A-P (2.19 cm)	A-P (0.59 cm)

Table 2. Average Absolute Margin Differences of MRI and X-ray Images

Imaging	Mean (cm)	Standard Deviation (cm)
Coronal MRI	0.75	0.73
Sagittal MRI	0.83	0.76
Averaged MRI	0.74	0.77
Closest Margin MRI	0.71	0.70
Anterior-Posterior X-ray	1.09	0.79
Lateral X-ray	1.38	0.96
Averaged X-ray	1.11	0.84
Closest Margin X-ray	1.17	0.92

The results summary of the mean values and standard deviations of the absolute value of the margin differences for MRI and X-ray electronic margin measurements.

When data was available for only one of the two views a measurement for only that view was obtained. The average margin of each case was calculated by using both margin measurements. For X-ray, we averaged the anterior-posterior and lateral margin measurements, and for MRI we averaged the coronal and sagittal margin measurements. We also determined the margin difference when the MRI or X-ray with the closest predicted margin was used, i.e. the largest tumor extent on imaging. The mean and standard deviation of the differences between imaging and pathology reported margins was used to determine the variability of margin measurement differences and overall accuracy of each imaging technique.

RESULTS

1. How accurately do X-ray and MRI margin measurements reflect the true margin distance on pathology reports?

The mean margin difference was calculated for each view of X-ray and MRI individually, for the averaged margin measured with X-ray or MRI, and for the view with the closest margin in X-ray and MRI. The results showed that the average difference between the measured margin and the pathology margin was 1.09 cm and 1.38 cm for anterior-posterior and lateral X-ray respectively, and 0.75 cm and 0.83 cm for coronal and sagittal MRI respectively (Table 2). The averaged margin value using the two views of each imaging modality (for X-ray this was the average of the anterior-posterior and lateral margins and for MRI this was the average of the coronal and the sagittal margins) produced a mean margin difference of 0.74 cm for MRI and 1.11 cm for X-ray. Analysis of the view which provided the closest margin in each case yielded a mean margin difference of 0.71 cm for MRI and 1.17 cm for X-ray (Table 2).

2. Do X-ray or MRI margin measurements have smaller differences compared to pathology reports?

Margins measured from MRI had smaller differences with pathology reported margin than X-ray for most patients (Table 2). In 6 of 38 cases (16%) X-ray margin measurements had a smaller difference than MRI margin measurements while MRI had smaller margin differences in 32 of the 38 cases (84%). Of the 6 cases in which X-ray provided a more accurate margin per the pathology report, three were chondrosarcoma cases and three were osteosarcoma.

3. How many X-ray or MRI margin measurement differences were greater than 1 cm, 2 cm, and 3 cm from pathology reports?

When margin measured from X-ray or MRI were considered outliers at 1 cm or more of a difference from pathology reported margins, 36 of 70 images were outliers for X-ray and 17 of 66 were outliers for MRI margins (Table 3). When margins measured from X-ray or MRI were considered outliers at 2 cm or more of a difference from pathology reported margins there were 6 outliers of 66 MRI measurements and 14 outliers of 70 X-ray measurements (Table 3). There was 1 of 70 X-ray margin measurements which had a difference over 3 cm and 0 of 66 MRI margin measurements over 3 cm away from pathology reported margins (Table 3). We did not find that the imaging studies consistently over or underestimated the margins. MRI measurements overestimated the margin (i.e. the margin distance predicted by measurement was larger than the final pathology report) in 35/66 images and underestimated the margin (i.e. the margin distance predicted by measurement was smaller than the final pathology report) in 31/66 images. X-ray measurements overestimated the margin in 30/70 images and underestimated the margin in 40/70 images. Use of the X-ray film with the closest predicted margin to plan surgical margins of 1 cm, 2 cm, and 3 cm would have caused a positive resection margin in 2, 1 and 0 cases of 36 cases respectively. Use of the MRI view with the closest predicted margin to plan surgical margins of 1 cm, 2 cm, and 3 cm would have caused a positive resection margin in 1, 1 and 0 patients of 38 cases respectively.

4. Is there an X-ray or MRI view that consistently results in a smaller difference from pathology reports?

The X-ray data which yielded the smallest margin difference was the anterior-posterior view with a mean margin difference of 1.09 cm compared with the pathology reported margin (Table 2). The MRI data which yielded the smallest margin difference was the closest margin measurement for MRI with a mean difference of 0.71 cm compared to pathology reports (Table 2). For

Table 3. Outliers of Margin Measurement Differences from X-ray and MRI

Imaging Technique	Total Measurements	Outliers ≥ 1 cm	Outliers ≥ 2 cm	Outliers ≥ 3 cm
X-ray Anterior-Posterior	36	17	5	0
X-ray Lateral	34	19	9	2
MRI Coronal	36	9	3	0
MRI Sagittal	30	8	3	0

The number of margin measurements from each imaging technique listed which had a difference greater than 1 cm, 2 cm, or 3 cm compared to the pathology reported margin

MRI, the closest margin was from the coronal view in 21 out of 38 cases and the sagittal view in 17 out of 38 cases. For X-ray the closest margin was viewed from the anterior-posterior film in 22 of 36 cases and the lateral film in 14 of 36 cases.

DISCUSSION

Background and rationale

The treatment of primary bone sarcomas with limb-salvage surgery is planned using X-ray and MRI of the tumor and affected bone. The accuracy of these studies is critical to ensure complete removal of the tumor with a sufficient margin to prevent local recurrence and to preserve the patient's limb function.[12,15] We aimed to study and compare the accuracy of preoperative X-ray and MRI for planning surgical margins in these limb-salvage procedures. Many studies have evaluated the accuracy of MRI for bone tumor imaging, although to our knowledge no other studies have made this evaluation in comparison to X-ray and made all measurements electronically on modern imaging software. We found that MRI margin measurements were closer to pathology reported margins than X-ray and the difference between MRI measurements and the true margin were never greater than 3 cm.

Limitations

This study had a number of limitations. First the two reviewers were non-blinded to the information in the pathology reports. However, this potential bias was minimized by having both reviewers first measure independently, then discuss and agree upon all margin measurements. Second, due to the retrospective nature of the study the accuracy of the pathology reports could not be verified. Inaccuracies in pathology reports would call into question their use as the true margin distance. However, the measuring of margins is routine for all bone sarcoma, and the technique is familiar and standardized for our institution. Furthermore, the majority of the margin measurements on imaging agreed closely with the pathology reports which suggests this potential issue is unlikely to have significant impact to this investigation's primary findings. Third, discrepancy between MRI measurements and the pathology report may be present due to differences in the plane sectioned and the plane imaged. We addressed this concern by using multiple image sequences to determine the measurements. In some MRI cases, plain T1 imaging was unavailable for sagittal or coronal and T1 fat-suppressed or short tau inversion recovery (STIR) was used instead. STIR has been shown to slightly overestimate the tumor size more than T1 weighted imaging,[17] although this would have a very minor impact on the margin measurements and STIR and T1 fat-suppressed are valid imaging techniques.

1. How accurately do X-ray and MRI margin measurements reflect the true margin distance on pathology reports?

We found the most accurate MRI margin measurements and X-ray margin measurements had a difference of 0.71 cm and 1.09 cm, respectively, when compared to pathology report margins. Previous studies reported increased accuracy using MRI for surgical planning. In Jin et al. the average difference in tumor length from MRI measurements and pathology report measurements was 2.7 mm.[18] This degree of accuracy was also found by Gillespy et al. which reported an average tumor length difference of 4.9 mm from MRI compared to pathology.[19] Onikul et al. found larger discrepancies and reported an average difference of tumor length measured from MRI of 1.5 cm.[20] Our findings compare favorably in magnitude with these reports and add the first observations using electronic measurement tools in imaging software.

2. Do X-ray or MRI margin measurements have smaller differences compared to pathology reports?

Margins predicted from MRI were more accurate than X-ray in all categories and MRI had less variability in margin differences than X-ray. Our findings support the use of MRI over X-ray when it is available, although our findings also show X-ray may be considered when MRI is unavailable. There were a small number of patients (6/38 [16%]) where radiographs performed better than MRI. This supports using both modalities when possible, in particular where there is a mineralized intraosseous component that is easily seen on X-ray.

3. How many X-ray or MRI margin measurement differences were greater than 1 cm, 2 cm, and 3 cm from pathology reports?

Our study found that a surgical margin of 1 cm, 2 cm, and 3 cm would have caused a positive resection margin in 2, 1 and 0 cases of 36 patients respectively if the margin planning used X-ray alone. Use of the MRI to plan surgical margins of 1 cm, 2 cm, and 3 cm would have caused a positive resection margin in 1, 1 and 0 cases of 38 cases respectively. This result suggests that planning a 3 cm margin when using X-ray or MRI will predictably result in a negative intramedullary margin. Stevenson et al. conducted a study specific to chondrosarcomas and suggested a 4 mm margin to be used for all grades of chondrosarcoma.[21] In a different study Thompson et al. determined a margin of at least 1 cm should be used for pediatric bone sarcomas because of the accuracy of MRI images.[22] For both X-ray and MRI, the view with the closest predicted margin (i.e. the view which shows the largest tumor extent) provided fewer cases with positive margins for the outlier analysis. We found that the vast majority of patients (37/38, 97%) would have had a negative margin resection with only a 1 cm planned margin. However, our cohort focused on patients treated with an en bloc resection of one joint of a long bone. In these patients, there is not a compelling need to be within millimeters of the edge of tumor, as the reconstructive options and functional results are similar even with several additional centimeters of diaphyseal resection. Therefore, as long as there is not a need to preserve bone, a 3 cm planned margin will result in a clear resection. If a closer margin is warranted to accommodate a specific reconstruction, a 1 cm margin is likely to be adequate with diligent preoperative review of imaging.

4. Is there an X-ray or MRI view that consistently results in a smaller difference from pathology reports?

Our study suggests preoperative electronic margin measurements from MRI images are most accurate when the imaging with the closest predicted margin is used. In other words, when there is a discrepancy between the anticipated margins measured on orthogonal views, clinicians should use the distance of the closest prediction as the true anticipated margin. Specifically, we found that the margin difference of MRI imaging with the closest predicted margin yielded an average margin difference of 0.71 cm compared to the true margin. For X-ray the margins predicted from anterior posterior imaging were the most accurate of the X-ray measurements with an average margin difference of 1.09 cm. Clinicians should use the MRI view with the closest predicted margin (i.e. the view which shows the largest tumor extent) when planning surgical margins on electronic software.

CONCLUSION

In conclusion, MRI provided smaller differences in margin measurements than X-ray, in addition to lower variability. Selection of the MRI series with the closest predicted margin provided the closest estimate to the true margin, while anterior-posterior X-ray measurements were more accurate than the average view measurement or the closest predicted margin measurement. MRI is the ideal imaging modality for planning intramedullary surgical margins for primary bone sarcomas. In the absence of the need for bone preservation to accommodate skeletal reconstruction, a 3 cm margin should be planned to ensure complete removal of the intramedullary tumor extension.

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CHANGES IN MUSCLE VOLUME AND COMPOSITION AFTER TREATMENT OF HIP DYSPLASIA WITH PERIACETABULAR OSTEOTOMY

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ABSTRACT

Background: Periacetabular osteotomy (PAO) is a common treatment for pre-arthritic hip dysplasia in young adults. The purpose of this study was to better understand changes in muscle volume and composition after PAO visualized using magnetic resonance imaging (MRI).

Methods: A prospectively collected series of individuals that underwent PAO for hip dysplasia were reviewed to identify subjects with pre- and post-operative MRI. In our practice, MRI was obtained preoperatively and greater than 6 months after PAO for persistent hip pain. MRI sequences were selected to optimize visualization of the muscle volume, fatty infiltration, and hip joint cartilage. MRI images were selected at predetermined bony landmarks and analyzed using 3D Slicer (©2021, www.slicer.org) software to measure muscle diameter and calculate muscle cross-sectional area (CSA) in 17 individual muscles surrounding the hip. Muscle atrophy was graded using the Goutallier classification for fatty infiltration and acetabular cartilage condition was graded using the Outerbridge classification. We compared pre- and post-operative muscle area and composition as well as cartilage for each case.

Results: A series of six female patients met our inclusion criteria. Mean age was 26 years at time of surgery. All cases had MRI sequences adequate for muscle volume measurements. Fatty infiltration and cartilage changes were recorded in four subjects with appropriate MRI sequences. Separating muscle groups, external rotators underwent the largest volume increase. Hip flexors demonstrated mild volume decrease. CSA change among external rotators averaged +12%, hip flexors -9.3%, and hip abductors -9.2% after PAO. All muscles had either the same or increased fatty infiltration after surgery, with gluteus medius and iliacus undergoing the most average increase. Similarly, cartilage condition worsened by a small margin in this series.

Conclusion: Our results provide preliminary indication that PAO may have noticeable effects on muscle characteristics and cartilage in the early postoperative period. This was a limited case series of subjects with adequate pre- and post-operative MRI imaging.

Level of Evidence: IV

Keywords: periacetabular osteotomy, mri, muscle volume

INTRODUCTION

Hip dysplasia is a common deformity involving inadequate acetabular coverage of the femoral head, altering the mechanical environment in the hip joint by decreasing load-bearing surface. These changes accelerate joint degeneration and can lead to osteoarthritis onset at a young age.[1] Thus, symptomatic young adults are indicated for surgical correction, most commonly through a procedure known as a periacetabular osteotomy (PAO), in order to preserve the native joint. PAO is known to be highly effective, allowing for realignment of the dysplastic acetabulum and reduction or elimination of symptoms for many years in a majority of appropriately selected patients.[2,3]

While effective, the surgical approaches for PAO are complex and involve significant dissection. A variety of approaches have been developed and described, including the classic and modified Smith-Peterson approaches, the ilioinguinal approach, and the direct anterior approach.[4] Each makes compromises between exposure, operative time, and dissection of surrounding structures. Proper postoperative management plays a significant role in the success of these procedures; however, there is no standardized rehabilitation therapy protocol following PAO.[5] Thus, physical therapists must consider the surgical approach and the patient's preoperative state as they follow general rehabilitation principles, such as progressive reloading of the bone and muscle/tendon systems in the early postoperative period. Although

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Table 1. Demographics of the Studied Patient Population

Parameter	Value (SD, range)
Number of patients (hips)	6 (6)
Age at time of surgery	25.8 (7.2, 18 to 36)
Female hips (% of all hips)	100%
Right sided hips	100%
Height (m)	1.64 (0.09, 1.50 to 1.75)
Weight (kg)	66.4 (11.5, 47.6 to 80.0)
BMI (kgm2)	25.0 (5.9, 18.6 to 35.6)
Interval from surgery to follow-up MRI (years)	1.40 (0.64, 0.75 to 2.51)

major complications of PAO have been documented,[6] the effects of the surgery on individual muscles surrounding the hips is unclear. It is known that elevation of gluteal muscle origin in various approaches can lead to abductor weakness. Yasunaga et al. found that Trendelenburg gait may be observed postoperatively in patients undergoing PAO, however, this resolved in all cases within 6 months.[7] Similarly, Ko et al. described postoperative limping in 11 of 38 hips (28.9%) 4 months after treatment with a modified Ollier transtrochanteric approach.[8] A study by Ezoe et al. provided further insight into these deficits, by showing that an alternate approach with abductor-sparing curved osteotomy is effective at preserving abductor muscle-strength postoperatively. Slightly more is known about the iliocapsularis muscle, which has been identified as an important stabilizing muscle in those with hip dysplasia. Babst et al. compared a group of dysplastic hips to those without, showing that patients with dysplastic hips typically have iliocapsularis hypertrophy and less fatty infiltration.[9]

In the present study, we aimed to evaluate a wider array of muscles and reveal common weaknesses that may not be obvious clinically. The purpose of the present study was to better understand the impact of PAO on the size and composition of muscles surrounding the hip in the perioperative period, and if so, which muscles are the most affected. With this information, rehabilitation efforts may be optimized to target certain muscle groups, in order to improve patient outcomes. We also performed a preliminary investigation into cartilage changes before and after surgery in this series. It is thought that the changes in mechanical loading following PAO can have measurable effects on the biochemical composition of the articular cartilage.[10,11] Yet, clinical evaluations of cartilage condition in the postoperative period have not been conducted.

METHODS

Patient Selection

A series of pre- and post-operative magnetic resonance imaging (MRI) scans from patients who underwent PAO to treat hip dysplasia were compared to determine changes in muscle volume and composition. Under IRB approval, subjects were selected from a prospectively collected, consecutive series of patients in a single surgeon's (MCW) practice. Medical records were reviewed to document patient demographics. Indication for PAO was hip pain that persisted despite non-surgical treatments including physical therapy, activity modification, and in some cases intra-articular corticosteroid injections with a lateral center edge angle of Wiberg (LCEA) < 20° or a LCEA 20 -25° and evidence of hip joint hypermobility. Surgeries were performed using a rectus sparing, modified Smith-Peterson approach using previously described techniques[12,13] between May 2017 and February 2019. Inclusion criteria were patients with both pre- and post-operative MRI scans of the operative hip. Preoperative MRI scans were obtained in all patients indicated for PAO preoperatively. Postoperative MRI scans were less common and, in our practice, were typically obtained greater than 6 months after PAO due to persistent hip joint pain following surgery. Of the analyzed postoperative scans in our cohort, interval from surgery to MRI averaged 1.4 years (range: 9 months - 2.5 years). MRI sequences were selected for analysis under guidance of a musculoskeletal radiologist (NF) on a patient-by-patient basis in order to optimize visualization of the muscle volume, fatty infiltration, and hip joint cartilage. Ultimately, six hips from six subjects were available for analysis (Table 1). Of these, four patients had MRI sequences optimal for evaluation of fatty infiltration and four had sequences optimal for assessment of the cartilage condition before and after surgery.

Muscle Characteristics Assessment

Muscle condition was assessed with three parameters: 1) muscle diameter, 2) cross-sectional area (CSA), and 3) fatty infiltration. Predetermined bony landmarks served as identifiers for standardized locations, or MRI "slices," at which measurements were made. Using a scheme first described by Glynn, et al.,[14] we used four axial cuts, including the sciatic notch, acetabular roof, femoral head center, and ischial tuberosity. In addition, two sagittal cuts were used, including through the lateral quarter of the femoral head and through the transverse acetabular ligament. Open-source 3D Slicer (©2021, www.slicer.org) software was utilized to measure muscle diameter and calculate muscle CSA in 17 individual muscles surrounding the hip (Figure 1). Measurements were averaged for each muscle and compared between

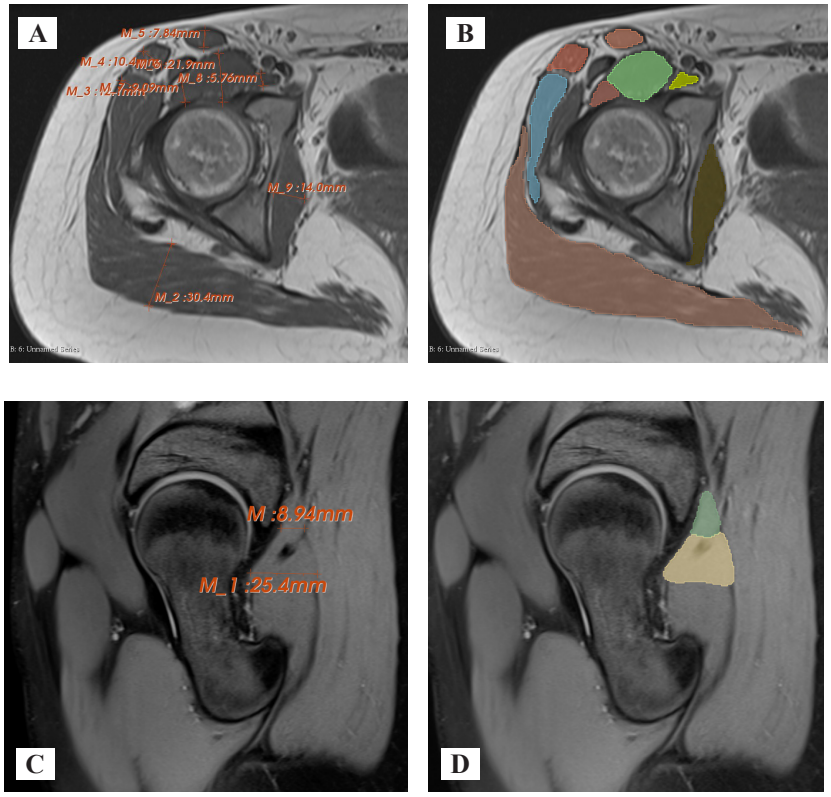

Figure 1. Examples of muscle diameter and cross-sectional area measurements in the axial (A, B) and sagittal (C, D) planes. In the axial plane at the level of the femoral head center, the gluteus maximus, gluteus medius, tensor fasciae latae, sartorius, iliacus, iliocapsularis, psoas, and obturator internus muscles were assessed. In the sagittal plane at the lateral quarter of the femoral head, the superior and inferior gemelli muscles were assessed.

groups of subjects using percentage changes. Fatty infiltration of muscles was determined using the Goutallier classification,[15] where Grade 0 indicates normal muscle; Grade 1 is characterized by some fatty streaks; Grade 2 shows increased streaking but less than 50% fatty muscle atrophy; Grade 3 is defined by an equal amount of muscle and fat; and Grade 4 has more than 50% fatty muscle atrophy. Fatty infiltration was evaluated on T1 weighted MRI sequences.[16,17] All muscle measurements were performed by an independent observer (NIB), who was not involved in the surgeries, under the supervision of a musculoskeletal radiologist (NF).

Cartilage Condition Assessment

Cartilage condition was assessed in patients with fat saturated proton-density or T2 weighted MRI sequences.[18,19] Cartilage was graded with the modified Outerbridge classification,[20] where Grade 1 is defined by focal areas of hyperintensity with normal contour; Grade 2 includes blister-like swelling/fraying of articular cartilage extending to surface; Grade 3 shows partial-thickness cartilage loss with focal ulceration; and Grade 4 is characterized by full-thickness cartilage loss with underlying bone reactive changes.

RESULTS

Six hips from six subjects met inclusion criteria for the study (Table 1). Of these, all six had MRI sequences conducive to muscle area measurements, while four had sequences appropriate for fatty infiltration grading and four had sequences in which cartilage could be analyzed. The mean age at time of surgery was 26 (range: 18-36). All patients were female and all operations were right-sided. On average, of the 17 studied muscles in each patient, 5 muscles increased and 12 decreased in diameter (Table 2). 8 muscles increased in CSA while 9 decreased. External rotators such as superior and inferior gemelli underwent the most CSA increase by percentage, in part due to their small size. On average, the external rotators increased in CSA by 12%. A majority of the hip flexors underwent a mild amount of volume decrease, an average change of 9.3%. Similarly, hip abductors decreased in CSA by an average of 9.3%. Vastus lateralis had the greatest decrease in both diameter and CSA. The iliocapsularis muscle on average, decreased in CSA by a small margin of 4.3%.

All muscles had either the same or increased amounts of fatty infiltration after PAO, with gluteus medius and iliacus undergoing the most atrophy on average. A

Table 2. Average Results from Measurement of Hip Muscle Diameter Change, CSA Change, and Fatty Infiltration Grade Change of the 17 Muscles

Muscle group	Muscle	Diameter change % (range)	CSA change % (range)	FI grade change (range)
Hip flexors	iliacus	-14.6 (-33.2 to 3.7)	-8.1 (-35.3 to 42.3)	0.5 (0 to 2)
	psoas	-4.9 (-31.7 to 64.8)	-21.6 (-79.1 to 263.7)	0.3 (0 to 1)
	sartorius	-16.2 (-34.1 to 59.4)	-14.1 (-26.4 to 1.9)	0.2 (0 to 1)
	rectus femoris	-0.3 (-35.1 to 71.6)	5.8 (-37.1 to 173.4)	0.0 (0 to 0)
	pectineus	-3.8 (-17.6 to -2.7)	-13.5 (-15.1 to -2.1)	0.3 (0 to 1)
Hip extensors	gluteus maximus	6.8 (-17.8 to 17.2)	1.2 (-7.1 to 4.1)	0.0 (0 to 0)
Hip abductors	gluteus minimus	-16.6 (-40.6 to 9.6)	-29.6 (-61.6 to -15.0)	0.0 (0 to 0)
	gluteus medius	11.3 (-10.7 to 24.4)	-2.7 (-30.3 to 18.2)	0.5 (0 to 1)
	tensor fascia latae	-0.7 (-19.7 to 2.9)	4.6 (-55.5 to 6.5)	0.0 (0 to 0)
External rotators and stabilizers	obturator externus	-2.2 (-18.2 to 22.2)	0.3 (-80.7 to 182.9)	0.0 (0 to 0)
	quadratus femoris	-16.5 (-45.1 to 8.3)	-2.0 (-32.8 to 15.9)	0.0 (0 to 0)
	superior gemelli	45.2 (18.4 to 114.9)	36.6 (-79.1 to 707.2)	0.0 (0 to 0)
	inferior gemelli	9.4 (-23.9 to 77.5)	27.7 (-75.0 to 354.0)	0.0 (0 to 0)
	obturator internus	-0.3 (-38.6 to 52.4	4.2 (-28.0 to 33.2)	0.0 (0 to 0)
	piriformis	0.6 (-9.7 to 13.8)	6.0 (-31.4 to 61.5)	0.0 (0 to 0)
	iliocapsularis	-10.8 (-42.2 to 16.9)	-4.3 (-90.5 to 213.3)	0.3 (0 to 1)
Knee extensors	vastus lateralis	-23.0 (-37.7 to -1.9)	-35.2 (-65.6 to -7.1)	0.0 (0 to 0)

majority of the hip flexors experienced increases in fatty infiltration on average, while none of the external rotator muscles had increased atrophy in any patient. Cartilage condition worsened in all studied hips. One patient increased from Grade 0 chondromalacia preoperatively to Grade 1 postoperatively, two patients increased from Grade 1 to Grade 2, and one patient increased in severity within a Grade 3 rating after surgery.

DISCUSSION

This case series provides preliminary data indicating that PAO surgery may have noticeable effects on muscle characteristics and cartilage in the early postoperative period. PAO is known to be a safe and effective operation for pre-arthritic hip dysplasia, but periods of immobilization and inactivity increase muscle atrophy. With increasing knowledge of the effects of PAO on the characteristics of muscles surrounding the hip, early rehabilitation is recommended to help prevent muscular inhibition, atrophy, and joint stiffness while protecting bony healing. We found that certain groups of muscles, such as the hip flexors, undergo more CSA loss and fatty infiltration than others, such as the external rotators, which appear to increase in size and do not show signs of atrophy after surgery. It is hoped that rehabilitation efforts can be optimized to target certain muscle groups, such as the hip flexors and hip abductors, in order to maximize function and patient satisfaction.

Our analysis confirmed that hip abductors undergo a significant amount of volume decrease on postoperative MRI. When grouped and averaged, gluteus minimus, gluteus medius, and tensor fascia latae reduced in CSA by 9.2%. Along with known clinical findings of Trendelenburg limp in a significant proportion of patients after PAO,[7,8] this indicates that these muscles should be targeted during rehabilitation efforts. Additionally, iliocapsularis, a muscle known to provide important stabilization to the hip,[9] reduced on average in diameter by 10.8% and in CSA by 4.3%, potentially indicating that PAO is effective at increasing biomechanical stability of the hip and decreasing strain on this muscle. Whereas atrophy of other hip muscles represents a negative effect of PAO, decreasing the abnormal hypertrophy of the iliocapsularis in patients with hip dysplasia suggests one benefit of the operative treatment.

We found preliminary imaging-based data that cartilage condition in patients with hip dysplasia is initially worsened in the early postoperative period. Our data concur with current knowledge that articular cartilage biochemistry may be altered after PAO. Hingsammer et al. found that mean dGEMRIC index decreased at one year after PAO but subsequently recovered at two years postoperatively.[10] Due to mean time to follow-up MRI of 1.4 years, this finding brings up the question of whether cartilage imaging findings would improve on later follow-up scans.

This analysis was limited by several factors. First, the small number of patients available for inclusion was a result of the rarity of post-operative MRIs, all of which were obtained for persistent hip pain after surgery. Additionally, many of these patients obtained imaging at outside facilities without a standardized protocol, and therefore the scans that were available did not always provide all the sequences appropriate for the measurements made in this work. Furthermore, data regarding MRI manufacturer and magnetic field strength is not known for these scans. While this could not be controlled in our cohort of patients, standard sequences were selected for analysis and those without the optimal sequences were excluded from the study. In our cohort, there was an inconsistent length of time between surgery and postoperative MRI between subjects. However, the shortest period of 9 months in our study is longer than the 3-month interval necessary to show postoperative fatty infiltration.[14] Despite this, our measurement of fatty infiltration may have been limited because the Goutallier classification was originally described for use with computed tomography (CT), yet was used here with MRI. Lastly, due to the fact that patients who underwent postoperative MRI typically had persistent pain, it can be inferred that these patients were the most likely to suffer from continued pathology in the hip. Thus, these results may best represent those patients with inferior outcomes from PAO. Our results also represent a single surgeon's practice and a single surgical approach. A future study may address these issues by calling for postoperative MRI scans in all PAO patients and including patients from multiple surgeons.

While the current study was limited by number of participants and availability of appropriate MRI sequences, this work provides pilot data indicating a future prospective study with well-defined imaging sequence and timing criteria would be beneficial. Our preliminary results indicate that PAO has noticeable effects on muscle diameter and CSA, as well as cartilage condition in the early postoperative period. We found that hip abductors and flexors underwent mild CSA decreases after PAO while external rotators increased in CSA. Additionally, stabilizer muscles such as iliocapsularis experienced mild decreases in CSA, potentially owing to the increased mechanical stability provided by the PAO. Fatty infiltration and cartilage condition stayed the same or worsened in all studied hips postoperatively, however, recovery of cartilage condition was not assessed with long-term follow-up imaging. While our study was a limited case series assessment, a controlled analysis of a higher number of subjects with a pre- and post-operative MRI imaging protocol may be beneficial for identifying statistically significant changes in muscles and cartilage surrounding the hip joint following PAO surgery. Additionally, employing advanced MRI techniques could enable a more sophisticated data analysis. For example, Dixon sequences have recently shown promise for quantification of fatty infiltration measurement,[21] which could be used rather than qualitative Goutallier grading. Finally, other body composition or muscle quantification methods could be used as an alternative to MRI.

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TELEMEDICINE FOR HIP PRESERVATION PATIENTS: ACCESS, ABILITY AND PREFERENCE

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ABSTRACT

Background: Recent events have resulted in rapid rises in the use of telemedicine in orthopaedic surgery, despite limited evidence regarding patient preferences or concerns. The purpose of this study is to determine access to and, ability to use telemedicine technology in an adult hip preservation patient population, as well as determine associations with patient characteristics. Additionally, we seek to understand patients' perceived benefits, risks and preferences of telemedicine.

Methods: We performed a cross-sectional survey administered on patients scheduled to undergo joint preservation surgery by one of three surgeons at a single academic institution. Both preoperative and postoperative established patients were included and called for a telephone administered survey if a date of surgery was scheduled between October 1, 2019 and March 30, 2020 and were 18 years or older. The survey had seven sections with 45 questions relating to demographics, technology access, videoconferencing capability, confidence using technology, telehealth experiences, perceptions.

Results: 101 patients completed the survey (48% response rate, 101/212). Overall, 99% of participants reported using the internet, 94% reporting owning a device capable of videoconferencing, and 86% of patients had participated in a video call in the past year. When asked for their preferred method for a physician visit: 79% ranked in-person as their first choice and 16% ranked a videoconference visit as their first choice. Perceived benefits of telemedicine visits included reduced travel to appointments (97% agree) and reduced cost of attending appointments (69% agree). However, patients were concerned that they would not establish the same patient-physician connection (51% agree) and would not receive the same level of care (38% agree) through telemedicine visits versus in person visits.

Conclusion: The majority of hip preservation patients have access to and are capable of using the technology required for telemedicine visits. However, patients still prefer to have in person visits over concerns that they will not establish the same patient-physician connection and will not receive the same level of care. Telemedicine visits in hip preservation patients may be most attractive to return patients with an established doctor-patient relationship, particularly those with concerns for long distances of travel and associated costs.

Level of Evidence: III

Keywords: telemedicine, joint preservation, technology, access, hip, ability, preference, videoconferencing

INTRODUCTION

Telemedicine is increasingly utilized in all medical specialties including orthopaedics. Using telemedicine can augment or replace traditional in-person office visits.[1] Potential benefits of telemedicine include reduction of cost for patients, society and the healthcare system.[2] Telemedicine has been successful in multiple surgical and medical specialties including urology, neurology and pediatrics.[3] The COVID-19 pandemic has accelerated the growth of telemedicine utilization in orthopedics in response to social distancing practices. However, there are inherent limitations associated with telemedicine such as a detailed physical examination, and accessibility to patients.[4] Additionally, telemedicine visits require both the patient and the physician to have internet access along with a device capable of videoconferencing.[5]

There is limited literature regarding the use of telemedicine as well as patient perceptions regarding telemedicine in the hip preservation patient population.[3,6,7] These patients may have varying access to and experience with the technology required to perform telemedicine visits. The recent atypical time period as-

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Table 1. Survey Completion

Factor	Yes (N=101)	No (N=117)	p-value
Age	35.4±16.1	34.8±16.4	0.77[a]
Race*			0.57[d]
Black or African American	2(2.0)	6(5.2)	
Non-white Hispanic or Latino	1(1.0)	1(0.86)	
White	96(97.0)	109(94.0)	
Gender			0.18[c]
Female	75(74.3)	77(65.8)	
Male	26(25.7)	40(34.2)	

*Data not available for all subjects. Missing values: Race = 3.
Values presented as Mean ± SD, Median [P25, P75], Median (min, max) or N (column %).
p-values: a=ANOVA, b=Kruskal-Wallis test, c=Pearson's chi-square test, d=Fisher's Exact test.

sociated with the COVID 19 pandemic provided a unique opportunity to examine a large group of telemedicine visits in a short period of time.

The purpose of our study is to determine access to and, ability to use telemedicine technology in an adult joint preservation patient population, as well as determine associations with patient demographic characteristics (age, sex, race/ethnicity). Additionally, we sought to understand patients' perceived benefits, risks and preferences of telemedicine.

METHODS

We performed a cross-sectional survey on patients scheduled to undergo hip preservation surgery (hip arthroscopy, periacetabular osteotomy, surgical hip dislocation, or proximal femoral osteotomy) between October 1, 2019 and March 30, 2020 by one of three surgeons at a single academic institution. Institutional review board approval was obtained prior to initiation of the study. All patients were established patients with one of the three surgeons. Patients were excluded if they were under the age of 18 years old. A total of 212 patients met inclusion criteria for the study. All eligible patients were individually called, either preoperatively or postoperatively, to participate in the telephone administered survey and three contact attempts were made for each potential participant. Patients were verbally consented prior to administration of the survey (see appendix for full survey). The survey had seven sections with 45 questions relating to demographics, technology access, videoconferencing capability, confidence using technology, telehealth experiences and preferences, telehealth perceptions, and app use for remote monitoring. The survey typically took five to ten minutes to complete. 127 eligible patients (59%) were reached via telephone, of those, 101 (80%) agreed to participate for an overall response rate of 48% (101/212).

Chi-square tests were used to explore if a relationship exists between the demographic data and the telemedicine related outcomes. Fisher's Exact test used wherever there were fewer than 5 responses within a group. For the sole continuous predictor age, ANOVA were used to test for differences across grouping. A p-value less than 0.05 was considered significant.

RESULTS

A total of 101 patients completed the survey. There was no significant difference in age (both 35 years old, p=0.77), gender (75% female vs 66% female, p=0.18) or race (97% white vs 85% white, p=0.57) among those who completed versus those who did not complete the survey (Table 1). Overall, 85% of participants had at least some college education with 15% having a high school degree or less.

Our study found that patients largely had access to technology with 99% of participants reporting using the internet, 98% reporting owning a device capable of videoconferencing and 86% of patients had participated in a video call in the past year. The majority of patients were employed full or part-time (54%) while 23% were students, 10% retired and 8% unemployed.

A total of 63% of participants had done a telehealth visit with a physician. Participants who have had a previous telemedicine visit had statistically higher access to some forms of technology [ownership of a laptop (94% vs 79%, p<0.001)]. However, there were no differences in preferences or perceptions of telemedicine compared to those who had not had a telemedicine visit. Participants with a higher level of education (some college or greater) had statistically higher access to some forms of technology [ownership of a laptop (97% vs 67%, p<0.001), tablet (66% vs 20%, p<0.001), and smartwatch (64% vs 27%, p<0.001)]. Similarly, those with higher level of education reported higher rates of prior use of telehealth platforms [use of online portal to check test results/labs (88% vs 67%, p=0.029) or communicate with healthcare team (85% vs 60%, p=0.023)] (Table 2). There were no differences in reported confidence using technology and perceptions of telemedicine in participants with a higher level of education.

When asked for their preferred method for a physician visit, 79% ranked in-person as their first choice, followed by 16% preferring a video visit. Perceived benefits of telemedicine visits included reduced travel to appointments (97% agree or strongly agree), easier to attend appointments (83% agree or strongly agree), and reduced cost of attending appointments (69% agree or strongly agree). However, patients were concerned that they would not

Table 2. Patient Demographics of Respondents vs Non-Respondents

Factor	High School or Less (N=15)	Some College or Greater (N=86)	p-value
Age	33.5±20.7	35.8±15.3	0.61[a]
Own Laptop			*<0.001*[c]
no	5(33.3)	3(3.5)	
yes	10(66.7)	83(96.5)	
Own Tablet			*<0.001*[c]
no	12(80.0)	29(33.7)	
yes	3(20.0)	57(66.3)	
Own Smartwatch			*0.007*[c]
no	11(73.3)	31(36.0)	
yes	4(26.7)	55(64.0)	
Used online portal to view test results			*0.029*[c]
no	5(33.3)	10(11.6)	
yes	10(66.7)	76(88.4)	
Used online portal to communicate with healthcare team			*0.023*[c]
no	6(40.0)	13(15.1)	
yes	9(60.0)	73(84.9)	

Values presented as Mean ± SD, Median [P25, P75], Median (min, max) or N (column %).
p-values: a=ANOVA, b=Kruskal-Wallis test, c=Pearson's chi-square test, d=Fisher's Exact test.

establish the same patient-physician connection (51% agree or strongly agree), would not receive the same level of care (38% agree or strongly agree), and believed their physician would not spend the same amount of time with them (24% agree or strongly agree) through telemedicine visits versus in person visits.

We also wanted to identify future uses of telemedicine with the hip preservation population. When asked if they would feel comfortable installing a secure app onto their smartphone that would allow their physician to perform remote monitoring of recovery and long-term function, 85% said "yes". Of those that said "yes", 95% would be comfortable receiving surveys sent through the app, 98% would be comfortable with activity data (heart rate, steps) collected and sent to their physician after their review, 95% would be comfortable with activity data (heart rate, steps) collected and sent to their physician during approved intervals, and 71% would be comfortable with activity data (heart rate, steps) collected and sent to their physician without notifying them first. Additionally, of those that said "yes", 94% and 98% would feel comfortable with activity data (heart rate, step count) being collected on their smart phone and smart watch/wearable activity monitor, respectively. 95% stated they would be comfortable wearing a smart brace capable of monitoring activity and function for short periods of time, however, only 59% would be comfortable with an implanted device at the time of surgery capable of continuous monitoring of joint activity and device function.

DISCUSSION

The utilization of telemedicine continues to increase throughout all fields of medicine, including orthopaedics. The COVID-19 pandemic has led to a recent rise in the use of telemedicine, which gave a unique opportunity to examine a large group of telemedicine visits and understand the feasibility of this technology within specific orthopedic patient populations. Our study found the majority of hip preservation patients in our practice have access to and are capable of using the technology required for telemedicine visits. Participants recognized the potential benefits of telemedicine as less time spent traveling to and lower cost of attending appointments. Although our patients have the ability to use technology and appreciate the potential benefits of telemedicine, patients still prefer in-person visits over concerns that they will not establish the same patient-physician connection and will not receive the same level of care.

Participants with a higher level of education (some college or greater) had statistically higher access to some forms of technology but no differences in preferences or perceptions of telemedicine. Additionally,

patients who had previously done a telemedicine visit with any physician did not have significant differences in preferences or perceptions of telemedicine compared to those who had not had a telemedicine visit with a physician. In the hip preservation patient population, this highlights that patients with an established physician-patient relationship who have concerns over long travel distances and associated cost may be most interested in continued telemedicine care.

There are similarities and differences in the literature in comparison to our study. Similar to our study Soegaard et al. found that patients identified convenience, reduced travel and time as associated benefits of telemedicine.[8] However, unlike in our study, 98% opted to have telehealth postoperative visits. In another study 71% of patients were concerned with the lack of personal contact with the orthopaedic surgeon via telemedicine.[1] Manz et al. determined patient satisfaction in a foot and ankle orthopedic practice was significantly lower for telemedicine visits than for in-person visits.[6] A randomized controlled trial found that 86% of remote consultation patients preferred video-assisted consultation as the next visit.[9] Additionally, no difference was observed in patient-reported health after 12-months between the groups randomized between video-assisted remote consultation and standard in-person consultation.[9] Nikolian et al. found telemedicine to be safe and efficient for postoperative management as an alternative to in-person visits with 85% of patients satisfied with their telemedicine visit.[10] However, Barrack et al. found routine postoperative visits provide little practical value and represent a time and cost burden for both patients and surgeons, however, patients reported high satisfaction and found the visits worthwhile.[11]

Travel time to medical care is particularly relevant to the application of telemedicine. Manz et al. found that patients living within 50 miles of the clinic had lower satisfaction with telemedicine than those greater than 50 miles from the clinic.[12] Previous research has demonstrated that telemedicine has the potential to increase healthcare access to patients. The patients in our study travel from various locations and did recognize reduction in cost as a benefit of telemedicine visits.

Telemedicine has been shown to reduce health care costs by decreased staffing, maintenance and travel burden.[13] Buvik et al. found that the video-assisted orthopaedic consultations were cost-effective provided that the number of consultations performed per year was greater than 183.[14] Harno et al. also found that telemedicine reduced direct costs by 45%.[13]

There are still many challenges associated with telemedicine. Prior to policy changes at the onset of the COVID-19 pandemic, Medicare only paid for video consultation if the patient lived in a designated rural Health Professional Shortage Area and reimbursement by private insurance varied.[15] Technical difficulties such as loss of camera control, nonfunctional audio and being unable to connect to the videoconference serve as another challenge associated with telemedicine. Additionally, there is concern regarding reliable physical examination that is critical to orthopaedics.[16] Some physicians will only evaluate orthopaedic patients through telemedicine when high-quality audio-video or imaging technology is not critical for diagnosis and treatment.[4] The standardization of virtual examinations and measurements are necessary to improve generalizability of telehealth in the field of orthopaedic surgery. Additional research is needed to assess and determine the reliability of virtual joint assessment.

Our study has several limitations. First, this study was performed during a very atypical time period on which to draw conclusions and may have biased responses in favor of telemedicine. However, study participants largely preferred in-person visits even though telemedicine reduced the risk of exposure to COVID-19. Additionally, our response rate was only 48%, and therefore we may have had selection bias as a result of our methods. Furthermore, some of the survey questions were subjective which may allow varied interpretation. As this is the first report performed using this survey, it has not been validated for inter- or intra-observer reliability. Lastly, this study was done at a single academic institution with a wide geographic catchment area, encompassing both urban and rural populations. Future studies are necessary to assess for differences identifying complications through telemedicine in comparison to in-person visits and to assess the cost-benefit ratio for the doctor and staff in the joint preservation population.

In conclusion, the majority of joint preservation patients reported having access to and ability to use technology required for telemedicine visits and identified the perceived benefits of reducing the time spent traveling to and cost of attending appointments, and being easier to attend appointments. Despite these benefits and access to technology, patients' concerns that they will not establish the same patient-physician connection and will not receive the same level of care influenced their preference towards having in-person visits. Telemedicine visits in hip preservation patients may be most attractive to return patients with an established doctor-patient relationship, particularly those with concerns for long distances of travel and associated costs.

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OPEN VERSUS ARTHROSCOPIC SURGICAL MANAGEMENT FOR RECALCITRANT TROCHANTERIC BURSITIS: A SYSTEMATIC REVIEW

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ABSTRACT

Background: While excision of the trochanteric bursae to treat lateral hip pain has increased in popularity, no comparison exists between the surgical outcomes and complications of the open and arthroscopic techniques involving trochanteric bursectomy. The purpose of this study was to determine the efficacies and complication rates of arthroscopic and open techniques for procedures involving trochanteric bursectomy.

Methods: The terms "trochanteric," "bursectomy," "arthroscopic," "open," "outcomes," and "hip" were searched in five electronic databases. Fifteen studies from 120 initial results were included. Patient-reported outcomes (PRO), pain, satisfaction, and complications were included for analysis.

Results: Five hundred-two hips in 474 total patients (77.7% female) were included in this study. The average age was 54. The fourteen distinct PRO scores that were reported by the included studies improved significantly from baseline to final mean follow-up (12-70.8 months for open; 12-42 months for arthroscopic) for both approaches, demonstrating statistically significant patient benefit in a variety of hip arthroscopy settings (P > 0.05). The complication rates of all procedures ranged from 0%-33% and failure to improve pain ranged from 0%-8%. Patient satisfaction with surgery was high at 95% and 82% reported a willingness to undergo the same surgery again. No significant mean differences were found between the open and arthroscopic techniques.

Conclusion: The open and arthroscopic approaches for trochanteric bursectomy are both safe and effective procedures in treating refractory lateral hip pain. No significant differences in PROs, pain, total complications, severity of complications, and total failures were seen between technique outcomes.

Level of Evidence: IV

Keywords: sports medicine, hips, trochanteric bursa, bursectomy

INTRODUCTION

Trochanteric bursitis, commonly identified with greater trochanteric pain syndrome (GTPS), is an inflammatory condition characterized by lateral hip pain and tenderness near or over the greater trochanter of the femur.[1-4] Femoral neck shaft angle, activity levels, and hormone physiology are believed to affect prevalence, though the exact etiology is multifactorial in origin.[1,3,5-8] Converging evidence, however, suggests that GTPS results primarily from degeneration or tendinopathy in the gluteus medius and minimus musculature.[9-14] This can be caused by aberrant lower extremity biomechanics and imbalances that result from trauma to the lower extremity, instability, overuse, and/or compression of the gluteal nerve branches.[6,8,10,15,16] Other theories posit that GTPS is the result of repetitive microtrauma to the interposed bursa caused by friction between the greater trochanter and iliotibial band, as in the case of external coxa saltans or "snapping hip."[5,17-21] Bursal-derived pain in GTPS has also been supported by intraoperative findings.[2,5,18,19,22]

Conservative management of GTPS includes activity modification, ice, oral NSAIDs (non-steroidal anti-inflammatory drugs), and corticosteroid and platelet-rich plasma (PRP) injections.[1,7,20,21,23,24] While prior investigations reported that 90% of patients with GTPS experienced pain relief with two years of non-operative management,[3] more recent literature reports that only about 64% of patients find relief after one year and 71% after five years in the primary care setting.[7] Additionally, GTPS symptoms often recur and require several rounds of conservative therapy.[23]

Recalcitrant cases with imaging concerning for abductor tears or intraarticular pathology that have not

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Table 1. A Summary of the Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Minimum average follow-up of one year or greater	Review articles
Studies that report on surgical outcomes involving trochanteric bursectomy	Non-human studies
PROs used pre and post-operatively	Case reports (<5 patients)
	Single-patient case studies
	Hip procedures performed without trochanteric bursectomy
	Preoperative values were not included in PRO reporting
	Non-English studies
	Technique reports
	Overlapping patient populations
	Expert opinion articles (Level V evidence)

responded to extensive conservative management are often referred for surgical intervention.[1,3,25,26] Trochanteric bursectomy can be performed alone or conducted with concomitant procedures like abductor repairs and iliotibial band lengthening when indicated. While open procedures were traditionally used, arthroscopic treatment of this disease has become increasingly popular.[5,12,17-19,27-31]

Both open and arthroscopic trochanteric bursectomy have demonstrated success in treating refractory lateral hip pain. Despite this, little research has been conducted to contrast patient reported outcomes (PROs) between the two approaches to determine if postoperative function can be improved and complication rates minimized. The purpose of this systematic review is to summarize existing PROs and complications between these two approaches and to assess if one approach consistently produces better outcomes. We hypothesize that the arthroscopic approach will generate better outcomes, lower pain scores, and fewer complications.

METHODS

Search Strategy

This systematic literature review was structured to adhere to the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines (PRISMA). An electronic search was conducted in October of 2019 by two authors using five databases: Google Scholar, Scopus, PubMed Medline, Web of Science, and Cochrane Central Register of Clinical Trials. Search methodology included associating the keywords "hip," "trochanteric,"and "bursectomy" with "arthroscopic," "open," and "outcomes" to ensure the inclusion of relevant articles. Bibliographies of studies meeting the inclusion criteria were also reviewed and relevant referenced materials were evaluated for inclusion.

Identification of Eligibility

Eligible studies included a trochanteric bursectomy, with a minimum mean follow-up of one year and the use of pre- and postoperative PROs. Manuscripts addressing surgery of the hip joint or gluteal repairs without resection of a trochanteric bursa and those that did not report preoperative values were excluded. Other exclusion criteria consisted of cadaveric, biomechanical, histologic, kinematic, and studies not written in English as well as analyses of nonoperative management. Case reports with fewer than five patients, review articles, technique reports, single-patient case studies, expert opinion (Level V) articles, and patient populations that overlapped were also excluded (Table 1).

Statistical Analysis

Analyses were performed with SPSS Version 25.0 (IBM, Armonk, NY) and Microsoft Excel Version 16.35 (Microsoft Corporation, Redmond, WA). Preoperative outcomes, postoperative outcomes, and change in score (CIS) for each PRO were first normalized (corrected) on a 0.0-1.0 scale. Study outcomes for the Visual Analog Score (VAS), Modified Harris Hip Score (mHHS), the Hip Outcome Score – Activities of Daily Living Subscale (HOS-ADL), and the Hip Outcome Score – Sport-Specific Subscale (HOS-SSS) were then presented graphically and frequency-weighted means were assigned to all studies based on the number of hips in each investigation. The more hips evaluated in a study, the greater the weight assigned. Due to the heterogeneity of the available data and a lack of reported outcome variance, pooling results for a meta-analysis was not possible. Other demographic and outcome variables like age, length of follow-up, PRO measures, complications, and failures have been reported descriptively. Significance was determined as $P < 0.05$.[8] Modified Coleman metholodology (MCMS) and methodological index for non-randomized

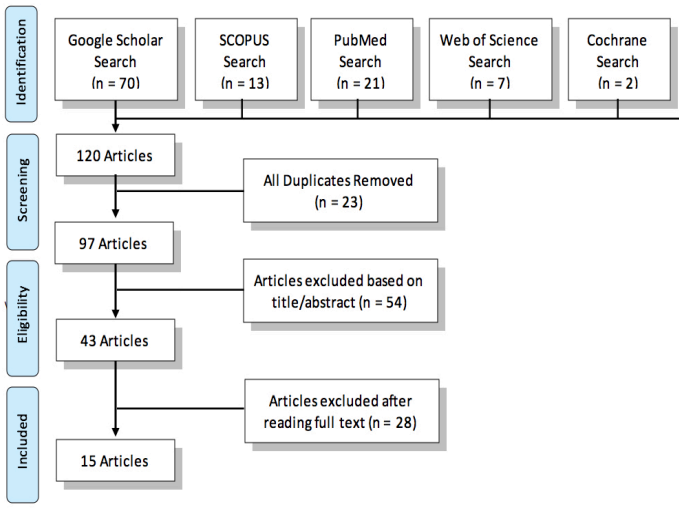

Figure 1. Study Selection Process (PRISMA Diagram).

studies (MINORS) tables were used to assess the quality of the included studies and evaluate their risk of bias, respectively. To describe agreement between the two evaluating authors, an F-ratio and intraclass coefficient (ICC) were determined to be 13.13 (P = .003) and 0.219, respectively, indicating inter-reviewer agreement.

RESULTS

Search Results

One-hundred twenty publications were identified following a search through five electronic databases that were relevant to our inquiry; after the removal of 23 duplicates, 97 distinct articles remained. Fifty-four articles were excluded based on the title or abstract of the manuscript, while 28 were excluded after reading the full-text. After applying the eligibility criteria defined above, 105 articles were ultimately excluded and 15 total articles were included (Figure 1).

Study Characteristics

The fifteen studies accepted for inclusion were published between 1997 and 2018 with nine employing an arthroscopic approach and six utilizing an open approach. Seven of the studies were prospective and eight were retrospective. All studies included a mean follow-up of at least 12 months (range, 12-70.8 months). Two studies[5,19] reported a loss of follow up with 26% and 11.9% of patients, respectively, at the final assessments of one PRO. A summary of study characteristics for the arthroscopic and open surgical techniques can be found in Table 2 and Table 3, respectively.

Patient Characteristics and Quality of Included Studies

A total of 502 hips in 474 patients were included in this study. An arthroscopic approach was used for 315 hips with a weighted mean of 48 hips per study (Figure 2) and a mean age of 52.5 ± 11.0 years (range, 35-63.5 years), while an open procedure was used for 187 hips with a weighted mean of 71 hips per study (Figure 3) and a mean age of 56.9 ± 10.4 years (range, 40.3-67.7 years). Excluding one study[33] that did not stratify their sample by sex, 77.7% of all patients were female. The

Table 2. Overview of the Included Studies Utilizing Arthroscopic Techniques

Arthroscopic										
Author	Year	Location	Journal	Level of Evidence	Patients	Hips	Average Age (y)	Follow-up (m)	Concomitant Procedures - n (%)	Additional Surgeries/Complications - n (%)
Baker et al.[17]	2007	USA	*Arthroscopy*	IV	25	25	61.9	26.1	None Reported	Seroma - 1 (4%)
Domb et al.[28]	2013	USA	*AJSM*	IV	15	15	57.8	27.9	Abductor repair - 15 (100%)	Superficial infection - 1 (6.67%)
Domb et al.[33]	2014	USA	*OJSM*	IV	46	50	50	31	Gluteus medius repair - 13 (26%)	Unspecified and non-surgical complications - 9 (18%)
Domínguez et al.[31]	2015	Spain	*Arch Orthop Trauma Surg*	IV	23	23	51.34	12	ITB release - 23 (100%)	None Reported
Drummond et al.[5]	2016	Australia	*Arch Orthop Trauma Surg*	IV	49	57	65	20.7	ITB release - 57 (100%) Gluteus medius repairs - 7(12.3%)	None Reported
Vap et al.[18]	2019	USA	*Arthroscopy*	III	72	72	36.7	42	Hip arthroscopy for FAI with labral repair and ITB lengthening - 72 (100%)	Stiffness - 2 (2.78%) Continues pain - 3 (4.17%) Drainage from sutures - 1 (1.38%) Dysphagia - 1 (1.38%) Capsular tear - 1 (1.38%)
Van Hofwegen et al.[29]	2013	USA	*JSOA*	IV	12	12	63.5	36.7	ITB release - 12 (100%) Osteophyste removal - 2 (16.7%)	Incomplete resolution of pain - 1 (8.33%) Recurrence of pain - 1 (8.33%) Hematoma formations w/subsequent heterotopuc ossification - 2 (16.67%)
Wiese et al.[19]	2004	Germany	*Int. Ortho*	IV	45	51	51	25	ITB release - 51 (100%)	Hematoma - 3 (7.84%)
Yoon et al.[30]	2014	South Korea	*Hip & Pelvis*	IV	7	10	35	19	Gluteal sling release - 2 (20%)	Incomplete resolution of pain - 1 (10%)

* = iHOT-33 scores not collected on 15 hips.
† = post-operative scores collected for 37 of 45 patients.
ITB, Iliotibial band.

Table 3. Overview of the Included Studies Utilizing Open Techniques

Arthroscopic										
Author	Year	Location	Journal	Level of Evidence	Patients	Hips	Average Age (y)	Follow-up (m)	Concomitant Procedures - n (%)	Additional Surgeries/Complications - n (%)
Bucher et al.[34]	2014	UK/Australia	*Hip Int*	IV	22	22	62	12	Augmented abductor repair - 22 (100%)	Catheter-related complication leading to prostatic resection surgery - 1 (4.54%)
Craig et al.[35]	2014	New Zealand	*AZ Journal of Surgery*	IV	15	17	60	47	ITB lengthening - 15 (100%) Gluteus minimus repair - 1 (6.7%)	Wound seroma - 1 (5.88%) Glute minimus tendon tear - 1 (5.88%)
Davies et al.[38]	2013	USA	*JBJS*	IV	18	19	67.7	70.8	Abductor repair - 19 (100%)	None Reported
Ebert et al.[36]	2018	UK/Australia	*Hip Int*	IV	110	110	63.2	12	Augmented abductor repair and ITB lengthening - 110 (100%)	Hematoma - 1 (0.91%) Superficial wound infections - 2 (1.82%) DVT/PE - 1 (0.91%)
Govaert et al.[37]	2003	The Netherlands	*JBJS*	IV	10	12	48.3	23.5	Trochanteric reduction osteotomy - 12 (100%)	None Reported
Slawski et al.[26]	1997	USA	*AJSM*	IV	5	7	40.3	20	ITB release - 7 (100%)	None Reported

ITB, Iliotibial band.

mean modified Coleman methodology score was 54.0 ± 5.90. The included studies scored particularly well on diagnostic certainty in enrolled patients (5.0 ± 0.0), outcome criteria (9.8 ± 0.8), and percentage of patients with follow-up (4.9 ± 0.05). The mean score for study size was poor (1.0 ± 2.2), as the majority of studies included fewer than 40 patients (Table 4). In the MINORS assessment, methodologies were good overall (Table 5) with mean scores of 11.54 ± 1.5 for non-comparative studies and 17.0 ± 1.4 for comparative studies. Non-comparative studies[5,17,19,26,28-31,34-37] scored well in clearly stating aims (2.0 ± 0.3), inclusion of consecutive patients (1.77 ± 0.44), use of appropriate endpoints (2.0 ± 0.0) and follow-up periods (2.0 ± 0.0), and a patient loss to follow-up less than 5% (1.85 ± 0.38). Both comparative studies[18,33] scored well in clearly stating aims (2.0 ± 0.0), use of appropriate endpoints (2.0 ± 0.0) and follow-up periods (2.0 ± 0.0), and contemporary groups (2.0 ± 0.0). Due to the surgical nature of the included studies, none used a blinded evaluation of outcomes and thus scored poorly for an unbiased assessment of endpoints.

Patient Reported Outcomes (PROs)

A total of fourteen PROs were reported by the fifteen included studies: the mHHS,[18,19,28,31,33] VAS,[5,17,19,28,30,31,33,34,36] HHS,[17,26,35,36,38] HOS-SSS,[18,28,31,33] HOS-ADL,[18,28,31,33] Oxford

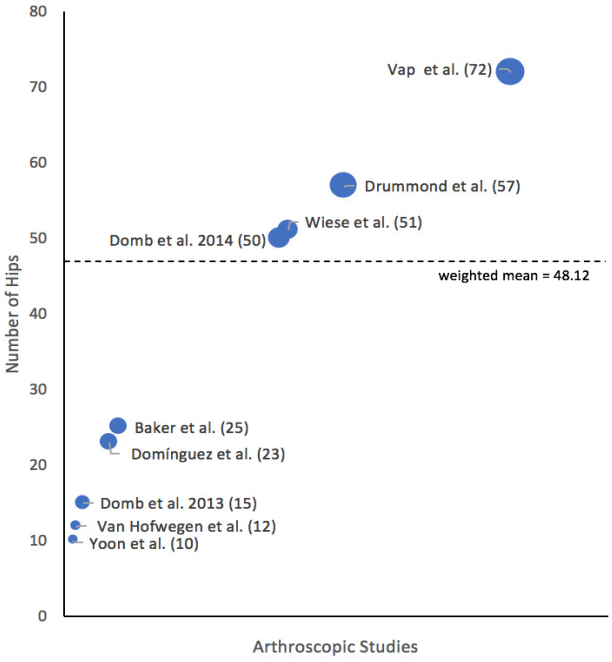

Figure 2. Weighted mean number of hips of the nine arthroscopic studies.

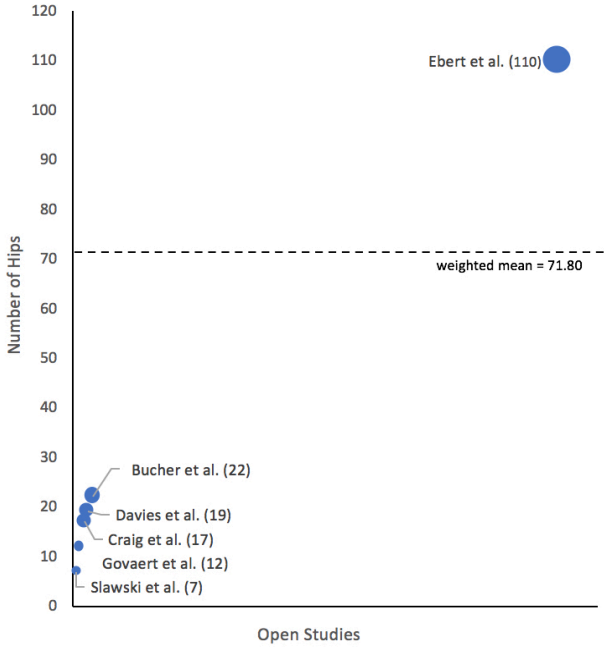

Figure 3. Weighted mean number of hips of the six open studies.

Table 4. Coleman Methodology Scoring for Each Included Study

Author	Study Size (10)	Mean Follow-up (5)	Percentage of Patients with Follow-up (5)	Number of Interventions Per Group (10)	Study Type (15)	Diagnostic Certainty (5)	Description of Surgical Technique (5)	Description of Postoperative Rehabilitation (5)	Outcome Criteria (10)	Procedure for Assessing Outcomes (10)	Description of Participant Selection Process (15)	Total (100)
Baker et al. 2007[17]	0	0	5	10	0	5	5	3	10	6	10	54
Bucher et al. 2014[34]	0	0	5	10	0	5	5	3	10	6	10	54
Craig et al. 2014[35]	0	3	5	10	0	5	3	0	10	6	10	52
Davies et al. 2013[38]	0	3	5	10	0	5	5	3	10	6	10	57
Domb et al. 2013[28]	0	0	5	10	0	5	5	5	10	6	10	56
Domb et al. 2014[33]	0	0	5	5	0	5	0	0	10	6	10	41
Domínguez et al. 2015[31]	0	0	5	10	0	5	3	3	10	6	10	52
Drummond et al. 2016[5]	4	0	5	10	0	5	5	3	10	6	10	58
Ebert et al. 2013[36]	7	0	5	10	0	5	5	3	10	6	10	61
Govaert et al. 2003[37]	0	0	5	10	0	5	5	5	10	6	10	54
Slawski et al. 1997[26]	0	0	5	10	0	5	5	3	10	6	10	54
Van Hofwegen et al. 2013[29]	0	3	5	10	0	5	5	0	7	3	10	48
Vap et al. 2017[18]	4	3	5	10	10	5	3	0	10	6	10	56
Wiese et al. 2004[19]	0	0	3	10	0	5	3	0	10	6	10	47
Yoon et al. 2014[30]	0	0	5	10	0	5	3	5	10	6	10	54
Mean Score ± SD	1.0 ± 2.17	0.8 ± 1.37	4.87 ± 0.52	9.67 ± 1.29	0.67 ± 2.58	5.0 ± 0.00	4.0 ± 1.46	2.4 ± 1.92	9.8 ± 0.77	5.8 ± 0.77	10.0 ± 0.0	54.0 ± 5.90

*Scores awarded based on the 37 patients that provided PRO responses at the final 2-year post-operative follow-up.

Hip Score (OHS),[5,34,36] Nonarthritic Hip Score (NAHS),[2] Western Ontario and McMaster Universities Arthritis Index (WOMAC),[18,31] Short Form-36,[17,34] Short Form Health Survey-12 Physical Component Score (SF-12 PCS),[18,36] International Hip Outcome Tool (iHOT-33),[36] Japanese Orthopaedic Association hip score (JOA),[19] Merle d'Aubigné and Postel system score,[37] and Lower Extremity Activity Scale (LEAS).[38] Also included were two study-specific numerically reported scores assessing hip pain and function. PRO use varied significantly but the most commonly used were the VAS (Figure 4), used in nine of the included studies; followed by the mHHS (Figure 5) and HHS (Figure 6), both in five studies; as well as the HOS-SSS and the HOS-ADL (Figure 7), each used by four of the included studies.

All reported outcomes, regardless of the surgical technique used, indicated the same positive trend in medical improvement postoperatively (Table 6). The ten studies[5,17,18,28,29,34-38] that reported on patients' satisfaction with their surgery demonstrated the vast majority of patients had a positive experience with 95% (range, 79%-100%) of patients "very satisfied" or "satisfied"[5,17,18,28,29,34-38] and 82% (range, 72-93%) explicitly agreeing that they would have the surgery again.[17,29,35,38]

Where the MCID is defined as the smallest outcomes difference that patients perceive as beneficial,[39-41] Nwa-

Table 5. MINORS Risk of Bias Assessment for Each Included Study

Author	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to the aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss to follow-up less than 5%	Prospective calculation of the study size	Contemporary groups	Baseline equivalence of groups	Adequate statistical analyses	Total (16 non-comparative; 24 comparative)
Baker et al. 2007[17]	2	1	2	2	0	2	2	0	-	-	-	11
Bucher et al. 2014[34]	2	2	2	2	0	2	2	2	-	-	-	14
Craig et al. 2014[35]	1	2	2	2	0	2	2	0	-	-	-	11
Davies et al. 2013[38]	2	2	1	2	0	2	2	0	-	-	-	11
Domb et al. 2013[28]	2	2	2	2	0	2	2	2	-	-	-	14
Domínguez et al. 2015[31]	2	2	2	2	0	2	2	0	-	-	-	12
Drummond et al. 2016[5]	2	1	1	2	0	2	1	0	-	-	-	9
Ebert et al. 2013[36]	2	1	2	2	0	2	2	2	-	-	-	13
Govaert et al. 2003[37]	2	2	2	2	0	2	2	0	-	-	-	12
Slawski et al. 1997[26]	2	2	1	2	0	2	2	0	-	-	-	11
Van Hofwegen et al. 2013[29]	2	2	1	2	0	2	2	0	-	-	-	11
Wiese et al. 2004[19]	2	2	1	2	0	2	1	0	-	-	-	10
Yoon et al. 2014[30]	2	2	1	2	0	2	2	0	-	-	-	11
Mean Score ± SD	1.97 ± 0.28	1.77 ± 0.44	1.54 ± 0.52	2.0 ± 0.00	0.00 ± 0.00	2.0 ± 0.00	1.85 ± 0.38	0.46 ± 0.88	-	-	-	11.54 ± 1.45
Domb et al. 2014[33]*	2	1	2	2	0	2	1	0	2	1	1	16
Vap et al. 2017[18]*	2	2	1	2	0	2	1	0	2	2	2	18
Mean Score ± SD	2.0 ± 0.00	1.5 ± 0.71	1.5 ± 0.71	2.0 ± 0.00	0.00 ± 0.00	2.0 ± 0.00	1.0 ± 0.00	0.00 ± 0.00	2.0 ± 0.00	1.5 ± 0.71	1.5 ± 0.71	17.0 ± 1.41

Each item may be given a score of up to 2, making the maximum score for comparative studies 24 and the maximum score for non-comparative studies 16.
*Comparative studies.

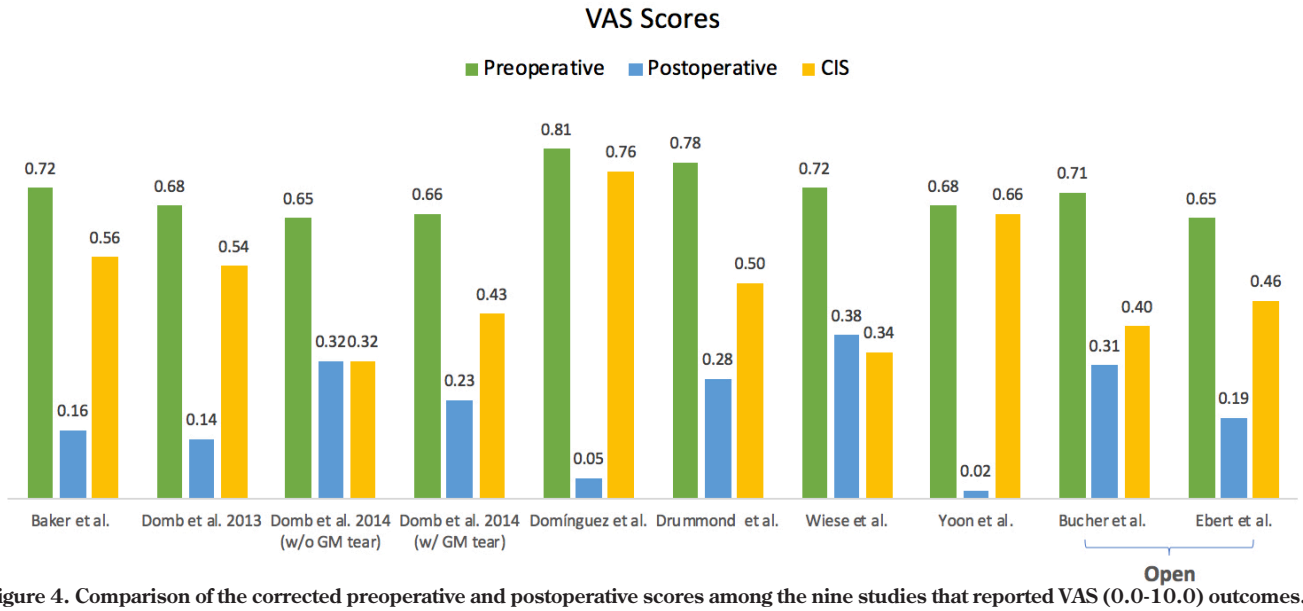

Figure 4. Comparison of the corrected preoperative and postoperative scores among the nine studies that reported VAS (0.0-10.0) outcomes. Seven of the nine studies used an arthroscopic approach and all outcomes were collected at a minimum of one year after surgery.

chukwu et al.[42] and Martin et al.[41] established 6.9-, 9-, and 6-point improvements as the respective MCID values for the mHHS, HOS-ADL, and HOS-SSS. In the one study that did report individual patient outcomes,[28] 80% of patients achieved the MCID for the mHHS, 93.3% did so for the HOS-ADL, and 100% for the HOS-SSS. For the same PROs, 80%, 60%, and 60% of patients surpassed the patient acceptable symptomatic state (PASS) values (74, 87, and 75, respectively) defined by Chahal et al.[43] in hip arthroscopy patients at 1 year. For all PROs, including the VAS, NAHS, and HHS in which no standard MCID or PASS has been established for this procedure, a statistically significant improvement was observed at the final follow-ups compared to baseline ($P < 0.05$).

Concomitant Procedures

In addition to its principle use in treating recalcitrant trochanteric bursitis or refractory GTPS, surgical excision of the trochanteric bursae was often performed alongside other procedures, addressing associated pathologies. For example, cases of coxa saltans involved iliotibial release or IT band lengthening with the removal of the inflamed underlying bursa after ruling out other potential causes like radiculopathy. Van Hofwegen et al.[29] and Weise et al.[19] reported excising the bursa in patients who had already undergone hip arthroplasty, with both reporting a significant positive change in outcome ($P < 0.05$). The most commonly performed procedures in

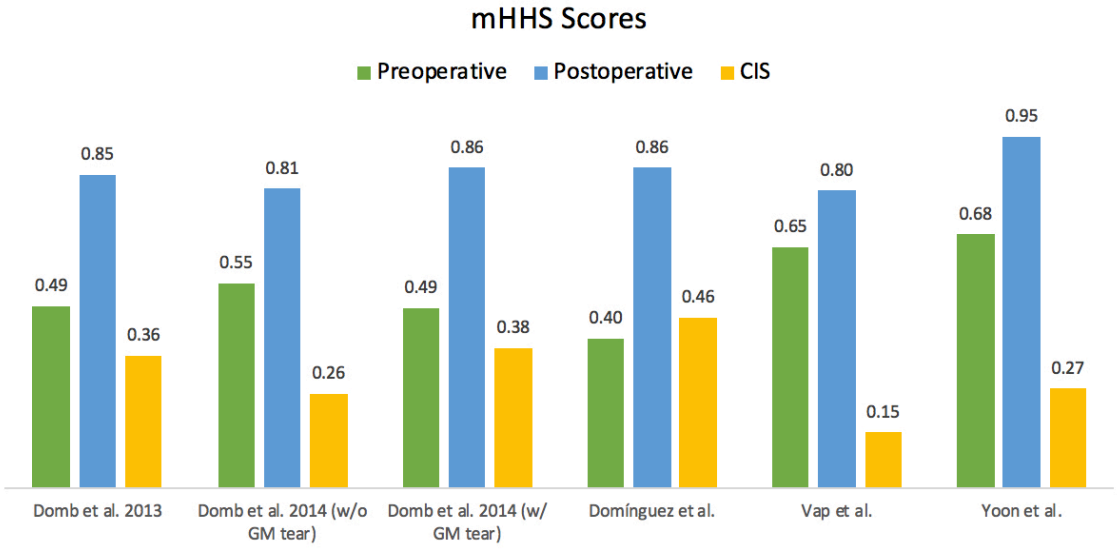

Figure 5. Comparison of the corrected preoperative and postoperative scores among the five studies that reported mHHS (0.0-100.0) outcomes. All five studies used an arthroscopic approach and outcomes were collected at a minimum of one year after surgery.

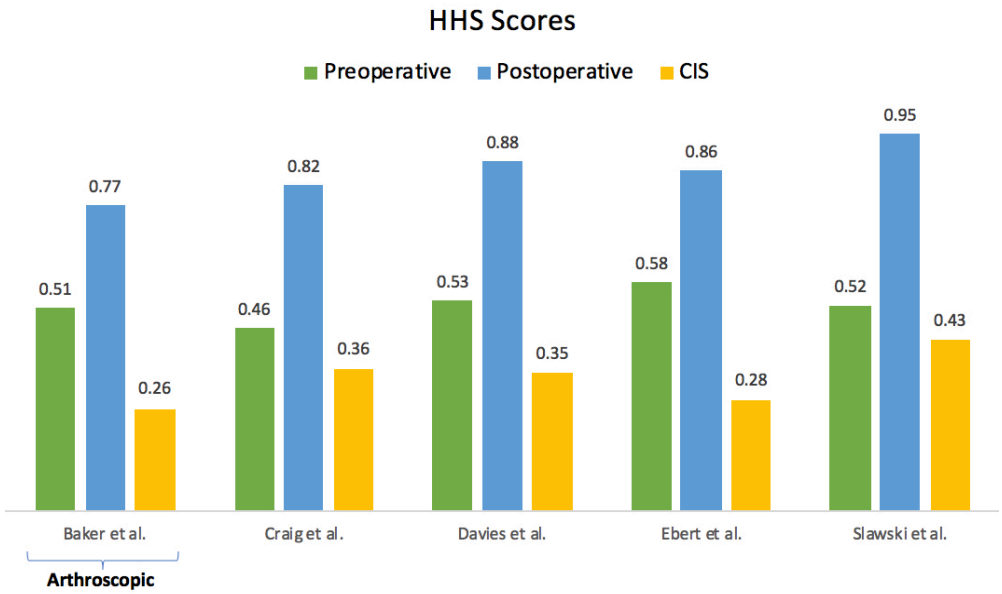

Figure 6. Comparison of the corrected preoperative and postoperative scores among the five studies that reported HHS (0.0-100.0) outcomes. Four of the five studies used an open approach and outcomes were collected at a minimum of 1 year after surgery.

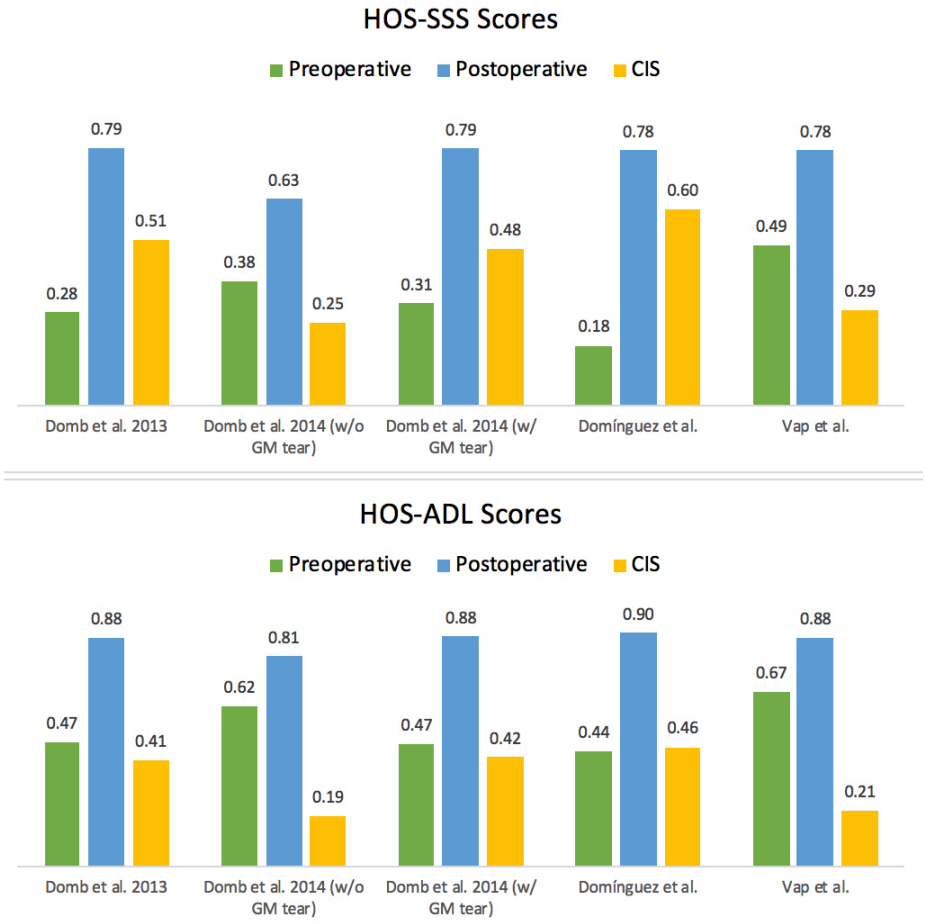

Figure 7. Comparison of the corrected preoperative and postoperative scores among the four studies that reported A) HOS-SSS (0.0-100.0) and B) HOS-ADL (0.0-100.0) outcomes. All four studies used an arthroscopic approach and outcomes were collected at a minimum of one year after surgery.

Table 6. Patient-reported Outcomes From Most to Least used by Included Studies

PRO	# Studies Reported	Study (Year)	Technique	Hips Evaluated	Mean Pre-Operative Score	Corrected Mean Pre-Op Score	Mean Post-Operative Score	Corrected Mean Post-Op Score	Corrected CIS	Significance
VAS (0-10)	9	Baker et al. 2007[17]	Arthroscopic	25	7.20	0.72	1.60	0.16	0.56	P = 0.0001
		Bucher et al. 2014[34]	Open	22	7.10	0.71	3.10	0.31	0.40	P < 0.001
		Domb et al. 2013[28]	Arthroscopic	15	6.80	0.68	1.40	0.14	0.54	P < 0.001
		Domb et al. 2014[33]	Arthroscopic	33 (w/o GM tear)	6.45	0.65	3.24	0.32	0.32	P < 0.01
				13 (w/ GM tear)	6.62	0.66	2.31	0.23	0.43	P < 0.01
		Domínguez et al. 2015[31]	Arthroscopic	23	8.10	0.81	0.48	0.05	0.76	P < 0.001
		Drummond et al. 2016[5]	Arthroscopic	57	7.80	0.78	2.80	0.28	0.50	P < 0.001
		Ebert et al. 2018[36]	Open	110	6.50	0.65	1.90	0.19	0.46	P < 0.05
		Wiese et al. 2004[19]	Arthroscopic	45	7.20	0.72	3.80	0.38	0.34	P < 0.05
		Yoon et al. 2014[30]	Arthroscopic	10	6.80	0.68	0.20	0.02	0.66	DNR
mHHS (0-100)	5	Domb et al. 2013[28]	Arthroscopic	15	48.95	0.49	84.60	0.85	0.36	P < 0.002
		Domb et al. 2014[33]	Arthroscopic	33 (w/o GM tear)	55.25	0.55	80.75	0.81	0.26	P < 0.01
				13 (w/ GM tear)	48.55	0.49	86.36	0.86	0.38	P < 0.01
		Domínguez et al. 2015[31]	Arthroscopic	23	40.20	0.40	86.29	0.86	0.46	P < 0.001
		Vap et al. 2017[18*]	Arthroscopic	72	65	0.65	80	0.80	0.15	P < 0.05
		Yoon et al. 2014[30]	Arthroscopic	10	68.20	0.68	94.80	0.95	0.27	DNR
HHS (0-100)	5	Baker et al. 2007[17]	Arthroscopic	25	51	0.51	77	0.77	0.26	P = 0.0001
		Craig et al. 2014[35]	Open	17	46	0.46	82	0.82	0.36	P = 0.00001
		Davies et al. 2013[38]	Open	19	53	0.53	88	0.88	0.35	P < 0.000001
		Ebert et al. 2018[36]	Open	110	57.60	0.58	85.80	0.86	0.28	P < 0.05
		Slawski et al. 1997[26]	Open	7	51.70	0.52	95	0.95	0.43	DNR
HOS-SSS (0-100)	4	Domb et al. 2013[28]	Arthroscopic	15	28.18	0.28	78.83	0.79	0.51	P < 0.002
		Domb et al. 2014[33]	Arthroscopic	33 (w/o GM tear)	37.84	0.38	62.92	0.63	0.25	P < 0.01
				13 (w/ GM tear)	30.82	0.31	78.58	0.76	0.48	P < 0.01
		Domínguez et al. 2015[31]	Arthroscopic	23	18	0.18	77.90	0.78	0.60	P < 0.001
		Vap et al. 2017[18*]	Arthroscopic	72	49	0.49	78	0.78	0.29	P < 0.05

*Vap et al. scores above reflect the chronic trochanteric bursitis group only and not the control group.
† Post-operative iHOT-33 scores reported for only 42 of 57 hip operations.
§ Wiese et al. reported post-operative scores for the 37 patients that provided responses to the final follow-up.

Table 6. Patient-reported Outcomes From Most to Least used by Included Studies (cont.)

PRO	# Studies Reported	Study (Year)	Technique	Hips Evaluated	Mean Pre-Operative Score	Corrected Mean Pre-Op Score	Mean Post-Operative Score	Corrected Mean Post-Op Score	Corrected CIS	Significance
(HOS-ADL 0-100)	4	Domb et al. 2013[28]	Arthroscopic	15	47.47	0.47	88.10	0.88	0.41	P < 0.002
		Domb et al. 2014[33]	Arthroscopic	33 (w/o GM tear)	61.59	0.62	80.62	0.81	0.19	P < 0.01
				13 (w/ GM tear)	46.93	0.47	88.45	0.88	0.42	P < 0.01
		Domínguez et al. 2015[31]	Arthroscopic	23	44.11	0.44	89.77	0.90	0.46	P < 0.001
		Vap et al. 2017[18*]	Arthroscopic	72	67	0.67	88	0.88	0.21	P < 0.05
OHS (0-48)	3	Bucher et al. 20143[4]	Open	22	22.40	0.47	41.10	0.86	0.39	P < 0.001
		Drummond 2016[5]	Arthroscopic	57	20.40	0.43	37.30	0.78	0.35	P < 0.001
		Ebert et al. 2018[36]	Open	110	25.30	0.53	39.90	0.83	0.30	P < 0.05
NAHS (0-100)	2	Domb et al. 2013[28]	Arthroscopic	15	46.02	0.46	76.74	0.77	0.31	P < 0.002
		Domb et al. 2014[33]	Arthroscopic	33 (w/o GM tear)	53.92	0.54	78.05	0.78	0.24	P < 0.01
				13 (w/ GM tear)	46.46	0.46	80.58	0.81	0.34	P < 0.01
SF-12 PCS (0-100)	2	Ebert et al. 2018[36]	Open	110	33.20	0.33	44.10	0.44	0.11	P < 0.05
		Vap et al. 2017[18*]	Arthroscopic	72	42.20	0.42	50.50	0.51	0.08	P < 0.05
WOMAC (0-96)	2	Domínguez et al. 2015[31]	Arthroscopic	23	63.32	0.66	5.22	0.05	0.61	P < 0.001
		Vap et al. 2017[18*]	Arthroscopic	72	27.80	0.29	12.20	0.13	0.16	P < 0.05
Short Form-36 (0-100)	1	Baker et al. 2007[17]	Arthroscopic	25	53.60	0.54	57.70	0.58	0.04	P = 0.001
		Bucher et al. 2014[34]	Open	22	29.70	0.30	44.40	0.44	0.15	P < 0.001
Modified JOA (0-100)	1	Wiese et al. 2004[19]	Arthroscopic	37	40.50	0.41	72.60	0.73	0.32	P < 0.05
LEAS (0-18)	1	Davies et al. 2013[38]	Open	19	6.70	0.37	8.80	0.49	0.16	P < 0.000001
Merle d'Aubigné and Postel (0-18)	1	Govaert et al. 2003[37]	Open	12	15.80	0.88	27.50	0.92	0.04	DNR
iHOT-33 (0-100)	1	Drummond et al. 2016[5]	Arthroscopic	57	23.80	0.24	70.20	0.70	0.46	P < 0.001

*Vap et al. scores above reflect the chronic trochanteric bursitis group only and not the control group.
† Post-operative iHOT-33 scores reported for only 42 of 57 hip operations.
§ Wiese et al. reported post-operative scores for the 37 patients that provided responses to the final follow-up.

Table 7. The Most Frequently Performed Procedures in Addition to Trochanteric Bursectomy

Reported Concomitant Procedure	Study
Lengthening of the iliotibial band	Craig,[35] Ebert,[36] Vap,[18] Wiese[19]
Glute medius repair	Craig,[35] Davies,[38] Domb,[28] Domb,[33] Drummond,[5] Ebert[36]
Glute minimus repair	Craig,[35] Davies,[38] Drummond,[5] Ebert[36]
Acetabuloplasty	Domb,[28] Vap[18]
Trochanteric reduction osteotomy	Domb,[28] Vap,[18] Govaert,[37]
Microfracture	Domb[28]
Capsular plication	Domb[28]
Iliopsoas release	Domb[28]
Selective labral debridement	Domb[28]
Labral repair	Domb,[28] Vap[18]
Labral reconstruction	Domb[28]
Partial glute medius release	Govaert[37]
Fascia lata fasciotomy	Dominguez[31], Ebert,[36] Govaert[37]
Iliotibial band release	Baker[17], Bucher,[34] Drummond,[5] Govaert,[37] Slawski,[26] Van Hofwegen,[29] Wiese,[19] Yoon[30]
Selective tendon debridement	Bucher,[34] Ebert[36]
Augmented tendon repair	Bucher,[34] Ebert[36]
Enthesophyte/Osteophyte removal	Ebert,[36] Van Hofwegen[29]
Hip arthroscopy for FAI	Vap[18]
Gluteal sling release	Yoon[30]
Prior ipsilateral hip arthroplasty	Van Hofwegen,[29] Wiese[19]

the included literature were gluteus medius repairs, gluteus minimus repairs, lengthening of the iliotibial band, and iliotibial band release. All procedures performed concomitantly to the trochanteric bursectomies of the included studies are outlined in Table 7.

Complications and Failures

Thirty-four total cases (6.8%) reported a post-surgical complication with severity ranging from stiffness to further surgical intervention and incidence rates ranging from 0% to 33.3%. The study reporting the highest complication rate had the lowest number of enrolled patients (n = 12),[29] all of whom had undergone prior ipsilateral hip arthroplasty or hemiarthroplasty. In another study involving gluteus medius tears, four patients (8.0%) went on to have THA and three underwent revision procedures (6.0%).[33] Two studies[2,36] reported failure rates of 4.0% and 2.7%, respectively. Six studies[5,26,30,31,37,38] (3 open, 3 arthroscopic) reported no complications whatsoever. The percentage of the total cases that went on to have total hip arthroplasty was 0.8% (4/502), all of which came from the same study. Altogether, open cases produced ten total incidents of complication (range, 0%-11.8%)[26,34-38] while the arthroscopic cases produced thirty-five (range, 0%-33.3%).[5,17-19,28-31,33] Rates of failure with descriptions of the reported complications are summarized in Table 8.

DISCUSSION

This study consists of a large systematic review of trochanteric bursectomy, including over 500 hips, and demonstrates the efficacy of open and arthroscopic treatments for refractory GTPS. A review of both approaches exhibits a consistent and significant improvement in hip scores such as the HHS and HOS in addition to functional and pain metrics such as the SF-36 and VAS. Of note, both approaches yielded improvements beyond the minimally clinically important difference for all relevant hip scores. With regard to patient-perceived benefit, the majority of patients from both cohorts were very satisfied with their surgical results and indicated willingness to choose the same treatment course.

Complication profiles were similar between the two approaches and 0% to 33% of all the included procedures yielded complications. Failure to improve pain ranged from 0 to 8% and the most common complications reported were stiffness, surgical site infection, and hematomas. While the total number of complications favored the open approach, this could likely be attributed to the greater number of cases employing an arthroscopic technique. The less invasive approach allows the correction of multiple peritrochanteric pathologies in the same operative setting, which may have driven up complication rates as well. Total number of failures were low across all studies and the severity of complications did not appear to favor one approach over the other.

The average age was 52.5 in the arthroscopic cohort and 56.9 in the open cohort with the majority of patients being female, findings that are consistent with the existing literature. Yoon et al.[30] and Vap et al.[18] both reported a mean age below 40, which is younger than the previously reported populations with GTPS. However, they also included patients with snapping hip and femoroacetabular impingement, respectively, conditions that are more commonly treated in younger patients. Epidemiologically, exclusion criteria differed across studies but all had similar inclusion criteria consisting of a differential diagnosis of recalcitrant lateral hip pain, marked sensitivity over the greater trochanter, and failed non-operative treatment including lifestyle modifications, NSAIDs, physical therapy, and/or corticosteroid injections. In general, these findings correlated with the orthopedic literature by suggesting an outcomes preference for younger patients undergoing arthroscopic trochanteric bursectomy,[30,31,33] though because the included patient populations were not uniform, no clear relationship between age and outcomes measures could be drawn.

Table 8. Summary of the Complication and Failure Rates of the Included Studies

Surgical Approach	Study	Complications	Failures
Arthroscopic	Baker et al. 2007[17]	1 seroma (4%)	1 (4%)
Arthroscopic	Domb et al. 2013[28]	1 superficial infection (6.67%)	0 (0%)
Arthroscopic	Domb et al. 2014[33]	9 unspecified and non-surgical complications (18%)	4 conversions to THA (8%) 3 revisions (6%)
Arthroscopic	Domínguez et al. 2015[31]	0 (0%)	0 (0%)
Arthroscopic	Drummond et al. 2016[5]	0 (0%)	0 (0%)
Arthroscopic	Vap et al. 2017[18]	2 w/ stiffness (2.78%) 3 w/ continued pain (4.17%) 1 w/ drainage from sutures (1.38%) 1 w/ dysphagia (1.38%) 1 capsular tear (1.38%)	0 (0%)
Arthroscopic	Van Hofwegen et al. 2013[29]	1 w/ incomplete resolution of pain (8.33%) 1 w/ recurrence of pain (8.33%) 2 hematoma formations w/ subsequent heterotopic ossification (16.67%)	0 (0%)
Arthroscopic	Wiese et al. 2004[19]	4 hematomas (7.84%)	0 (0%)
Arthroscopic	Yoon et al. 2014[30]	1 w/ incomplete resolution of pain (10%)	0 (0%)
Open	Bucher et al. 2014[34]	1 catheter-related complication leading to prostatic resection surgery (4.54%)	0 (0%)
Open	Craig et al. 2014[35]	1 wound seroma (5.88%) 1 glute minimus tendon tear (5.88%)	0 (0%)
Open	Davies et al. 2007[38]	0 (0%)	0 (0%)
Open	Ebert et al. 2013[36]	1 hematoma (0.91%) 2 superficial wound infections (1.82%) 1 DVT/PE (0.91%)	3 (2.73%)
Open	Govaert et al. 2003[37]	0 (0%)	0 (0%)
Open	Slawski et al. 1997[26]	0 (0%)	0 (0%)

While the majority of patients with GTPS can be treated nonoperatively,[1,7,20,21,23,24] this study demonstrates similarly strong results for both open and arthroscopic trochanteric bursectomy in those indicated for surgery. Surprisingly, neither approach produced any significant differences with regard to changes in outcome scores or complication rates, though this may be related to the small size of the study groups. The low overall complication prevalence in both approaches also reinforces the safety of surgically excising the trochanteric bursae. As both approaches have illustrated the efficacy and safety of this procedure, surgical decisions should be tailored to surgeon experience and patient preference. Future, prospective investigations may provide more insight into the differences between the two approaches.

Limitations

This study represents the first systematic review examining outcomes of surgical treatment for GTPS. While we have searched the literature extensively using several databases and limiting selection bias with a broad search strategy and specific inclusion criteria, there were several limitations. Though reflective of the current research into trochanteric bursectomy, the majority of the included studies offered Level IV evidence with an inherent lack of blinding that predisposed studies to the presence of detection bias. Additionally, only seven studies across both open and arthroscopic techniques reported standard error or confidence intervals, and did so for various outcome measurements. This lack of uniform statistical reporting and of individualized outcomes inhibited the pooling of means, thereby precluding a meta-analysis that would allow for a more precise comparison of the open and arthroscopic approaches. Furthermore, the investigation by Baker et al.[17] was the only study to perform no concomitant procedures, with another study reporting as many as nine.[28] Though the performance of these procedures existed in both groups, this heterogeneity may have influenced outcomes via a performance bias and is another reason we limited the pooling of our results. It is worth noting, though, that the ubiquitous improvement of patient outcomes with

both approaches highlights the versatility of TB and it's capacity to be performed with other periarticular procedures in a single operative setting. Ultimately, this review underscores that heterogeneous study design, small sample sizes, and a lack of standardized reporting of outcome measures across each investigation have made it difficult to collate the outcomes of open versus arthroscopic trochanteric bursectomy using a formal statistical analysis. Ideally, future comparative investigations and reviews of randomized controlled trials can provide stronger recommendations contrasting the two approaches.

CONCLUSION

The open and arthroscopic approaches for trochanteric bursectomy are both safe and effective procedures in treating refractory lateral hip pain. No significant differences in PROs, pain, total complications, severity of complications, and total failures were seen between technique outcomes.

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PROMIS VERSUS LEGACY PATIENT-REPORTED OUTCOME MEASURES FOR SPORTS MEDICINE PATIENTS UNDERGOING ARTHROSCOPIC KNEE, SHOULDER, AND HIP INTERVENTIONS: A SYSTEMATIC REVIEW

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ABSTRACT

Background: The Patient-Reported Outcomes Measurement Information System (PROMIS®)‡ was designed to monitor the global wellbeing of patients, with the Physical Function Computer-Adaptive Test (PF-CAT) component focused specifically on functional outcome. PROMIS aims for increased item-bank accuracy, lower administrative burden, and decreased floor and ceiling effects compared to legacy patient-reported outcome measures (PROMs). Our primary research outcomes focused on sports medicine surgical populations, which may skew younger or have wide-ranging functional statuses. Specifically, for this population, we questioned if PROMIS PF-CAT was equal to legacy PROMs in (1) construct validity and (2) convergent/divergent validities; and superior to legacy PROMs with respect to (3) survey burden and (4) floor and ceiling effects.

Methods: Searches were performed in April 2019 in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, utilizing PubMed, Cochrane Central, and Embase databases for Level I-III evidence. This resulted in 541 records, yielding 12 studies for inclusion. PROM data was available for patients undergoing arthroscopic orthopaedic procedures of the knee, shoulder, and hip. Measures of construct validity, convergent/divergent validity, survey burden, and floor/ceiling effects were evaluated for PROMIS PF-CAT versus legacy PROMs.

Results: PROMIS PF-CAT demonstrated excellent or excellent-good correlation with legacy PROMS for physical function and quality of life for patients undergoing arthroscopic interventions of the knee, shoulder, and hip. Compared to legacy PROM instruments, PROMIS PF-CAT demonstrated the lowest overall survey burden and had the lowest overall number of floor or ceiling effects across participants.

Conclusion: PROMIS PF-CAT is an accurate, efficient evaluation tool for sports medicine surgical patients. PROMIS PF-CAT strongly correlates with legacy physical function PROMs while having a lower test burden and less incidence of floor and ceiling effects. PROMIS PF-CAT may be an optimal alternative for traditional physical function PROMs in sports medicine patients undergoing arthroscopic procedures. Further studies are required to extend the generalizability of these findings to patients during postoperative timepoints after shoulder and hip interventions

Level of Evidence: III

Keywords: patient-reported outcome measures, prom, promis, sports medicine, knee arthroscopy, hip arthroscopy, shoulder arthroscopy, outcomes-based research, systematic review

INTRODUCTION

The National Institutes of Health developed the standardized Patient-Reported Outcomes Measurement Information System (PROMIS®)‡ to monitor physical, social, and mental wellbeing of patients.[1,2] In the age of value-based care and shared decision-making between patients and surgeons, Patient-Reported Outcome Measures (PROMs) are often employed to assess patient-specific variables. A specific sub-analysis in the PROMIS group, PROMIS Physical Function Computer-Adaptive Test (PF-CAT), has been determined to effectively assess the same information as legacy PROMs, while requiring fewer questions on average and having less statistical interference for low and high-scoring patients. PROMIS

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‡PROMIS®, Patient-Reported Outcomes Measurement Information System®, and the PROMIS® logo are marks owned by the U. S. Department of Health and Human Services.

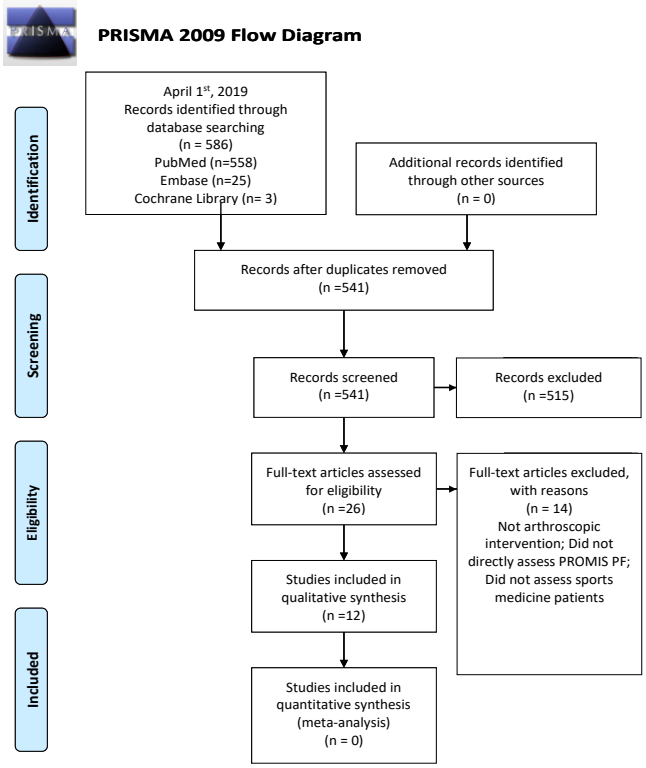

Figure 1. Included and Excluded Studies of PROMIS PF-CAT for Sports Medicine Patient Populations.

PF-CAT has been deemed advantageous for use in general orthopaedic patients, both pre- and postoperatively.[2,3]

Any widely-utilized PROM should demonstrate high content validity, reliability, and item responsiveness across survey participants.[1,2,4] Previous literature has demonstrated that PROMIS PF-CAT correlates strongly with previously validated PROMs for patients undergoing arthroscopic procedures of the knee, shoulder, and hip. PROMIS PF-CAT test/re-test reliability is also equivalent to or exceeding that of legacy measures.[4-6] In addition, PROMIS PF-CAT has demonstrated a reduced survey burden (number of questions and/or time for completion) as compared to legacy PROM instruments. For patient populations which tend to score on the low or high end of legacy measures, PROMIS PF-CAT has the advantage of the lowest overall floor and ceiling effects (attaining the bottom or top 15% scores, respectively) compared to legacy PROMs.[7-10] Increased item-bank accuracy, lower administrative burden, and decreased floor and ceiling effects make PROMIS PF-CAT an attractive alternative for orthopaedic sports medicine practices. In busy sports medicine practices PROMIS is both efficient and adaptive, and accommodates a population which tends to skew younger, functionally high-level, and therefore prone to ceiling effects on non-adaptive PROMs.[11]

The purpose of this systematic review was to assess the utility of PROMIS-PF-CAT for patients undergoing

Inclusion Criteria	Exclusion Criteria
• PROMIS PF-CAT specifically used as a patient-reported outcome measure	• PROMIS PF-CAT not used as a patient-reported outcome measure
• Orthopaedic patients undergoing arthroscopic operative interventions of the knee, shoulder, or hip	• Patients not indicated for operative arthroscopic interventions of the knee, shoulder, or hip
• Level I, II, or III evidence	• Level IV or V evidence
• English language studies	• Non-human studies
• Human studies	• Non-English language studies

Figure 2. Inclusion and Exclusion Criteria for Review Literature.

arthroscopic sports medicine interventions of the knee, shoulder, and hip. Specifically, for this population, we questioned if PROMIS PF-CAT was equal to legacy PROMs in (1) construct validity and (2) convergent/divergent validities; and superior to legacy PROMs with respect to (3) survey burden and (4) floor and ceiling effects. We hypothesized that PROMIS would correlate strongly with legacy sports medicine PROMs of the knee, shoulder, and hip; while demonstrating decreased end-range statistical errors and overall lower survey burden compared to the legacy PROMs.

METHODS

A systematic review was performed in April 2019 in accordance with the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (PRISMA) utilizing PubMed, Cochrane Central, and Embase databases. Eligible Level I, II, or III studies published on or before April 2019 included patients undergoing operative arthroscopic sports medicine interventions of the knee, shoulder, or hip at the preoperative and/or postoperative timepoints and utilization of PROMIS PF-CAT as a patient-reported outcome measure. PubMed MeSH terms for the patient-reported outcomes search component included:

"(((((((patient-reported outcomes measurement information system) OR patient-reported outcomes measurement information systems) OR patient reported outcomes measurement information system) OR patient reported outcomes measurement information systems) OR PROMIS)) AND (physical function OR physical functions OR PF OR pf))"

MeSH terms for the patient population/target intervention included:

"((((((((((shoulder joint) OR knee joint) OR hip joint) OR acromioclavicular joint) OR knee ligament) OR meniscus) OR rotator cuff) OR anterior cruciate

Table 1. Patient Demographic Data and Individual Study Inclusion/Exclusion Criteria, by Joint

	Author	Year	Level of Evidence	Number of Patients (% male)	Mean Age (Range) or ±Std (years)	Mean BMI ±Std; kg/m3 or Weight (lbs)	Condition and/or Procedure Type	Inclusion Criteria	Exclusion Criteria
Shoulder	Anthony et al.[7]	2017	II	82 (61.0%)	54 (22-72)	31.7±7.4	Rotator cuff repair	Preoperative diagnosis of RC[a] pathology	Incomplete survey data
	Anthony et al.[11]	2017	II	70 (74.3%)	27 (12-54)	27±5.1	Surgical management of shoulder instability	Scheduled for operative intervention	Incomplete survey data
	Patterson et al.[24]	2018	II	164 (51.8%)	58 (18-79)	30±6.2	Rotator cuff repair	Primary rotator cuff repair, preoperative PROMs[b]	Revision rotator cuff repair, younger than age 18, incomplete survey responses
Knee	Bernholt et al.[20]	2018	III	75 (50.7%)	53.3 (22.2-72.7)	30.6±6.1	Arthroscopic partial meniscectomy	Had preoperative PROMIS scores	Additional procedures performed
	Chen et al.[21]	2018	III	233 (50.6%)	26.5±12.5	Not provided	ACL[c] reconstruction	Primary reconstruction, pre- and post-operative PROMIS scores	None
	Hancock et al.[8]	2017	III	107 (34.6%)	37.7±16.0	29.6±6.3	Arthroscopic meniscal surgery	Scheduled for meniscal repair, meniscectomy, or debridement	Major simultaneous procedures or grade 4 OA
	Hancock et al.[9]	2018	III	100 (45%)	26 (11-57)	27.2±6.2	ACL reconstruction	Indicated for operative management of ACL injury	Significant simultaneous operations
	Meredith et al.[22]	2018	III	383 (55.4%)	40.2±13.6 (opioid), 39.0±16.7 (no opioid)	30±6.7 (opioid), 29.1±5.6 (non-opioid)	Knee surgery w/wo preoperative opioid use	Over 12 years of age, English speaking, not incarcerated or a ward of the state	No data on preoperative opioid use
	Papuga et al.[23]	2014	III	106 (46.2%)	29.5±13.3	167.7 lb	ACL reconstruction	Age 13+, scheduled for BTB[d] autograft ACL reconstruction	Disorders of balance, gait degeneration, or neuromuscular junction; dementia, depression, or cognitive impairment
	Scott et al.[11]	2018	II	111*	24±9.3	26.3±4.7	ACL reconstruction	Primary or revision reconstruction, age 14+, written English proficiency	Bilateral ACL reconstruction
Hip	Kollmorgen et al.[25]	2019	III	125 (18.4%)	38.1 (18-70)	26.6±5.01	Arthroscopic hip procedures	Age 18-80, completion of CAT and legacy scores	Repeat encounters, non-English speaking, no CAT data
	Sheean et al.[26]	2017	III	42 (71.4%)	32.2±6.4	186 lb (control), 198.7 lb (FAI)	FAI[e]	Unilateral hip pain, age 18-50, positive impingement test, relief after IA anesthetic injections	Radiographic evidence of OA[f]; history of femoral head pathology or hip dysplasia
	Nwachukwu et al.[34]**		II	196 (23.4%)	32.8±12.6	25.7±5.6	FAI[e]	Clinical and radiographic findings of symptomatic FAI, failure of conservative management	Prior surgery on hip; non-FAI indications, concomitant procedures; hip OA, dysplasia, or congenital disorders

Table 1: [a]RC:Rotator cuff; [b]PRO: Patient-Reported Outcome Measure; [c]ACL: Anterior cruciate ligament; [d]Patellar bone-tendon-bone graft; [e]Femroacetabular impingement; [f]Osteoarthritis; *sex data unavailable; study used for discussion purposes only, not meta-analysis

ligament) OR posterior cruciate ligament) OR collateral ligaments) OR cartilage, articular) AND (((((((((shoulder injury) OR knee injury) OR ligament injury) OR impingement syndromes, shoulder) OR hip injuries) OR patellofemoral syndrome) OR cartilage disease) OR bankart lesion) OR musculoskeletal injury)) AND (((endoscopy) OR minimally invasive surgical procedures) OR arthroscopy)"

Search components were then combined, with the English language filter being the only pre-established search restriction utilized. Search terms were then adapted for use in the other databases. Full search strategies are available upon request.

The search was conducted under the guidance of a trained librarian specializing in orthopaedic medicine. In total, 541 unique records resulted after removal of duplicate records, which was facilitated by software screening of the records supplemented by manual review. Of the 541 unique records, 515 articles were excluded for not meeting the necessary inclusion requirements and/or for aspects qualifying as exclusion criteria (Figures 1-2). Of the 26 full-text articles reviewed by 2 research assistants under the guidance of 2 fellowship trained sports medicine surgeons; 12 articles satisfied the inclusion criteria (Figures 1-2) and were included for quantitative and qualitative analyses (Table 1).

Table 2. Correlation of PROMIS PF-CAT with Legacy PROMs, Stratified by Joint

Legacy PROM Instrument	Knee [Pearson/ Spearman Correlation Coefficient]	Shoulder [Pearson/ Spearman Correlation Coefficient]	Hip [Pearson/ Spearman Correlation Coefficient]
SF-36 PF	0.80±0.04	74.5±3.54	
KOOS Sport	0.72±0.04		
IKDC	0.90*		
MARX	0.05±0.04**	0.26±0.04**	
SF-36 GH	0.18±0.08**	0.5*	
SF-36 Pain	0.56±0.06		
EQ-5D	0.68±0.05	0.60±0.04	
KOOS Symptoms	0.56±0.02		
KOOS Pain	0.59±0.01		
KOOS QoL	0.55±0.07		
ASES		0.55±0.12	
WORC		0.61*	
WOSI		0.49*	
mHHS			0.71*
iHOT-12			0.76*
HOOS ADL			0.87*
HOOS SS			0.81*
VR-6			
HOS Sports			
HOS ADL			
VAS			

Table 2. *Average value not available; **one or more of the individual p-values>0.05.

Measures of PROMIS PF-CAT construct validity, convergent validity, and divergent validity were evaluated as compared to legacy PROMs. Based on prior literature detailing research of the PROMIS PF-CAT instrument[7,11,12] the correlation cut-off (r=0.4) was used to differentiate between convergent correlations ($r>0.4$, $p<0.05$) and divergent correlations ($r<0.4$; $p>0.05$), respectively. Convergent validity was defined as moderate-strong correlation coefficients between survey instruments ($r>0.4$, $p<0.05$). Divergent validity was defined as weak or no correlation between survey instruments ($r<0.4$; $p>0.05$). Survey burden, floor effects, and ceiling effects were additional factors compared between PROMIS PF-CAT and legacy PROMs. When possible, data was stratified by anatomic location (knee, shoulder, hip) for additional analyses. The overall quality of included evidence was evaluated by two research assistants, utilizing the Modified Coleman Methodology, under the supervision of two fellowship trained orthopaedic surgeons.

Legacy Sports Medicine PROMs for Knee, Shoulder, and Hip

Legacy PROMs for the knee in the present study included the Knee Injury and Osteoarthritis (KOOS) battery [Activities of Daily Living (ADL), Quality of Life (QOL), Symptoms, Sports Participation (Sports), and Pain] and the International Knee Documentation Committee score (IKDC).[13] KOOS, depending on which tests in the battery are utilized, assesses functional, work-related, social, and emotional dimensions of knee symptoms.[13] IKDC assesses the functional status of the knee.[13]

Legacy PROMs for the shoulder included the Western Ontario Shoulder Instability Index (WOSI), Western Ontario Rotator Cuff Index (WORC), American Shoulder and Elbow Surgeons Score (ASES), and the SST (Simple Shoulder Test).[14,15] WOSI, WORC, and ASES assess the functional status of the shoulder and the impact of shoulder symptoms on work, social, and emotional aspects of patient lives.[14] SST assesses only functional status and work status.[15]

Legacy PROMs for the hip included the modified Harris Hip Score (mHHS), the International Hip Outcome Tool (iHOT-12), and the Hip Outcome Score (HOS) battery [Sports-Specific (SS) and Activities of Daily Living

Table 3. Convergent and Divergent Validities of PROMIS PF-CAT vs. Legacy PROMs, by Joint

		Convergent Correlations				Divergent Correlations			
	Study Author		Convergence Demonstrated [r>0.4; p<0.05]	Spearman Correlation Coefficient	p-value		Divergence Demonstrated [r<0.3; p>0.05]	Spearman Correlation Coefficient	p-value
Shoulder	Anthony et al.[1¥]					MARX	No	0.34	<0.01
						SF-36 GH	No	0.5	<0.01
	Anthony et al.[2¥]	ASES	Yes	0.67	<0.01	MARX	Yes	0.18	0.14
		WOSI	Yes	0.49	<0.01				
		SF-36 PF	Yes	0.72	<0.01				
	Shoulder Averages					MARX	Yes	0.26	0.075
Knee	Hancock et al.[8]	KOOS ADL	Yes	0.6	<0.01	MARX	Yes	0.05	0.59
		KOOS SPORT	Yes	0.76	<0.01	SF-36 GH	Yes	0.27	<0.01
		SF-36 PF	Yes	0.82	<0.01	SF-36 PAIN	No	0.6	<0.01
						KOOS SYM	No	0.57	<0.01
						KOOS PAIN	No	0.6	<0.01
						KOOS QOL	No	0.63	<0.01
						EQ-5D	No	0.62	<0.01
	Hancock et al.[9]	SF-36 PF	Yes	0.82	<0.01	SF-36 GH	Yes	0.12	0.22
		KOOS SPORT	Yes	0.7	<0.01	SF-36 PAIN	No	0.51	<0.01
		KOOS ADL	Yes	0.74	<0.01	KOOS SYM	No	0.54	<0.01
						KOOS PAIN	No	0.58	<0.01
						KOOS QOL	No	0.49	<0.01
						EQ-5D	No	0.70	<0.01
						MARX	Yes	0.08	0.46
	Papuga et al.[23]	IKDC	Yes	0.90*	<0.01				
	Knee Averages	KOOS ADL	Yes	0.67	<0.01	MARX	Yes	0.07	0.53
		KOOS SPORT	Yes	0.73	<0.01	SF-36 GH	Yes	0.20	0.12
		SF-36 PF	Yes	0.82	<0.01	SF-36 PAIN	No	0.56	<0.01
						KOOS SYM	No	0.55	<0.01
						KOOS PAIN	No	0.59	<0.01
						KOOS QOL	No	0.56	<0.01
						EQ-5D	Yes	0.35	0.24

*Pearson correlation coefficient used by Papuga et al. only

[1¥]Anthony et. al "Preoperative Performance of the Patient-Reported Outcomes Measurement Information System in Patients With Rotator Cuff Pathology"

[2¥]Anthony et. al "Performance of PROMIS Instruments in Patients With Shoulder Instability"

Table 4. PROMIS PF-CAT Administration Data: Survey Burden, Floor Effects, and Ceiling Effects by Joint

	Study Author	Average Questions ±std	Floor Effects (%)	Ceiling Effects (%)
Shoulder	Anthony et al.[7]	4.3±1.2	0	1 (1.2%)
	Anthony et al.[11]	4.6±1.8	0	0
	Patterson et al.[24]	Not provided	Not provided	Not provided
Shoulder Averages ±std		4.5±1.5	0	(0.6%±0.9%)
Knee	Bernholt et al.[21]	Not provided	Not provided	Not provided
	Chen et al.[23]	Not provided	Not provided	Not provided
	Hancock et al.[8]	4.4±1.4	0	0
	Hancock et al.[9]	4.2±0.9	0	0
	Meredith et al.[22]	Not provided	Not provided	Not provided
	Papuga et al.[23]	Not provided	Not provided	Not provided
	Scott et al.[10]	4.0±1.6	0	0
Knee Averages ±Std		4.2±0.2	0	0
Hip	Sheean et al.[26]	Not provided	Not provided	Not provided
	Kollmorgen et al.[25]	4.1	Not provided	0
Hip Averages*		4.1	Not provided	0
Total		4.3±0.2	Not Provided	0

*Data not available for multi-study calculation of averages

(ADL)].[16] The HOS battery and iHOT assess functional status; and work-related, social, and emotional concerns related to hip symptoms.[16] The mHHS focuses on the physical function of the hip.[16]

Additional legacy sports medicine PROMs assessed across patients undergoing operative interventions of the knee, shoulder, and hip included the EuroQol Five Dimensions test (EQ-5D), Veterans Rand 6 Domain (VR-6D), Marx Activity Rating Scale (Marx) and the Short Form Survey (SF-36) test battery [Physical Function (PF), General Health (GH), and Pain subscales].[17-19] VR-6D assesses physical and emotional status and SF-36 assesses physical, emotional, and work-related ability to function.[18,19] EQ-5D assesses physical, emotional, social, and work-related aspects of health.[18] Marx assesses overall physical function.[17]

RESULTS

Study Population Demographics and Characteristics

The present review included 12 studies of patients undergoing arthroscopic interventions of the knee (7),[8-10,20-23] shoulder (3),[7,11,24] and hip (2)[25,26] (Table 6). In total, PROM data was available for assessment from 1105 knee arthroscopy patients, 210 shoulder arthroscopy patients, and 167 hip arthroscopy patients. Demographic variables for the arthroscopic populations were investigated in groups, stratified by joint undergoing surgery. Knee patients were 51.9% male (547 patients), with a mean age of 34.2 years (range: 11-72 years), and a mean BMI of 28.7±5.9 kg/m^2 (data not available for 2/7 studies). Shoulder patients were 67.1% male (102 patients), with a mean age of 46.3 years (range: 12-79 years), and a BMI of 29.4±6.3 kg/m^2). Hip patients were 31.7% male (53 patients), with a mean age of 32 years (range: 18-70 years), and a mean BMI of 26.6±5.0kg/m^2 (Table 1). The notably wide patient age ranges were helpful in assessing what limitations, if any, were present in PROMIS PF-CAT adaptations to avoid floor or ceiling effects.

The majority of the included studies (9/12, 75.0%) directly compared PROMIS PF-CAT with legacy PROMs assessing physical function, such as ASES (shoulder),[1] KOOS (knee),[19] and mHHS (hip)[26,41] (Table 2).[1,2,19,20,26,33,39,41] PROMs assessing general measures of health were also compared to PROMIS PF-CAT.[1,2,19,20] The remaining 3 studies examined the ability of PROMIS PF-CAT to detect additional measures of health and function.[4,11,28,32] Construct validity, convergent validity, divergent validity, survey burden, floor effects, and ceiling effects were evaluated for PROMIS PF-CAT in comparison to the legacy PROMs (Tables 3-5).[1,2,19,20,26,32,39]

PROMIS PF-CAT versus Legacy Patient-Reported Outcome Measures

Survey Validity in the Context of Varying Joint Procedures

In total, 4 of the 7 knee arthroscopy studies (57.1%) compared PROMIS PF-CAT to legacy knee PROMs

Table 5. Question Burden for PROMIS PF-CAT vs. Legacy PROMs

PROM Instrument†	Questions	Health Domains Assessed
PROMIS PF-CAT	4-12	Physical Function
SF-36	36	General Health, includes Physical Health (10 questions)
EQ-5D	6	Overall Function
VR-6D	12	Physical and emotional function
WOSI	21	Shoulder function, work ability, emotional and social impact
WORC	21	Shoulder function, work ability, emotional and social impact
ASES	11	Shoulder function, work ability, emotional and social impact
SST	12	Shoulder function and work ability
Marx	4	Knee Activity Rating Scale
IKDC	10	Knee function
KOOS	43	Knee Pain, Symptoms, Function, and Quality of Life
mHHS	8	Hip function
iHOT-12	12	Hip function, work ability, emotional and social impact
HOS	31	Hip function, work ability, emotional and social impact

†Table 5 Key
- PROMIS PF (CAT): Patient-Reported Outcomes Measurement Information System, Physical Function (Computer-Adaptive Testing)
- SF-36 (PF, GH, PAIN): Short Form Survey (Physical Function, General Health, Pain)
- EQ-5D: EuroQol Five Dimensions
- WOSI: Western Ontario Shoulder Instability Index
- WORC: Western Ontario Rotator Cuff Index
- ASES: American Shoulder and Elbow Surgeons Score
- MARX/MARS: Marx Activity Rating Scale
- SST: Simple Shoulder Test
- KOOS (ADL, QOL, Symptoms, Sport, Pain): Knee Injury and Osteoarthritis Outcome Score (Activities of Daily Living, Quality of Life, Symptoms, Sports Participation, Pain)
- IKDC: International Knee Documentation Committee
- mHHS: Modified Harris Hip Score
- iHOT-12: International Hip Outcome Tool
- HOS(-SS, -ADL): Hip Outcome Score (Sports-Specific, Activities of Daily Living)
- VR-6D: Veterans Rand 6 Domain

(Table 2).[8-10,23] PROMIS PF-CAT demonstrated excellent correlation with SF-36 PF (r=0.80, p<0.01) and IKDC (r=0.90, p<0.01)[32]; and excellent-good correlations with the KOOS sub-scales ADL (r=0.66, p<0.01) and Sports (r=0.67, p<0.01).[8-10] Moderate convergent validity with PROMIS PF CAT was present for SF-36 Pain (r=0.56, p<0.01) and KOOS subscales of Symptoms (r=0.55, p<0.01), Pain (r=0.59, p<0.01), and Quality of Life (r=0.56, p<0.01).[8,9] Divergent validity was demonstrated for Marx (r=0.07, p=0.53), SF-36 GH (r=0.20, p=0.12), and EQ-5D (r=0.35, p=0.24) (Table 3).[8,9]

PROMIS PF-CAT was compared with legacy shoulder PROMs in all three included studies of patients undergoing shoulder arthroscopy (100%) (Table 2).[7,11,24] PROMIS PF-CAT demonstrated excellent correlation with SF-36 PF (r=0.74, p<0.01) and good correlation with ASES (r=0.51, p<0.01).[7,11,24] PROMIS PF-CAT demonstrated convergent validity with ASES (r=0.67, p<0.01), SF-36 PF (r=0.72, p<0.01), and WOSI (r=0.49, p<0.01).[11] Divergent validity was present for Marx (r=0.26, p=0.08) (Table 3).[7,11]

Of the two included studies assessing hip arthroscopy patients, only Kollmorgen et al.[27] compared PROMIS PF-CAT to legacy hip PROMs (50%) (Table 2). PROMIS PF-CAT demonstrated excellent correlations with both mHHS (r=0.71, p<0.05) and iHOT-12 (r=0.76, p<0.05). Sheean et al. did not directly report correlation coefficients in their study of hip arthroscopy patients.[41] Due to limited data, convergence and divergence values were unable to be reported for arthroscopic interventions of the hip.

Survey Burden, Floor Effects, and Ceiling Effects

In the studies of arthroscopic knee interventions, data from completed survey instruments was available from the preoperative timepoint for 590/1105 (53.4%) patients. Additionally, survey data was available for 515/1105 (46.6%) knee arthroscopy patients from both the preoperative and postoperative timepoints. Of the patients undergoing arthroscopic shoulder interventions, survey data was available for 210/210 (100%) of participants from the preoperative timepoint. Similarly, survey data for 364/364 (100%) of hip arthroscopy patients was available from the preoperative timepoint. It is noted that postoperative survey data in literature qualifying for this review is currently only available for arthroscopic procedures of the knee.

The mean number of PROMIS PF-CAT questions completed by patients undergoing arthroscopic intervention was stratified by joint (Table 4). To acquire all necessary outcome measures data, patients undergoing knee arthroscopy had to answer an average of 4.2±0.2 questions. Shoulder arthroscopy patients answered an average of 4.5±1.5 questions, and hip arthroscopy patients averaged slightly less, answering 4.1 questions (no standard deviation available).[7-11,20-26] The survey burden for each legacy PROM is provided in Table 5 for comparison. With the exception of the Marx scale for the knee (4 questions), PROMIS PF-CAT required fewer questions than all other legacy sports medicine PROMs, which ranged as high as 43 questions (KOOS). PROMIS PF-CAT also had floor and ceiling effects reported for at least one study in each subgroup of knee, shoulder, and hip; all reported effects being minimal (1.6%) to none (0%) (Table 4).

Study Evidence Quality

For the included studies, the mean consensus Modified Coleman Methodology Score (MCMS) was 54 (range: 32-50). Scores were influenced by the nature of validation studies examining PROM instruments; most studies did not directly assess traditional surgical

Table 6. Study Outcome Measures utilizing PROMIS PF-CAT for Arthroscopic Interventions of the Shoulder, Knee, and Hip

	Author	Year	Condition and/or Procedure Type	Outcome Measure	Results
Shoulder	Anthony et al.[1]	2017	Rotator cuff repair	Correlation[b] of PROMIS PF CAT[a] with traditional shoulder and upper extremity PROMs[c]	PROMIS PF CAT had excellent correlation with SF-36 PF[a]; excellent-good correlations with EQ-5D[a], WORC[a]; no floor effects; 1 ceiling effect.
	Anthony et al.[2]	2017	Surgical management of shoulder instability	Correlation[b] of PROMIS PF CAT with traditional shoulder and upper extremity PROMs	PROMIS PF CAT had excellent correlation with SF-36 PF; excellent-good correlation with ASES[a], no ceiling effects.
	Patterson et al.[24]	2018	Rotator cuff repair	Correlation[d] of PROMIS PF CAT with ASES and SST[a]	PROMIS PF-CAT had weak correlations with ASES and moderate correlations with SST.
Knee	Bernholt et al.[20]	2018	Arthroscopic partial meniscectomy	Ability of PROMIS to detect early variations in postoperative outcomes	Preoperative PROMIS PF-CAT scores were significantly lower than the general population. At 6 weeks postoperatively, significant improvements in PF scores were seen.
	Chen et al.[21]	2018	ACL (anterior cruciate ligament) reconstruction	Changes in PROMIS scores postoperatively; predictive ability of preoperative PROMIS scores to identify patients who will not achieve MCID[e]	Patients on average had significant improvement in PROMIS PF-CAT measures.
	Hancock et al.[8]	2017	Arthroscopic meniscal surgery	Correlation of PROMIS PF-CAT with legacy PROM instruments	PROMIS PF-CAT had high correlations with SF-36 PF, KOOS Sport[a]; high-moderate correlations with KOOS QOL[a], EQ-5D. Average number of PROMIS questions (4). No floor or ceiling effects.
	Hancock et al.[9]	2018	ACL reconstruction	Correlation of PROMIS PF-CAT with current measures of knee PROMs, PROMIS test burden, floor/ceiling effects[f]	PROMIS PF-CAT demonstrated high correlations with SF-36 PF, EQ-5D, KOOS ADL[a], and KOOS Sport. Mean number of questions (4.2). No floor or ceiling effects.
	Meredith et al.[22]	2018	Knee surgery with, without preoperative opioid use	Correlation of clinical variables and PROMs with opioid use. (significance at $p<0.05$)	Preoperative opioid use was associated with worse scores using PROMIS and legacy PROM instruments.
	Papuga et al.[23]	2014	ACL reconstruction	Time to administer PROMIS, correlation of PROMIS and legacy PROMs, ability of PROMIS to identify patients likely to have poor outcomes	PROMIS took less time to administer and detected functional changes better than IKDC[a]. Patients with poor outcomes had significantly lower PROMIS scores.
	Scott et al.[10]	2018	ACL reconstruction	Correlation[b] between PROMIS PF CAT and legacy PROMs	PROMIS PF-CAT had excellent, excellent-good, or good correlations with SF-36 PF, KOOS-ADL, KOOS-Sport, KOOS-QOL, and EQ-5D preoperatively and postoperatively. Minimal floor and ceiling effects, mean 4 questions.
Hip	Kollmorgen et al.[25]	2019	Arthroscopic hip procedures	Correlation[g] of PROMIS with legacy measures, PROMIS floor and ceiling effects	PROMIS PF-CAT had strong correlations with mHHS[a], iHOT-12[a], HOS-SS[a], HOS-ADL[a], and VR-6D[a]. Ceiling effects were not demonstrated for any PROMIS measures.
	Sheean et al.[26]	2017	FAI	PROMIS score differences between FAI (femoroacetabular impingement) patients and controls, association of PROMs and PF measures[h]	Significant differences were found for legacy PROMs, physical performance, and PROMIS measures between the FAI and control group.
	Nwachukwu et al.[34]	2019	FAI	Correlation of PROMIS with legacy PROMs for hip arthroscopy patients undergoing operative intervention for FAI	PROMIS PF-CAT demonstrated good-excellent correlations with legacy hip-specific instruments as well as hip-related quality of life measures

Table 6 Key

[1]Anthony et al. "Preoperative Performance of the Patient-Reported Outcomes Measurement Information System in Patients With Rotator Cuff Pathology"
[2]Anthony et al. "Performance of PROMIS Instruments in Patients With Shoulder Instability"

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[a]see key below for PROM acronyms
[b]Excellent >0.7, excellent-good 0.61-0.7, good 0.4-0.6, poor 0.2-0.3; significance at p<0.05
[c]PROMs= Patient-Reported Outcome Measures
[d]Very strong 0.90-1.00, strong 0.70-0.89, moderate 0.50-0.69, weak 0.30-0.49, none 0.00-0.29; significance at p<0.05
[e]MCID= minimal clinically important difference (significance at p<0.05)
[f]High 0.7+, high-moderate 0.61-0.69, moderate 0.4-0.6, moderate-weak 0.31-0.39, weak 0.3-; significance at p<0.05
[g]Strong >0.7, mod-strong 0.5-0.7, weak 0.3-0.5, negligible 0-0.3; significance at p<0.05
[h]High r>0.5, moderate r=0.3-0.5, low r<0.3; significance at p<0.05

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[a]Patient-Report Outcome Measures (PROM) Instruments
PROMIS PF (CAT): Patient-Reported Outcomes Measurement Information System, Physical Function (Computer-Adaptive Testing)
SF-36 (PF, GH, PAIN): Short Form Survey (Physical Function, General Health, Pain)
EQ-5D: EuroQol Five Dimensions
WOSI: Western Ontario Shoulder Instability Index
WORC: Western Ontario Rotator Cuff Index
ASES: American Shoulder and Elbow Surgeons Score
MARX/MARS: Marx Activity Rating Scale
SST: Simple Shoulder Test
KOOS (ADL, QOL, Symptoms, Sport, Pain): Knee Injury and Osteoarthritis Outcome Score (Activities of Daily Living, Quality of Life, Symptoms, Sports Participation, Pain)
IKDC: International Knee Documentation Committee
mHHS: Modified Harris Hip Score
iHOT-12: International Hip Outcome Tool
HOS(-SS, -ADL): Hip Outcome Score (Sports-Specific, Activities of Daily Living)
VR-6D: Veterans Rand 6 Domain

outcome measures, and smaller sample sizes were used. These factors lowered the overall MCMS scores. Consensus by the authors when comparing independently determined scores was that certain MCMS measures of study quality—including type of study, clearly defined endpoints, and demographic data of patients—were adequate. Despite lower scores for other MCMS criterion, such as outcome measures and radiographic measurements, the average value of included studies was "Good" per MCMS standards.

DISCUSSION

In the current study, excellent-good correlations were found between PROMIS PF-CAT and legacy PROMs for sports medicine patient populations undergoing arthroscopic interventions of the knee, shoulder, and hip. This demonstrates the flexibility of PROMIS PF-CAT to independently collect outcome measures data which previously required utilization of multiple, joint-specific legacy PROMs. It also suggests a high construct validity for PROMIS PF-CAT, a vital element signaling that it does measure the intended endpoint(s), presuming validity of the legacy PROMs to which it is compared.[9,43] PROMIS PF-CAT was able to measure these endpoints while demonstrating the lowest overall survey burden, and minimizing floor and ceiling effects—efficiently adapting across variable populations.

The current study also showed that PROMIS PF-CAT had the strongest convergent correlations with PROM instruments assessing physical function and quality of life measures; while demonstrating the strongest divergent correlations with PROMs assessing additional health domains. PROMIS PF-CAT correlating well with legacy PROMs measuring joint function is consistent with the design of PF-CAT to focus on patient physical function. The strong divergent correlations with measures of general health, in turn, imply that PROMIS PF-CAT is able to differentiate a specific measured attribute (physical function). Essentially, the convergence and divergence data shows that PROMIS PF-CAT is capable of differentiating between measures of function, pain, and quality of life; and it is closely tailored to assess physical function rather than measures of general health.[28-31]

Our findings differed from expectations regarding a frequently hypothesized divergent correlation in previous literature between PROMIS PF-CAT and PROMs assessing the general health of the patient. These results may partially be explained by the overlap in questions and attributes assessed by PROMIS PF-CAT; there are likely inter-domain overlaps between PROMIS PF-CAT and legacy general health PROMs such as KOOS Symptoms and EQ-5D, as reflected by some results reported in our review. However, by pooling convergence and divergence data from multiple studies, we were able to confirm that PROMIS PF-CAT does indeed have divergent correlation with more general measures of health, which do not traditionally overlap with joint health assessment themes.

Our results suggest that this single PROM instrument with a low overall survey burden may serve as a multi-domain alternative to employing numerous, lengthier legacy PROMs which individually assess one or two domains. PROMIS PF-CAT may provide the most utility for assessing physical function in multiple axial or central sites (shoulder, knee, hip).[21,25,26] This is particularly important for patient populations aiming to return to preinjury functional levels and/or return to sports; applicable to a large proportion of patients seen in orthopedic sports medicine practices.[32,33] Caution must be taken when extending generalizability to the postoperative timepoint due to a lack of postoperative correlations available for assessment, specifically for shoulder and hip arthroscopic procedures. Further investigations postoperatively are therefore warranted given the encouraging performance of PROMIS in the preoperative setting.[21,25,26]

Interestingly, a study by Nwachuckwu et al.[34] that was published after the study inclusion date demonstrated excellent to good correlation of PROMIS PF-CAT with legacy hip PROMs in 197 preoperative hips, including mHHS, HOS, and iHOT-12. This data supports and reinforces preoperative hip findings in the current study. Nwachukwu et al. also recently demonstrated that postoperative knee patient PROMIS PF-CAT scores demonstrated stronger legacy PROM correlations postoperatively versus preoperatively, without exhibiting any floor or ceiling effects.[35] Scott et al. similarly demonstrated strong postoperative correlations of PROMIS PF-CAT up to 2 years postoperatively for patients undergoing ACL reconstruction.[10] These more recent study findings continue to highlight the efficiency and effectiveness of PROMIS for both pre- and postoperative knee arthroscopy patients.

It is the unique design of PROMIS PF-CAT which allows for these dramatically reduced survey burdens, floor effects, and ceiling effects. It is constructed around the critical components of item response theory (IRT) and computer adaptive testing (CAT).[36] IRT uses item banks of validated questions, many drawn from legacy PROMs, to address specific domains such as physical function.[1,37] CAT then tailors each follow-up question based on the user's previous answer.[36,37] This combination decreases the number of questions needed to obtain focused information as compared with legacy PROMs.[36,37] In the present study, survey burden for PROMIS PF-CAT was dramatically lower than the static survey burden of legacy PROMs. Despite recent studies combining machine learning with legacy PROMs to decrease survey burden, the PROMIS PF-CAT survey burden remains significantly lower. Additionally, it is notable that the "learning enhanced" legacy PROMs remain static instruments and require additional validation.[38]

Floor effects and ceiling effects, respectively, have been defined as the lowest and highest 15% of scores possible on a survey instrument.[39,40] Young, active sports medicine patients may be especially prone to ceiling effects due to higher functional status that legacy PROMs may not capture.[9,11] The authors are not aware of floor or ceiling effects with PROMIS PF-CAT use, aside from ceiling effects of PROMIS Upper Extremity Version 1.0, which has subsequently been updated to version 2.0 with minimal ceiling effects. A recent systematic review and meta-regression analysis by Gulledge et al.[41] noted 0 floor and ceiling effects of PROMIS PF-CAT across 43 recent studies (published through 2018) of shoulder and knee patients, not limited to arthroscopic procedures. Nwachukwu et al. demonstrated that preoperatively, the PROMIS PF-CAT in a study of 197 hips did not demonstrate any floor or ceiling effects, suggesting that the PROMIS PF instrument has broad applicability for hip arthroscopy patients.

No floor or ceiling effects were noted for legacy PROMs in the current study specifically for patients undergoing arthroscopic shoulder interventions, indicating that these effects may not have been detected or may not have been fully assessed by these studies. Notably, PROMIS PF-CAT was only administered at the preoperative timepoint for patients undergoing arthroscopic shoulder and hip interventions in the included studies of the present review. Potential postoperative ceiling effects would not have been captured as patients continued their postoperative rehabilitation protocols, strengthening, and return to function/sport, warranting further investigation at postoperative timepoints.

Limitations

Due to the heterogeneity in study protocols, not all endpoints were assessed in each individual analysis, introducing the possibility of analysis bias. Additionally, heterogeneity in the patient populations prevented pooled estimates. Most included studies assessed number of question for survey completion rather than completion time; we adjusted our outcome analyses and results reporting accordingly. In the present review, PROMIS PF-CAT data was available only at the preoperative timepoint for patients undergoing shoulder or hip arthroscopy, limiting the generalizability of these findings. As more literature on the subject becomes available, further quantitative analyses are warranted to assess pooled estimates of important PROM measures such as convergent vs. divergent validity, and floor or ceiling effects. The findings of the present review may require revisiting to expand the conclusions and broaden the applicability of the findings.

CONCLUSION

PROMIS PF-CAT is an accurate, efficient evaluation tool for sports medicine surgical patients. PROMIS PF-CAT strongly correlates with legacy physical function PROMs while having a lower test burden and less incidence of floor and ceiling effects. PROMIS PF-CAT may be an optimal alternative for traditional physical function PROMs in sports medicine patients undergoing arthroscopic procedures. Further studies are required to extend the generalizability of these findings to patients during postoperative timepoints after shoulder and hip interventions.

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UTILIZATION OF PHYSICAL THERAPY PRIOR TO CONSULTATION FOR HIP PRESERVATION SURGERY

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ABSTRACT

Background: Comprehensive conservative care prior to arthroscopic hip surgery is recommended, but not all patients pursue a course of physical therapy (PT) prior to consulting a hip surgeon. The purpose of this study is to investigate the incidence and type of PT administered to patients with hip pain prior to consulting a hip surgeon.

Methods: We conducted a single-center, questionnaire-driven study at a young adult hip preservation clinic that exclusively treats patients with hip pain. Thirty (88%) of thirty-four consecutive new patients answered the 15-item questionnaire. The questionnaire was designed to inquire about the reason for the visit, type of formal PT received (hip strengthening, leg strengthening etc.), and additional treatments received prior to the visit (electric stimulation, narcotics etc.). Descriptive statistics were utilized to quantify the reason for visit, PT prior to the visit, and type of exercises performed during physical therapy.

Results: Overall, 21 (70%) patients received physical therapy prior to consulting with a hip surgeon. Of those who received PT, 91% (n=19) did hip strengthening exercises, 76% (n=16) did focused hip stretching exercises, 62% (n=13) did leg strengthening exercises, 57% (n=12) did joint mobilization exercises, and 52% (n=11) did focused core strengthening exercises. Only 48% (n=10) reported improvement in symptoms with PT. Of those who received additional treatments, 77% (n=20) took anti-inflammatory medications regularly, 50% (n=13) underwent electric stimulation, 31% (n=8) had chiropractic manipulation, 19% (n=5) underwent soft tissue mobilization, 15% (n=4) received steroid injections, and 12% (n=3) were prescribed narcotics for hip pain.

Conclusion: The present study offers insight into the incidence and type of formal PT patients with hip pain receive before consulting a hip surgeon. Treatment methods during PT visits are variable, which makes determining outcomes of conservative care difficult to assess in this population.

Level of Evidence: IV

Keywords: hip preservation, femoroacetabular impingement, physical therapy, hip pain

INTRODUCTION

Arthroscopic procedures to address both intra- and extra-articular pathologies have significantly increased over the years.[1-3] An insurance database review of patients undergoing hip arthroscopy revealed there was a 365% increase in incidence of the procedure from 2004 to 2009; the greatest increase in incidence occurred young adults aged 20-39.[4] Overall, this trend has continued with good outcomes and low complication rates.[5-9]

Most often, hip arthroscopy and other elective hip surgeries are only considered after a course of physical therapy (PT). Uncorrected strength and flexibility deficits can contribute to instability or excessive motion around a joint, which can exacerbate structural pathologies and cause chronic hip pain.[10] Some patients may not need surgical treatment after a course of physical therapy. For example, in a randomized controlled trial of patients with symptomatic femoroacetabular impingement (FAI), hip arthroscopy was compared with PT and activity modification for treatment, and nearly 1 in 5 patients (19%) achieved the study's acceptable level of improvement after therapy alone.[11] Another study did not find a difference between arthroscopic surgery and PT for treating FAI at any time point up to two-year follow-up.[12] For FAI, a course of physical therapy prior to surgery is appropriate and considered a primary treatment; however, the definition of an "adequate trial of physical therapy" prior to surgery is still unknown, and failed non-operative treatment is often cited as a criterion for surgery.[13-15]

Physical therapy prior to elective procedures is an important part of comprehensive conservative care, but not all patients pursue a course of PT prior to consulting a hip surgeon. Since PT is considered a primary treatment method of chronic non-arthritic hip pain, there

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YOUNG ADULT HIP CLINIC
University of Iowa Hospitals and Clinics
Department of Orthopaedic Surgery and Rehabilitation

NAME: _____ **DATE:** _____

1. Who referred you to the Young Adult Hip Clinic? (Primary Care Physician, Orthopaedic Surgeon, Friend/Acquaintance, Self-Referral): _____
2. How long has the condition been present? _____
3. Occupation/School Grade: _____
4. Athletics/Sports (prior to injury)? _____

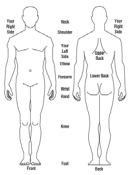
If you have hip pain, how would you rate it on the following scale?

0 1 2 3 4 5 6 7 8 9 10

No Pain Moderate Excruciating

5. Which activities cause pain?

☐ Sitting for prolonged period ☐ Jogging/Running ☐ Getting In/Out of Car
☐ Standing ☐ Climbing Stairs ☐ Pushing grocery cart
☐ Walking ☐ Sleeping on Side ☐ Other: _____

6.  Location of Pain/Condition:

Stabbing pain ////
Burning pain OOO
Aching pain XXX
Pins & needles VVV
Numbness ===

7. Have you been diagnosed with any of the following conditions?

☐ Impingement ☐ Perthes Disease
☐ Labral Tear ☐ Slipped Capital Femoral Epiphysis
☐ Hip Dysplasia ☐ Inflammatory Arthritis (Rheumatoid or Psoriasis)
☐ Hip Arthritis ☐ Other _____
☐ Avascular Necrosis

8. Have you had any physical therapy prior to this visit? ☐ Yes ☐ No
If yes, what type of exercises did you do?
☐ Hip Stretching ☐ Hip Strengthening ☐ Core Strengthening
☐ Joint Mobilization ☐ Leg Strengthening ☐ Other: _____

9. If you performed strengthening, did you feel challenged or fatigued following the exercises?

10. How long have you done Physical Therapy for?
_____ number of visits per week for _____ number of weeks

11. How often do you perform therapy home exercises?

☐ Never ☐ Less than 2 days a week ☐ Every other day ☐ Daily

12. What did Physical Therapy do for you?

☐ Pain relief ☐ Increased Strength ☐ Increased stability ☐ Nothing ☐ Other:_____

13. Have you had any of the following treatments:

☐ Electric Stimulation ☐ Anti-inflammatory medications
☐ Massage & ultrasound ☐ Narcotic medication
☐ Chiropractic Manipulation ☐ Other _____

14. What is your goal for the clinic visit today? (example - Recommendation for Physical therapy, Pain Medications, Injection treatments, Second Opinion Regarding Surgery, or Initial Surgical Evaluation)

_____

Physician Notes:

Figure 1. Young Adult Hip Clinic Patient Questionnaire.

is a need to determine the incidence of patients who receive therapy before seeing a hip surgeon. There is also a need to define the extent of an "adequate physical therapy intervention" prior to surgery. In this study, we sought to determine the incidence of patients who received PT for chronic hip pain prior to consulting a hip surgeon. We also investigated the different types of PT administered to patients with hip pain. Our hypothesis is that the incidence and type of physical therapy treatments received prior to consulting a hip surgeon are highly variable.

METHODS

To quantify the number of patients who received PT prior to consulting a hip surgeon, a 14-item questionnaire [Figure 1] was offered to 34 consecutive new patients at a young adult hip preservation clinic which exclusively treats patients with hip pain. The survey asked who referred them to the clinic, whether it was their primary care physician, an orthopedic surgeon, or a friend. Self-referrals were also recorded. Current and any former hip diagnoses were recorded. Patients were asked which activities caused pain, such as prolonged sitting, jogging or running, walking, climbing stairs, sleeping, or entering and exiting a vehicle.

To record the type of PT treatments received by patients, patients selected from a list of hip, leg, and core strengthening as well as stretching or mobility exercises. The options on the survey were broad to simplify patient understanding and recall. Specific exercises performed in previous physical therapy regimens were not recorded. If patients could not recall, they could also describe the type of therapy in their own words. The duration of therapy was documented as number of visits per number of weeks. Patients were asked if any improvements or goals were achieved during therapy. Finally, we asked patients if they received additional treatments, such as anti-inflammatory medications, steroid injections, electrical stimulation, chiropractic care, massage or ultrasound therapy, or narcotic medications. Responses from the questionnaire were totaled and descriptive statistics were used to report the results.

RESULTS

Thirty of 34 (88%) consecutive new patients consented to the study and answered the 15-item questionnaire. There were 20 females and 10 males with a mean age of 30.7 years old. Overall, 21 (70%) patients received physical therapy prior to consulting with a hip surgeon. Seventeen (57%) patients were referred to the hip clinic by an orthopedic surgeon, while 5 (17%) were referred by their primary care physician. Only 4 patients (13%) were self-referred or recommended by friends or family. The

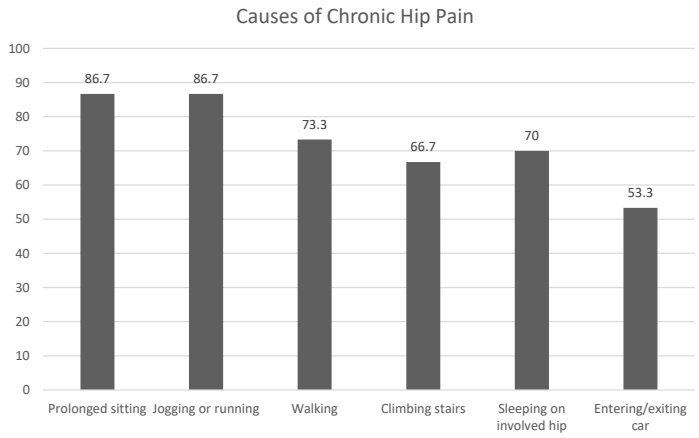


Figure 2.Chart displaying the most common causes of hip pain and reasons for seeking evaluation by a hip surgeon.

remaining patients did not indicate who referred them, or they were referred by other healthcare providers.

The most common causes of chronic hip pain and reasons for seeking evaluation by a hip surgeon were hip pain with prolonged sitting (87%), jogging or running (87%), and walking (73%) [Figure 2].

Of those who received PT, 91% performed hip strengthening exercises, 52% performed focused core strengthening and 57% had joint mobilization as part of their treatment plan [Figure 3].

Twenty-six patients (87%) received treatments in addition to therapy. These included anti-inflammatory medications (77%), electrical stimulation (50%), chiropractic care (31%), soft-tissue mobilization (19%), steroid injections (15%), and narcotic pain medications (12%). [Figure 4]

A total of 21 patients (70%) recorded their duration of therapy and whether they experienced improvement. Fourteen (67%) patients reported 1-3 PT visits per week. The most common duration of therapy was 4-8 weeks. Ten patients (48%) noted improvements in strength and stability, while 10 patients reported no improvement.

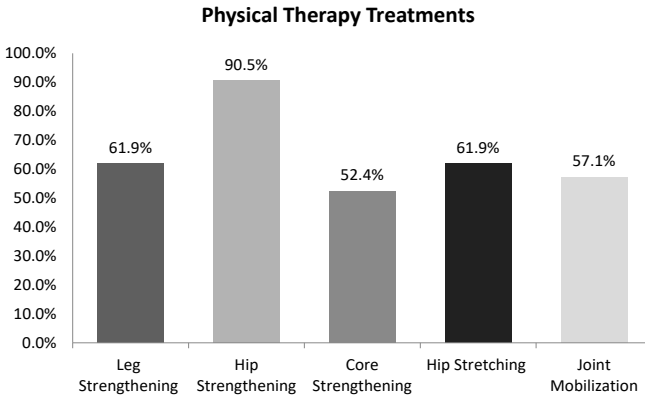


Figure 3. Chart displaying the different types of physical therapy treatments that patients received.

One patient indicated that PT made their pain worse. Of the 17 patients referred by an orthopedic surgeon, 8 (47%) patients reported no improvement, 2 patients (12%) reported improvement , and the remaining 7 patients (41%) did not comment. In comparison, 4 of the 5 patients (80%) referred by a primary care provider reported improvement after physical therapy. This difference in the proportion of patients who reported improvement after therapy was statistically significant (4 of 5 [80%] vs 2 of 17 [12%], Fisher exact test = 0.0093, $p<0.05$).

Finally, patients were asked to write their goals for therapy. Eleven patients (37%) wanted either a second or third opinion from the therapist, 10 (33%) patients indicated a pre-operative evaluation, and the remaining 9 (30%) indicated various reasons such as planning return to activity, pain control, or exercise recommendations.

DISCUSSION

This study relied on a questionnaire of new patients presenting to a young adult hip preservation clinic, which aimed to report the incidence and type of formal PT that patients received prior to their first visit. Our hypothesis was that the number of patients who received formal physical therapy and type of therapy treatments would be highly variable. The results of the study found that the majority of patients (70%) reported they received formal physical therapy prior to presenting to the young adult hip clinic. Most of these patients (97%) performed hip strengthening exercises, but only half reported performing joint mobilization (57%) and core strengthening (51%) exercises as part of their treatment regimen. An equal number of patients (10 patients) reported achieving some or no improvement after completing therapy. These results suggest that most patients try physical

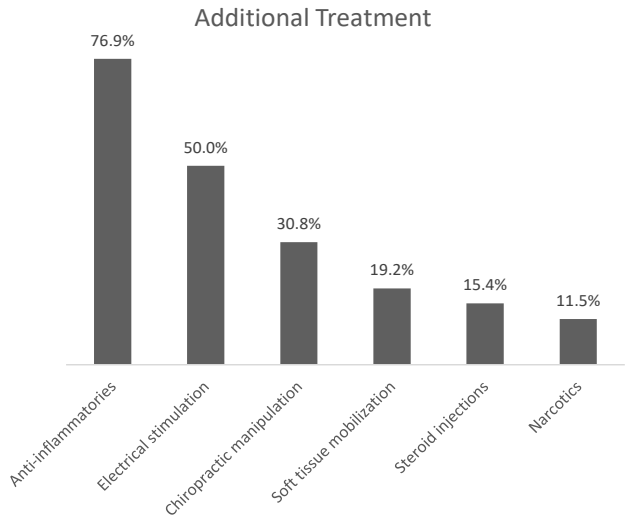


Figure 4. Treatments received in addition to physical therapy.

therapy prior to consulting a hip surgeon; however, the methods used in physical therapy regimens were variable and not all patients reported improvement after completing physical therapy.

Of the 21 patients who received PT, the most common types of therapy received were hip strengthening, hip flexibility, and leg strengthening. Most patients took anti-inflammatory medications and received electrical stimulation therapy as well. Roughly one third of patients were also treated with chiropractic manipulation. Due to the methods used in this study, the reliability of the duration of therapy regimens and whether improvement occurred was difficult to assess, as only 70% of respondents provided this information. It was also difficult to assess adherence to home therapy regimens. Regardless, only half of patients (47%) reported achieving subjective improvement in either strength and stability or pain relief with physical therapy. Interestingly, a greater proportion of patients who were referred by a PCP as opposed to an orthopedic surgeon reported achieving improvement after physical therapy (4 of 5 [80%] vs 2 of 17 [12%], $p<0.05$). However, the majority of patients referred by an orthopedic surgeon were seeking a 2nd or 3rd opinion for surgical evaluation. We speculate that this difference in subjective improvement may have been related to previous education about the need for surgical treatment to achieve improvement in their symptoms.

"Adequate non-operative management" and optimal dosage and prescription of exercise for patients with non-arthritic hip pain is still evolving. Recently, McGovern et al.[16] conducted a systematic review to better define adequate non-operative management of non-arthritic hip pain, such FAI, labral tears, or dysplasia. Based on a review of 49 studies describing non-operative management of hip pain, they recommended that rehabilitation efforts for chronic hip pain should include patient education, activity modification, limitation of aggravating factors, an individualized physical therapy protocol, and a home exercise program to decrease pain and improve function.16 Evidence suggests that PT of at least 12 weeks duration is recommended to correct chronic biomechanical dysfunction.[17-18] Individualized exercise-based programs including proximal hip and core strengthening, hip and lumbopelvic mobility, and neuromuscular exercises should be included. A well-designed therapy regimen for chronic, non-arthritic hip pain can help alleviate symptoms, postponing or negating the need for hip surgery.

This study has some limitations. The sample size certainly limits its results. The design of the study was also subject to recall bias, which made interpreting some of the data difficult. Not all patients reported the specific physician who referred them, which made it difficult to assess if they sought evaluation from a hip surgeon prior to their PT visits. Despite these limitations, this study offered some insight into the incidence of patients who received therapy prior to consulting a hip surgeon. Seventy percent of the patients reported they completed PT before seeing a hip surgeon, and nearly half of the patient were referred by an orthopedic surgeon. Thus, it is common for patients to seek the opinion of a surgeon prior to starting non-operative treatment.

CONCLUSION

These results suggest that most patients try physical therapy prior to consulting a hip surgeon; however, the methods used in physical therapy regimens are variable, and not all patients report improvement after completing physical therapy for hip pain. Thus, there is a need to further define "adequate non-operative management" and optimal dosage and prescription of exercise for patients with hip pain.

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ASSESSMENT OF FEMORAL VERSION SHOULD BE ASSESSED INDEPENDENTLY OF CONVENTIONAL MEASURES IN PATELLOFEMORAL INSTABILITY

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ABSTRACT

Background: The purpose of the present study is to determine the association between femoral version and traditional pathologic bony factors commonly used to measure and define patellofemoral alignment.

Methods: We performed a retrospective review of patients treated for patellofemoral instability (PFI) at a single institution. Patients included underwent magnetic resonance imaging (MRI) of the lower extremity using a rotational protocol prior to medial patellofemoral ligament reconstruction with or without tibial tubercle osteotomy. Those with a history of ipsilateral lower extremity surgery were excluded. Two independent reviewers measured femoral version, tibial tubercle-trochlear groove (TT-TG) distance, tibial tubercle-posterior cruciate ligament (TT-PCL) distance, and tibial torsion (TT). Pearson correlation coefficients were used to describe the relationships between all radiographic measures.

Results: A total of 51 knees (43 patients) were included. The average age and body mass index were 23.7 ± 9.33 years and 29.23 ± 8.04 kg/m2, respectively. The mean femoral version was 15.61 ± 11.57°. The degree of femoral version did not significantly correlate with TT-TG (r=0.103, p=0.474), TT-PCL (-0.086, p=0.550), or TT (r=0.111, p=0.438). Increased TT-TG distance was strongly associated with increased TT-PCL (r=0.470, p=0.001). In females, increased femoral version significantly correlated with increased TT (r=0.381, p=0.029).

Conclusion: Neither increased nor decreased amounts of femoral anteversion significantly correlated with TT-TG, TT-PCL, or TT. Therefore, assessment of femoral version should be measured independently of conventional measures when considering osteotomies to correct PFI.

Level of Evidence: IV

Keywords: patellofemoral instability, femoral version, tibial torsion, tt-tg

INTRODUCTION

Patellofemoral stability is maintained by chondral and bony alignment in addition to soft-tissue restraints that allow the patella to track within the trochlear groove during full knee range of motion.[1] The most important factors that maintain patellar stability are the shape of the trochlear groove, patellar height, and the fibers of the medial retinaculum, of which the medial patellofemoral ligament (MPFL) provides 50-70% restraint against lateral translation.[2] Patellar dislocations are relatively common knee injuries, with subsequent, recurrent instability events occurring in 29.6% of patient at 12-year follow-up.[3] Risk factors for recurrent dislocations included trochlear dysplasia, increased tibial tubercle-trochlear groove (TT-TG) distance, patella alta, age less than 18 years at the time of first dislocation, and female sex.[3]

It is important to identify anatomic risk factors in patients with patellofemoral instability (PFI), such as TT-TG distance, patella alta, or trochlear dysplasia.[4-7] Increased femoral anteversion (FA) has also been identified as a risk factor for recurrent PFI.[8,9] Normal femoral version is typically considered to be 5-20°, with increased FA >20°, and decreased FA <5°.[10,11] Outcomes following MPFL reconstruction (MPFLr) with tibial tubercle osteotomy (TTO) in patients with severely increased FA (>30°) have recently been demonstrated to be inferior to those with normal FA.[7] It is currently unknown if increased FA is correlated with other common anatomic risk factors for recurrent PFI. In order to optimize surgical treatment options, understanding how these anatomic risk factors in PFI relate to each other is important. The purpose of this study is to determine the association between femoral version and pathologic bony factors commonly used to measure and define patellofemoral alignment. Our hypothesis is that increased femoral anteversion will correlate with increased TT-TG distance.

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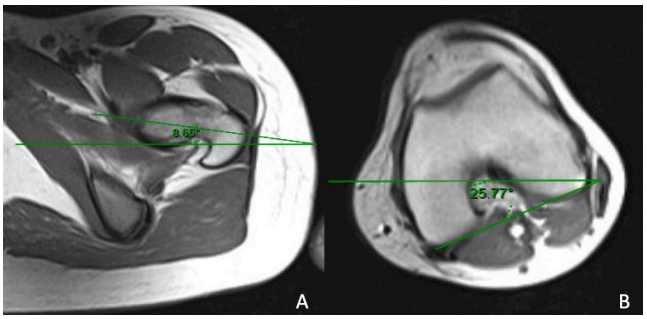

Figure 1A-B. Depiction of femoral version of the right lower extremity on preoperative magnetic resonance image (MRI), which demonstrate the angles between lines through the proximal femoral neck (A) and posterior femoral condyles (B) relative to the horizontal axis, totaling 34.42 degrees.

METHODS

This study was approved by the Institutional Review Board at the University of Iowa. We performed a retrospective review of patients treated for PFI. Patients underwent MPFLr with or without TTO at a single institution between October 2008 and 2014. Patients who received prior lower extremity re-alignment surgery were excluded. All patients underwent preoperative magnetic resonance imaging of the affected lower extremity using a rotational protocol which included images obtained through the hip, knee, and ankle, allowing calculation of femoral version and other bony factors in PFI. Two independent reviewers (RH and AM) measured the degree of femoral version and tibial torsion (TT), as well as tibial tubercle-trochlear groove (TT-TG) distance and tibial tubercle-posterior cruciate ligament (TT-PCL) distance. Inter-rater correlation coefficients (ICC) were calculated for each measurement. A random sample was also reviewed by a board-certified orthopedic surgeon (RW) to validate accuracy of measurements. All images were analyzed with a digital goniometer (PACS Imaging, Vue Motion, Carestream Health, Rochester, NY).

Femoral version

Femoral version was defined as the angle between a line parallel to the axis formed by the anterior and posterior cortices of the femoral neck and a line connecting the subchondral bone between the medial and lateral femoral condyles.[12] (Fig 1) A positive number was used to indicate femoral anteversion while a negative number indicated femoral retroversion. The ICC value for femoral version assessment was .975 (95% CI, .957-.986).

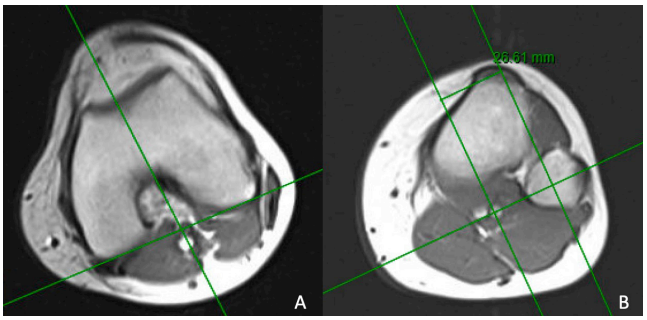

Figure 3. Magnetic resonance image depicting tibial tubercle-trochlear groove (TT-TG) distance, measured in millimeters (mm). (A) The measurement was made in parallel to the axis formed by the posterior femoral condyles. (B) In this example, the TT-TG distance measured 26.61 mm.

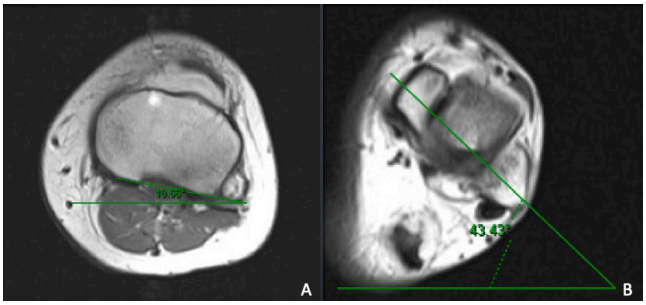

Figure 2. Depiction of tibial torsion of the right lower extremity on preoperative magnetic resonance image (MRI), which demonstrate the angles between lines connecting the posterior tibial condyles (A) and center of the medial and lateral malleolus (B) relative to the horizontal axis, totaling 54.09 degrees.

Tibial torsion

Tibial torsion was defined as the rotational angle between the proximal and distal tibia and was measured by finding the sum of the proximal and distal tibial angles.[13] (Fig 2) The proximal tibial angle is formed by the angle between the posterior condylar line and a horizontal parallel line. The distal tibial angle is formed by the axis through the midpoint of the medial and lateral malleolus at the distal tibia and a horizontal parallel line. The ICC value for tibial torsion was .915 (95% CI, .332-.973).

TT-TG

The tibial tuberosity-trochlear groove (TT-TG) distance was defined as the distance between the most anterior part of the tibial tuberosity and the deepest portion of the trochlear groove.[14] (Fig 3) The ICC value for femoral version assessment was .989 (95% CI, .953-.996).

TT-PCL

The tibial tuberosity-posterior cruciate ligament (TT-PCL) distance was defined as the distance between the center of the anterior part of the tibial tuberosity and the medial border of the PCL as it inserts on the tibia.[15] (Fig 4) The ICC value for femoral version assessment was .990 (95% CI, .966-.996).

Statistical Analysis

Descriptive statistics were performed. Numerical means were compared using an independent, two-tailed Students t-test, and categorical data were compared using a chi-square test. Pearson's correlation coefficient was used to determine any significant correlation be-

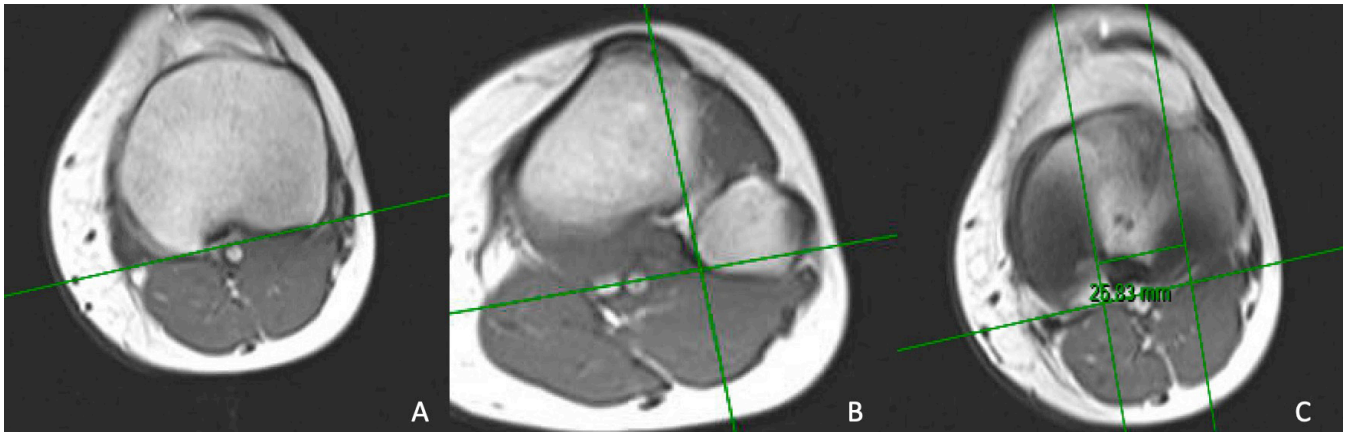

Figure 4. Sequential images demonstrating the measurement of tibial tubercle-posterior cruciate ligament (TT-PCL) distance (measured in millimeters, mm) on preoperative MRI. (A) Measurement of TT-PCL was made in parallel to the axis formed by the posterior tibial condyles. (B) Line drawn through the center of the anterior tibial tuberosity. (C) Parallel line drawn through the center of the insertion of the PCL. In this example, the TT-PCL distance is 25.83 mm.

tween radiographic measurements. A p-value <0.05 was considered statistically significant. Statistical analysis was completed using Excel v.16.43 (Microsoft Inc., Redmond, WA).

RESULTS

Patient Demographics

A total of 51 knees (43 patients) were included. The average age and body mass index (BMI) were 23.7 ± 9.33 years and 29.2 ± 8.04 kg/m2, respectively. (Table 1)

Table 1. Demographics

Patient Demographics	
Patients, n	51
Age (years)	23.7 ± 9.33
Females, n (%)	35 (68.6)
BMI (kg/m2)	29.23 ± 8.04
Operative side, n (% right)	23 (45.10)
Procedures*, n (%) *MPFLr with TTO* *TTO* *MPFLr*	 36 (70.59) 12 (23.53) 3 (5.88)
Baseline Measurements**	
Femoral Version (°)	15.61 ± 11.57 (12.39-18.83)
Tibial Torsion (°)	29.18 ± 8.03 (26.94-31.41)
TT-TG (mm)	20.85 ± 3.97 (19.74-21.95)
TT-PCL (mm)	24.52 ± 3.44 (23.57-25.48)

* Medial patellofemoral ligament reconstruction (MPFLr), tibial tubercle osteotomy (TTO).
**Data presented as mean ± standard deviation with 95% confidence intervals.

Relationship of Femoral Version to Measures of Patellofemoral Alignment

The results of our correlation analysis demonstrated that femoral version was not significantly correlated with TT-TG (r=0.103, p=0.474), TT-PCL (-0.086, p=0.550), or TT (r=0.111, p=0.438). (Table 2) When stratified by sex, increased femoral version significantly correlated with higher TT in females (r=0.381, p=0.029), but the remaining comparisons were insignificant (all p>0.05).

DISCUSSION

The results of this study determined femoral version did not correlate with TT-TG or TT-PCL in patients with PFI. Tibial tubercle-trochlear groove distance did not correlate with FV in the setting of both increased (>20°) and decreased FV (<5°). These results suggest that femoral version should be assessed independently of TT-TG distance in the setting of patellofemoral instability; these findings warrant further discussion.

In a 1994 anatomic radiographic study, Dejour et al. found patients with PFI had increased average FA (15.6

Table 2. Pearson Correlation Analysis of Continuous Variables

	TT-TG	TT-PCL	Femoral Version	Tibial Torsion
TT-TG	X	R = 0.47 P <0.001	R = 0.103 P = 0.474	R = -0.120 P = 0.40
TT-PCL	R = 0.47 P <0.001	X	R = -0.086 P = 0.550	R = -0.259 P = 0.067
Femoral Version	R = 0.103 P = 0.474	R = -0.086 P = 0.550	X	R = 0.111 P = 0.438
Tibial Torsion	R = -0.120 P = 0.400	R = -0.259 P = 0.067	R = 0.111 P = 0.438	X

R = correlation coefficient, p = p-value.
TT-TG = Tibial Tubercle – Trochlear Groove distance.
TT-PCL = Tibial Tubercle – Posterior Cruciate Ligament distance.

± 9.0°) compared to controls (10.8 ± 8.7°), but did not fully recognize excessive FA as a significant factor contributing to patellar instability.[8] Unrecognized excessive FA has more recently been described as a cause of both failure after initial surgery and recurrent PFI events.[9,16,17] Elevated FA lateralizes the overall force vector across the patellofemoral joint.[9,18] While analyzing a cohort of revision surgeries after primary MPFLr, Nelitz et al. found 2 of 19 failures were due to unrecognized increased FA.[17] In a more recent study, Zhang et al. evaluated outcomes after MPFLr with TTO and stratified patients by amount of FA (<20°, 20-30°, and >30°), and they found that patients with >30° of FA demonstrated inferior clinical outcomes, including greater patellar laxity, higher rate of residual J-sign, and lower patient-reported outcomes.[7] Therefore, the degree of femoral version is an important rotational factor to consider in patients with symptoms of PFI.

Radiographic workup of patients with patellofemoral instability directs surgical decision making, as the selection of the most appropriate procedure is dependent on the underlying anatomy.[1,4,19,20] It has been suggested that the complexity of measuring femoral version contributes to failure to recognize excessive FA before patellofemoral stabilization procedures.[17,21] Since unrecognized high FA may result in recurrent PFI and failure of primary surgery, measuring the amount of FA should be recognized as part of the treatment algorithm of PFI, especially for skeletally immature patients who may benefit more from a femoral de-rotational osteotomy.[16]

In our cohort, a standard lower extremity rotational MRI was used preoperatively to evaluate for excessive femoral version and tibial torsion. We did not find a significant correlation between high or low femoral version and TT-TG or TT-PCL distances. There is currently a limited amount of literature that examines the relationships between bony factors of patellofemoral stability. In the largest series to date, Imhoff et al.[20] evaluated images from 151 patients and found that those with high grade (HG) versus low grade (LG) trochlear dysplasia had significantly higher FA (HG: 16.8 ± 11.5° vs LG: 9.8 ± 11.0°) and TT-TG values (HG: 21.9 ± 5.4 mm vs LG: 19.0 ± 5.0 mm) (both $p<0.05$). A significant positive correlation was also found between femoral version and tibial torsion, TT-TG, and coronal mechanical axis (all $p<0.05$).[22] Another series of 30 patients from Diederichs et al.[13] did not find a correlation between femoral version with trochlear dysplasia or TT-TG distance. Liebensteiner et al.[23] explored the relationship between increased FA with trochlear dysplasia, and they found increased FA was correlated with a flatter, more dysplastic trochlea.

Limitations

We acknowledge the following limitations of our study. First, we were unable to corroborate recent correlations found between increased FA, trochlear dysplasia, and TT-TG distance. Our limited sample of patients with pre-operative rotational MRI certainly may have limited our ability to find any significant correlation between these values. In addition, we evaluated our group as a whole without stratifying between high or low-grade trochlea dysplasia. We also recognize this study was a retrospective study with associated weaknesses of study design.

CONCLUSION

Neither increased nor decreased amounts of femoral anteversion significantly correlated with TT-TG, TT-PCL, or TT. Therefore, assessment of femoral version should be measured independently of conventional measures of PFI. In cases of high femoral anteversion with normal TT-TG and PCL measurements, femoral de-rotation osteotomy can be considered.

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THE SAFETY OF ULTRASOUND GUIDED TENOTOMY AND DEBRIDEMENT FOR UPPER AND LOWER EXTREMITY TENDINOPATHIES: A RETROSPECTIVE STUDY

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ABSTRACT

Background: Ultrasound guided tenotomy (USGT) is a minimally invasive treatment option for patients with chronic tendinopathy. There are conflicting findings in the literature with some studies reporting severe complications and others reporting none. This variability is likely due to the small sample sizes of previous studies. We aimed to evaluate the risks associated with USGT and outcomes across multiple tendinopathy/fasciopathy sites in a large clinical sample.

Methods: Patients who had USGT were identified by retrospective review of charts. Complications, satisfaction, and outcomes (pain, quality of life) were assessed at baseline prior to the procedure (outcomes only), short-term follow up, and long term follow up.

Results: A total of 262 patients with 289 procedures were identified through chart review. There was a low complication rate of 0.7% including one superficial wound infection and one case of wound hypersensitivity. The majority of patients reported improvement in pain by short-term and long-term follow-up and improvement in function by long-term follow-up. The majority of responders reported being either 'very satisfied' or 'somewhat satisfied' with the procedure at short-term follow-up.

Conclusion: This study found that USGT is a safe procedure with a low complication rate in a heterogeneous sample. Study findings provide preliminary evidence on the utility of USGT to reduce pain and improve function with a high rate of patient satisfaction.

Level of Evidence: IV

Keywords: enthesopathy, tendinopathy, tenotomy, debridement

INTRODUCTION

Tendinopathy is a clinical syndrome characterized by pain and dysfunction related to mechanical loading of a tendon.[1] Multiple treatments have been reported to alleviate pain and improve function, but short and long-term outcome data are limited. Historically, tendinopathy treatment has focused on activity modification and rehabilitative exercise interventions with progression to surgery when conservative treatments have failed.[2] Minimally invasive ultrasound guided procedures are now becoming an option when surgical management is being considered. Ultrasound guided tenotomy and debridement (USGT) allows patients to return to normal activity sooner than traditional surgical procedures and may have less risk of complication. However, the current literature on USGT remains limited necessitating a higher level of evidence to understand the risks and effectiveness of this procedure.

There is currently a divide in the literature with 2 case series reporting serious complications due to USGT while other small studies report 0 complications. In particular for the Achilles tendon, a case series reported complications related to 6 procedures performed on the Achilles tendon including deep vein thrombosis (n = 1) and increased pain or no improvement in pain post-procedure (n = 5).[3] Another case series described 2 procedures that resulted in 6-week post-operative rupture of the Achilles tendon.[4] In contrast, another study on USGT for 25 patients with Achilles tendinopathy reported 0 complications and a success rate of 84% of patients with less pain and activity limitation.[5] Similarly, we previously reported that patients with Achilles tendinopathy had reduced pain and high patient satisfaction after USGT and the only complication out of 40 procedures was a superficial skin infection.[6] Moreover, the majority of data on USGT has focused on elbow tendinopathy with studies reporting no complications, decreased pain (>60%

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reduction) and/or high patient satisfaction (70% - 100%).[7-14] While the sample sizes for most of these studies were small with 30 participants or less,[7-14] our most recent study of 131 patients undergoing 144 procedures at the elbow had a 0% complication rate, decreased pain, and 70% patient satisfaction rate.[13] Larger studies examining the risk of USGT for a variety of upper and lower extremity tendinopathies are needed to inform clinical recommendations for patients and insurance policies regarding reimbursement.

The purpose of this retrospective study was to identify the types and frequency of risks associated with USGT in a large number of patients. A secondary aim of the study was to quantify potential benefits of this procedure by observing change in pain, quality of life, and patient satisfaction. To maximize the number of procedures that could be analyzed, we included data from the elbow (extensor and flexor tendons), knee (patellar tendon), midportion Achilles, insertional Achilles, and plantar fascia sites.

METHODS

Informed consent was waived and approved by the human subjects review board for the retrospective review of charts dated between September 2013 and June 2017 of all patients who had USGT for elbow tendons (common flexor and common extensor), patellar tendon, Achilles tendon (midportion and insertional), and plantar fascia. Review found a total of 262 patients (N = 87 elbow; N = 38 patellar; N = 23 midportion Achilles; N = 34 insertional Achilles; N = 80 plantar fascia). Some patients had more than one procedure performed during the study period making for a total of 289 procedures.

Data on complications were included from contact with the patient at any time point between date of procedure and long-term follow-up. Complication screening included infection, tendon rupture, hypersensitivity, or other as reported by the patient. Outcomes assessing pain and quality of life were assessed at baseline prior to the procedure, short-term follow up (6 weeks or 12 weeks), and long-term follow up (median 1.7 to 3.6 years depending on location). Short-term follow up data was gathered in clinic, while long-term follow up data was collected through online survey or phone survey which was also approved by the human subjects review board. Pilot testing for long-term follow-up was performed with the insertional AT group.[6] Based on our high survey completion rate and lack of information about quality of life, the SF-12 was added for the other sites to the long-term follow-up assessment.

Pain assessments varied by tendinopathy type depending on region-specific questionnaires. Pain was assessed for the patellar group on a 4-point scale modified from the Kujala scale: None, Slight and Occasional, Occasionally Severe, and Severe/Almost always present. Pain was assessed for the midportion Achilles, insertional Achilles, and plantar fascia groups on a 4-point scale from the American Orthopedic Foot and Ankle Score (AOFAS): None, Mild/Occasional, Moderate/Daily, and Severe/Constant. For the elbow tendon group (common flexor tendon and common extensor tendon), pain was assessed on a 4-point scale adopted from the Mayo Performance Scale: None, Mild/Occasional, Moderate/Daily, and Severe/Constant.

For all patients, quality of life was assessed using the Physical Component Summary (PCS) and Mental Component Summary (MCS) of the Short-Form 12-Item Survey (SF-12).[15] The SF-12 compares the study sample to the general population with t scores (mean 50; standard deviation 10).

Patient satisfaction at short term follow up was on a 5-point scale from Very satisfied (1) to Very dissatisfied (5). Patients were asked about any procedure-related complications at routine follow-up clinic visits (2-weeks, 6-weeks, 12-weeks). In addition, participants were asked to report any procedure-related complications at long-term follow-up via phone/email.

Procedure Description

General

All patients underwent a thorough clinical evaluation including a diagnostic ultrasound. Those with chronic clinical symptoms (> 3 months) and ultrasound findings amendable to treatment with USGT (regions of degenerative or calcified tissue) were indicated for the procedure. Mean duration of symptoms prior to procedure was calculated based on number of patients who responded: 15 months for patellar, 38.9 months for non-insertional Achilles, 26 months for insertional Achilles, 31 months for plantar fascia, and 22 months for elbow. Other treatment options were discussed with patients including physical therapy, injections, extracorporeal shockwave therapy, and traditional surgical approaches. However, most patients had failed multiple prior treatments including formal physical therapy (elbow: 49, patellar: 12, midportion Achilles: 17, insertional Achilles: 22, plantar fascia: 40) and cortisone injections (elbow: 47, patellar: 2, midportion Achilles: 2, insertional Achilles: 5, plantar fascia: 41).

All procedures were performed by the senior author (MMH) who is a sports medicine physician with fellowship training in diagnostic musculoskeletal and sports ultrasound and ultrasound guided procedures. The procedures were performed in an outpatient clinical procedure suite using sterile technique including sterile ultrasound transducer covers and sterile acoustic coupling gel. Live continuous ultrasound guidance was used

Table 1. Criterion Based Rehabilitation Progression Following Ultrasound Guided Tendon Debridement of the Upper Limb

Rehabilitation Phase	Estimated Timeline†	Special considerations	Restrictions	Goals	Functional test to progress to next phase
1	0-2 weeks	Early ROM encouraged starting day after procedure	1. Sling use only as needed for initial pain control 2. No lifting > 5 lbs 3. Limit repetitive use	1. Control swelling 2. Restore ROM 3. Muscle activation	1. Pain free elbow and shoulder ROM
2	2-6 weeks	Pain < 3/10 with all activities	1. No lifting > 5 lbs	1. Neuromuscular control 2. Proprioception 3. Gentle muscular strengthening	1. 5 lb lateral raise with elbow extended
3	6+ weeks	N/A	1. Monitor load progression‡	1. Progressive strengthening 2. Sport/region specific RTP preparation	1. Symmetric grip strength 2. 5 push- ups (standard or knee supported)
4	12+ weeks	Not applicable for all patients	N/A	1. Full unrestricted return to sport/work 2. Transition to maintenance program (S&C, personal trainer, self-directed HEP)	1. Specific to demands of sport/position 2. Guided by AT and S&C staff

NWB, Non-weight-bearing; ROM, Range of motion; PWB, Partial weight-bearing; WBAT, Weight-bearing as tolerated; RTP Return to play; AT, Athletic trainer; S&C, Strength and conditioning; HEP, Home exercise program
† To be used as a general guide based on biologic tissue healing. This timeline does not consider the location and extent of diseased tissue as well as other intrinsic patient factors that may impact time to clinical healing.
‡ Basic load progression principles: Pain level <3/10 with activity. Any pain associated with the activity should not persist into the following day. If pain persists then load needs to be decreased.

Table 2. Criterion Based Rehabilitation Progression Following Ultrasound Guided Tendon Debridement of the Lower Limb

Rehabilitation Phase	Estimated Timeline†	Special considerations	Restrictions	Goals	Functional test to progress to next phase
1	0-2 weeks	Early NWB pain free ROM encouraged starting day after procedure	1. PWB on crutches x 7 days (knee/hip) 2. WBAT in walking boot x 7 days (foot/ankle) 3. May d/c crutches/boot when able to walk pain free without a limp 4. Do not walk barefoot (foot/ankle)	1. Control swelling 2. Restore ROM 3. Muscle activation	1. Normal/symmetrical gait pattern (no assistive device) 2. Pain free passive ROM (ankle dorsiflexion, hip and knee flexion)
2	2-6 weeks	Pain < 3/10 with all activities	1. No running, jumping, cutting, pivoting	1. Neuromuscular control 2. Proprioception 3. Gentle muscular strengthening	1. Foot/Ankle: at least 1 unilateral SL heel raise through full ROM 2. Knee/Hip: Single leg squat through partial ROM
3	6+ weeks	N/A	1. Monitor load progression‡	1. Progressive strengthening 2. Sport/region specific RTP preparation	1. Lunge walk x 10 steps 2. 5 push- ups (standard or knee supported) 3. 10 single leg hops
4	12+ weeks	Not applicable for all patients	N/A	1. Full unrestricted return to sport/work 2. Transition to maintenance program (S&C, personal trainer, self-directed HEP)	1. Specific to demands of sport/position 2. Guided by AT and S&C staff

NWB, Non-weight-bearing; ROM, Range of motion; PWB, Partial weight-bearing; WBAT, Weight-bearing as tolerated; RTP Return to play; AT, Athletic trainer; S&C, Strength and conditioning; HEP, Home exercise program
† To be used as a general guide based on biologic tissue healing. This timeline does not consider the location and extent of diseased tissue as well as other intrinsic patient factors that may impact time to clinical healing.
‡ Basic load progression principles: Pain level <3/10 with activity. Any pain associated with the activity should not persist into the following day. If pain persists then load needs to be decreased.

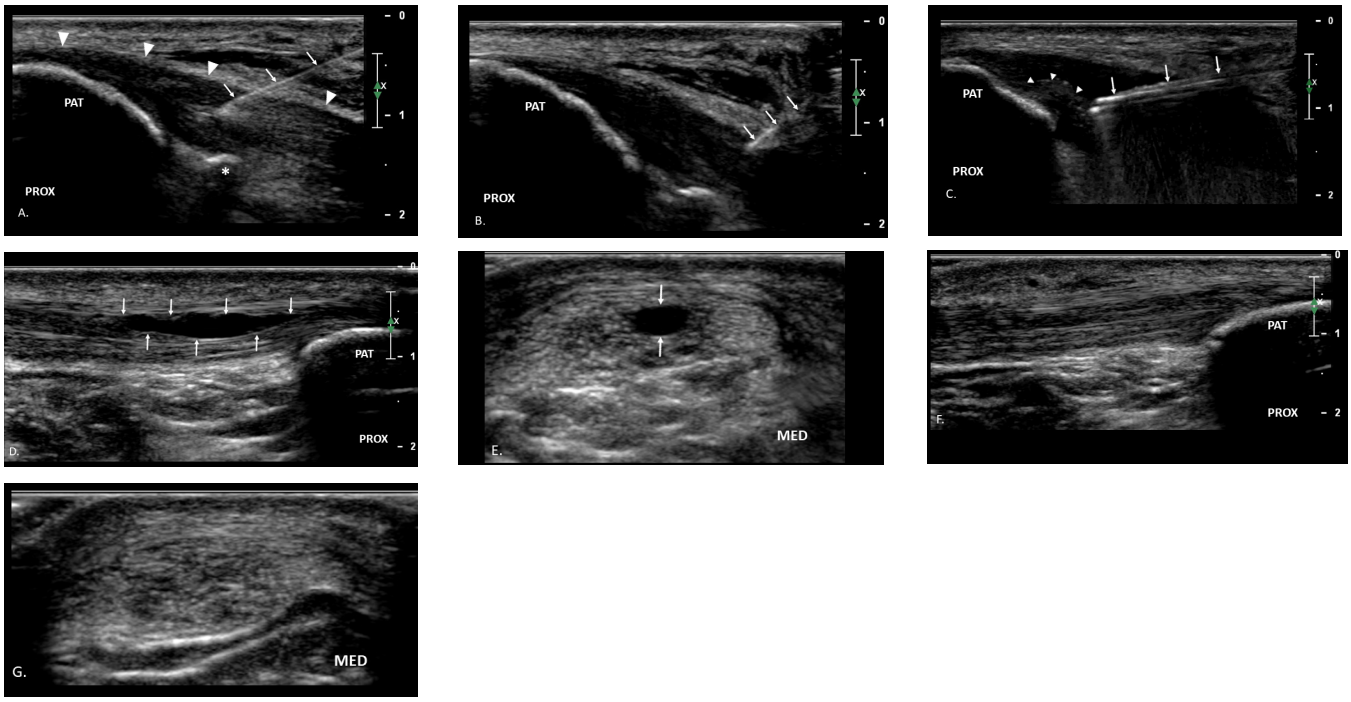

Figure 1. Distal to proximal approach to patellar tendon.
A. A 25 g 50 mm needle (arrows) is used to infiltrated local anesthetic into the subcutaneous tissues and into the patellar tendon (arrowheads). A small hyperechoic calcification is appreciated at the deep aspect of the tendon (asterisks). B. #11 blade (arrows) creates a tract into the tendon. C. The TX device (arrows) is guided into the region of pathologic tissue and debridement is performed. Hyperechoic micro-bubbles can be seen at the site of debridement (arrowheads) confirming the tissue has been removed. A companion case demonstrates long axis (D) and short axis (E) pre-procedure imaging with a partial thickness intrasubstance tear (arrows). Follow up imaging at 12 weeks post-procedure shows healing of tendon fibers in both long axis (F) and short axis (G). Patient was pain free and had returned to competitive running without limitation. PAT = patella, PROX = proximal, MED = medial.

throughout the procedures with either an iU22 or EPIQ ultrasound cart (Philips Healthcare, Bothell, WA) and a high frequency linear transducer (12-5 or 18-5 MHz). Anesthesia was achieved with local infiltration of either 1% lidocaine without epinephrine or a 50:50 mixture of 1% lidocaine without epinephrine and 0.5% ropivacaine. Between 5 and 10 mL of local anesthetic was used based on location and patient comfort. No one required sedation. A #11 blade was used to make an approximately 5 mm skin incision and create a tract to the tendon/fascia. This was always performed in-line with the tendon/fascia to avoid iatrogenic horizontal laceration of the fibers. The TX 1 or TX 2 device (Tenex Health, Lake Forest, CA) was then used to perform all tenotomy and debridement procedures. The TX 1 and TX 2 devices operate in an identical fashion utilizing ultrasound energy to cut and debride tissue while allowing for local saline irrigation and aspiration of the debrided tissue. Differences in the two devices include only length and external fabrication (plastic vs metal sheath). All procedures aimed to debride regions of degenerative or calcific tissue with special considerations at each location as detailed below.

The post-procedure protocol was individualized based on location and extent of pathology and desired functional demands. However, our general approach was 2 weeks of rest and then progressive rehabilitation. Pain free active range of motion was started on post-procedure day 1 for all procedure sites. Following treatment of the plantar fascia or Achilles tendon, patients could weight bear as tolerated, but a protective walking boot was used for the first 1-2 weeks. Partial weight bearing on crutches or full weight bearing in a knee immobilizer was prescribed for 1-2 weeks following patellar tendon debridement. All elbow patients had a 5-pound lifting restriction for the first 6 weeks. The soonest anyone could return to full activity was 6 weeks; however, most patients returning to sports activity or manual labor required 12 weeks prior to full clearance. Near the end of our study period a criterion-based rehabilitation protocol was adopted based on our experience (Tables 1,2).

Elbow

A detailed description of our technique at the elbow has been previously reported.[13] When treating the common extensor tendon, the patient was placed in a supine position with the head of the table raised approximately 30 degrees. The elbow was in slight flexion with the forearm pronated and resting on the table. A distal to

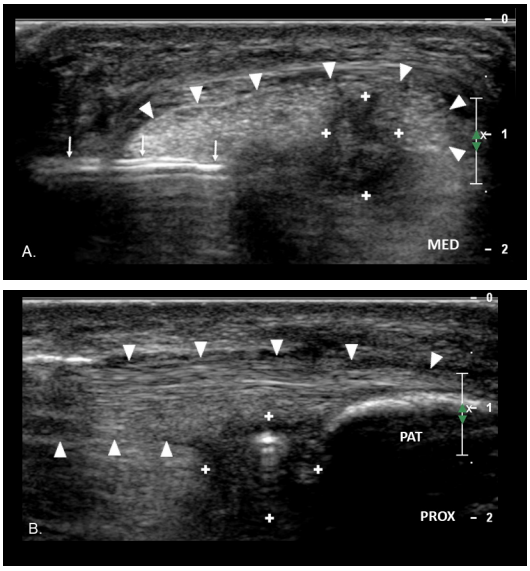

Figure 2. Lateral to medial approach to patellar tendon.
A. Short axis image of the patellar tendon (arrowheads) showing the TX device (arrows) advanced through the lateral tract created by the #11 blade and positioned just deep/posterior to the lateral patellar tendon fibers. The device is then used to debride the adherent fatty tissue as it is advanced into the region of degenerative tendon (+) which is then debrided. B. Long axis image of the patellar tendon (arrowheads) shows an out of plane view of the TX device microtip positioned within the hypoechoic degenerative tissue (+). Using both in plane and out of plane imaging relative to the device throughout the procedure is helpful to determine adequate treatment of the entire pathologic region of tendon while also avoiding the healthy superficial fibers. PAT = patella, PROX = proximal, MED = medial.

proximal approach was used. Care was taken to avoid the radial collateral ligament during both the incision and the debridement with the TX device as to not inadvertently destabilize the elbow.

The common flexor/pronator tendon was approached with the patient in a supine or side lying position with the elbow in extension and forearm supinated. The location of the ulnar nerve was confirmed and carefully monitored throughout the procedure with ultrasound. Keeping the elbow in relative extension provided additional protection to the nerve in cases of subtle instability. A similar distal to proximal approach was used.

Patellar Tendon

Patients were in a supine position with the knee flexed to approximately 30 degrees and supported on a pillow. Two separate techniques were used depending on the location and extent of pathology. A more standard distal to proximal approach allowed for debridement of the patellar attachment but required division of the superficial tendon fibers for introduction of the TX device (Figure 1). When the region of pathology predominately involved the deep fibers with posteriorly projecting nodularity into Hoffa's fat pad, a lateral to medial approach was taken (Figure 2). This allowed for more complete debridement of the involved tendon and limited debridement of the fat pad which typically becomes adherent to the region of tendinosis in these cases. The superficial fibers were completely spared with this second technique. Care was taken to avoid injury to the healthy portion of the tendon during the incision given the change to a short axis image of the tendon. The scalpel blade was maintained in an orientation longitudinal to the tendon fibers to further avoid potential for horizontal laceration.

Achilles Tendon

Patients were positioned prone with feet hanging free off the edge of the table to allow access to either the midportion or insertion of the Achilles tendon. We have previously published our technique for debridement of the Achilles insertion.[6] Midportion pathology was addressed in a similar manner with a distal to proximal approach with both scalpel and device introduced in the longitudinal axis of the tendon. The location of the sural nerve was confirmed prior to incision in all cases.

Plantar Fascia

Patient positioning was identical to the Achilles. Pre-procedure ultrasound imaging identified the medial calcaneal sensory nerve and lateral plantar nerve prior to incision. A medial approach was taken to the central cord origin. If there was concomitant lateral cord origin involvement, the TX device was advanced to this location from the medial side. In only rare cases of isolated lateral cord involvement was a lateral approach taken. If a lateral approach was considered, the location of the sural nerve was confirmed during the pre-procedural ultrasound imaging.

Analysis

Descriptive statistics were used to report patient satisfaction and complications (type, frequency) by site. In order to minimize sample bias and maximize the inclusion of all patients identified in the retrospective review, data on patient satisfaction and complication rate were included from any time point. Descriptive statistics were also used to report sample characteristics by group (tendinopathy/fasciopathy site). Non-parametric and parametric tests (Wilcoxon Signed Rank test for pain as a categorical variable; Paired t-test for quality of life as a continuous variable) were used to compare outcomes at baseline (prior to USGT) to follow-up (short-term or long-term). Only a single side per patient was used for analysis in the 27 patients who had USGT on both sides to fulfill the assumption of independence of observations. Due to high rates of missing data, we chose not to impute data for missing values in the statistical analysis. Patient reported outcomes in tables reflect all available responses at each time point and analyses of change

Table 3. Pain Measured as: 0, No Pain; 1, Mild/Occasional; 2, Moderate/Daily; 3, Severe/Constant Data Presented as Median [Interquartile Range]. Analyses Used Pair-Wise Deletion for Missing Data

	Elbow	Patellar	Achilles - Midportion	Achilles – Insertional	Plantar Fascia
Baseline	2.0 [2.0 to 2.0]	2.0 [1.0 to 2.0]	2.0 [2.0 to 2.5]	2.0 [2.0 to 2.0]	2.0 [2.0 to 3.0]
Short-term	1.0 [1.0 to 1.5]*	1.0 [1.0 to 1.0]	1.0 [0.0 to 2.0]	1.0 [1.0 to 2.0]*	1.0 [1.0 to 2.0]*
Number of pairs for analysis, p-value	n=34, p < 0.01	NA	n=5, NA	n=23, p < 0.01	n=39, p < 0.01
Long-term	0.0 [0.0 to 1.0]*	1.0 [0.0 to 1.0]*	1.0 [0.0 to 1.0]*	1.0 [1.0 to 1.0]*	1.0 [0.0 to 1.0]*
Number of pairs for analysis, p-value	n=37, p < 0.01	n=16, p = 0.03	n=13, p < 0.01	n=17, p <0.01	n=42, p < 0.01

NA, Not applicable due to paired samples n<10.
Sample size for descriptive statistics varies by group and time point: Elbow survey responders (Baseline, short term, long term): n = 57, 53, 59. Patellar survey responders (Baseline, short term, long term): n = 32, 2, 20. Midportion Achilles survey responders (Baseline, short term, long term): n = 17, 7, 17. Insertional Achilles total sample: n = (Baseline, short term, long term): n = 27, 26, 20. Plantar fascia (Baseline, short term, long term): n = 63, 52, 53.
Significant p-values are bolded.
*Significant differences relative to baseline, Wilcoxon signed rank tests, p < 0.05

reflect all available pairs for comparison between time points. Statistical significance was defined by $p \leq 0.05$.

RESULTS

The sample was mostly adults aged 40 to 60 years, except for the relatively younger patellar tendinopathy group. The mean age ± standard deviation (SD) was 48.8 ± 9.0 years for the medial/lateral elbow group (N=87), 27.1 ± 12.9 years for the patellar group (N=38), 50.6 ± 15.4 for the midportion Achilles group (N=23), 52.2 ± 11.6 years for the insertional Achilles group (N = 34), and 47.2 ± 12.2 for the plantar fascia group (N=80). The average body mass index (BMI) was in the obese category, except for the patellar tendon group which was in the overweight category. The mean BMI ± SD was 31.3 ± 10.0 kg/m^2 for the medial/lateral elbow group, 26.2 ± 7.6 kg/m^2 for the patellar group, 30.0 ± 7.8 kg/m^2 for the midportion Achilles group, 32.9 ± 7.5 kg/m^2 for the insertional Achilles group, and 30.4 ± 6.4 kg/m^2 for the plantar fascia group. The percentage of women varied by group (Elbow, 46%; Patellar, 24%; midportion AT, 65%; insertional AT 62%; plantar fascia, 76%).

There was a low complication rate of 0.7% (2/289 cases), including 1 superficial wound infection that resolved with oral antibiotics and 1 case of wound hypersensitivity. No serious complications were reported. Prior to USGT (baseline) the majority of patients reported, by region specific questionnaire, moderate/daily pain that decreased by short-term (2 to 12 weeks) and long-term (median 1.7 to 3.6 years depending on location) follow-up to mild/occasional pain (Table 3). In parallel, prior to USGT most patients reported abnormally low physical function (≥1 SD below the general population mean t-score of 50 on SF-12, PCS) yet by long-term follow-up patients were within normal range of physical function (Table 4). In contrast, at baseline our sample reported above average mental health scores, and therefore any improvement in MCS was minimal for all groups (Table 5). Additionally, patient satisfaction at short-term follow up (2, 6 or 12 weeks) was reported for each group with

Table 4. Function Measured with the SF-12, Physical Component Summary (PCS) and Presented as Mean ± SD The General Population Mean t-score= 50 and SD=10 Analyses Used Pair-Wise Deletion for Missing Data

	Elbow	Patellar	Achilles - Midportion	Achilles – Insertional	Plantar Fascia
Baseline	36.7± 6.5	41.7 ± 9.4	36.8± 9.8	40.8±9.4	36.0± 9.4
Short-term	41.7± 9.1*	33.6 ± 1.3	42.7 ± 10.2	44.0±7.1*	40.1± 9.4*
p-value	p < 0.01	NA	NA	p = 0.03	p < 0.01
Long-term	48.0± 5.5*	49.2 ± 3.9	49.2± 3.7*	Not Reported	48.0± 6.1*
p-value	p < 0.01	p = 0.20	p < 0.01	N/A	p < 0.01

NA, Not applicable due to paired samples n<10.
Sample size for descriptive statistics varies by group and time point: Elbow (Baseline, short term, long term): n = 71, 63, 58. Patellar (Baseline, short term, long term): n = 28, 2, 20. Midportion Achilles (Baseline, short term, long term): n = 17, 6, 17. Insertional Achilles (Baseline, short term, long term): n = 24, 23, N/A. Plantar fascia (Baseline, short term, long term): n = 59, 51, 54. Significant p-values are bolded.
*Significant differences relative to baseline, paired t-test, p < 0.05

Table 5. Mental Component Score (MCS) of the SF-12 Presented as Mean ± SD
The General Population Mean T-Score= 50 and SD=10
Analyses Used Pair-Wise Deletion for Missing Data

	Elbow	Patellar	Achilles - Midportion	Achilles – Insertional	Plantar Fascia
Baseline	56.4± 9.4	59.4 ± 4.8	52.6± 11.5	59.4±5.2	57.5± 8.3
Short-term	57.2± 8.4	63.5 ± 0.5	62.2± 4.4	59.8±3.7	57.9± 8.7
p-value	p = 0.51	NA	NA	p > 0.05	p = 0.62
Long-term	54.1± 8.7	57.7 ± 2.5	55.5± 5.0	Not Collected	56.8± 5.2
p-value	p = 0.07	p = 0.15	p = 0.56	N/A	p = 0.24

NA, Not applicable due to paired samples n<10.
Sample size for descriptive statistics varies by group and time point: Elbow (Baseline, short term, long term): n = 71, 63, 58. Patellar (Baseline, short term, long term): n = 28, 2, 20. Midportion Achilles (Baseline, short term, long term): n = 17, 6, 17. Insertional Achilles (Baseline, short term, long term): n = 24, 23, N/A. Plantar fascia (Baseline, short term, long term): n = 59, 51, 54. Significant p-values are bolded.
*Significant differences relative to baseline, paired t-test, p <0.05

a majority reporting either 'very satisfied' or 'somewhat satisfied' (Table 6).

DISCUSSION

This is currently the largest known study to date examining the safety and effectiveness of USGT with 262 patients and 289 procedures. The main study finding indicates USGT is a safe procedure with secondary findings indicating reduced pain, improved function, and high patient satisfaction over time.

There was a complication rate of 0.7%, which supports this procedure being considered low risk. This contrasts with reports of multiple complications in two recent case series of patients with Achilles tendinopathy treated with USGT using the TX device.[3,4] Sanchez et al. reported on six patients with various complications including worsening pain, partial tearing, and DVT and Gurin et al. reported two midportion ruptures following USGT.[3-4] However, based on their description of the cases, inappropriate technique or post-surgical rehabilitation was likely the primary contributor to the poor outcomes. They reported transverse tears which they speculated were the result of the ultrasound guided tenotomy. We recommend a longitudinal approach as described above with both the incision and debridement to avoid such transverse fiber disruption. Also, multiple cases report prolonged immobilization in a walking boot post-procedure which is not in line with current best practice. Tendons require loading to facilitate healing and early introduction of appropriate loading is one of the primary advantages to the minimally invasive technique. However, while early load introduction is important, progression must be in line with expected tendon healing. Details regarding appropriate load progression in the cases of tendon rupture were not available and may have contributed to the poor outcomes. While it is important to identify complications and risks of all procedures, it is also important to carefully assess contributors to those risks.

By 6 to 12 week follow up, reported pain decreased from moderate/daily pain to mild/occasional pain. The greatest pain reduction occurred in the elbow group, where pain further improved by long-term follow-up with a median pain rating of "None." This reduction in pain was consistent with multiple other studies that reported decreased post- procedure pain measured by the visual analog scale of pain (VAS).[7,9,12,14] Seng et al. reported a

Table 6. Patient Satisfaction at Short-Term Follow-up: 2 weeks (Patellar, Midportion Achilles); 6 or 12 Weeks (Elbow, Insertional Achilles, Plantar Fascia)
Values Presented as Number (% sample / % of respondents at short-term follow-up)

	Elbow	Patellar	Achilles - Midportion	Achilles – Insertional	Plantar Fascia
Very Satisfied	23 (24%/38%)	14 (34%/54%)	11 (42%/92%)	14 (41%/45%)	25(31%/44%)
Somewhat Satisfied	20 (21%/33%)	7 (17%/27%)	0 (0%/0%)	10 (29%/32%)	11(14%/19%)
Neutral	7 (7%/12%)	5 (12%/19%)	1 (4%/8%)	5 (15%/16%)	9(11%/16%)
Somewhat Dissatisfied	6 (6%/10%)	0 (0%/0%)	0 (0%/0%)	2 (6%/7%)	7(9%/12%)
Very Dissatisfied	4 (4%/7%)	0 (0%/0%)	0 (0%/0%)	0 (0%/0%)	5(6%/9%)
Missing	27 (37%/NA)	15 (37%/NA)	14 (54%/NA)	3 (9%/NA)	30(38%/NA)

Elbow survey responders: n = 60; Patellar survey responders: n = 26; Midportion Achilles survey responders: n = 12; Insertional Achilles survey responders: n = 31; Plantar fascia survey responders: n = 57.

decrease in pain from 0.5 ± 0.70 at 12 months to 0 ± 0.9 out of 10 at 36 months.[12] Barnes et al. and Boden et al. also noted similar improvements in VAS pain scores.[7,9]

At baseline, all groups had impaired physical function (SF-12 PCS 36.0 to 41.7). By short term follow up, most groups had small yet, statistically significant improvement in function (SF-12 PCS 40.1 to 44.0). Due to small sample size at short-term follow-up, the change from baseline to short-term was not statistically compared for the patellar tendon (n=2 at 6 weeks) and midportion Achilles groups (n=4 at 6 weeks, n=2 at 12 weeks). By long-term follow up, all groups reported physical function at a similar level as the general population mean (SF-12 PCS 48.0 to 49.2). A limitation of this study is lack of region-specific outcome measures, yet this global improvement in function is consistent with Boden et al. who reported improvements in function measured by the Quick Dash. Scores improved from 35.9 ± 5 to 12.5 ± 3.4 ($p<0.01$).[9] Significant improvement in the MCS component of the SF-12 survey was not found in any group. It should also be noted that the MCS was not impaired at baseline for any group and no further increase in this component was seen. Together, this indicates that USGT may affect quality of life related to physical function rather than quality of life related to the mental component.

Patient satisfaction at 6 or 12 weeks was collected in the elbow, insertional Achilles, and plantar fascia groups. Due to low response rate at 6- and 12-week follow-up for the patellar and midportion Achilles groups, patient satisfaction at 2 weeks was also included. The majority of respondents in the elbow, insertional Achilles, and plantar fascia groups (71%, 70%, and 63% respectively) reported either 'very satisfied' (or 'somewhat satisfied' at 6 or 12 weeks. Similarly, the majority of respondents in the patellar tendon and midportion Achilles groups (81% and 92% respectively) reported either 'very satisfied' or 'somewhat satisfied' at 2 weeks (Table 4). Despite patient reported improvements in pain or physical function a year post procedure, patients were reporting satisfaction as soon as 2 weeks post procedure. This was consistent with multiple other studies reporting high rates of patient satisfaction (≥ 70%).[5,7,8,10-14]

The generalization of these findings to all patients considering USGT is limited due the potential bias of missing data at each time point. Long term response rate was 63%; however, response rate at either short or long term was 95% allowing for a higher capture rate of any complication. Still, due to limits in response rate, this data should be interpreted with caution until larger prospective studies with region-specific outcome measures can better determine the safety and effectiveness of USGT. The analysis was adjusted accordingly with statistical comparisons over time limited to only those patients with baseline data. Therefore, patients with only short-term and/or long-term follow-up but not baseline data are included in descriptive data in tables, but not in statistical comparison over time. Patients without baseline data did not appear to differ from the overall sample, and descriptive data on all available patients was included to minimize selective sampling.

Finally, USGT has many potential benefits compared to traditional surgical management of chronic tendinopathy. The procedure is safely performed in an outpatient setting under local anesthesia. Not only does this limit anesthesia associated risks, but also significantly reduces cost. At our institution, an open surgical tenotomy costs approximately 3 times that of an USGT with real cost savings of up to $18,000 as we have previously reported.[6] The minimally invasive nature provides several benefits. The reduction in post-procedure pain obviates the need for opioid pain medication and therefore reduces risk of potential opioid dependence. As healthy tissues are relatively spared, there is an accelerated rehabilitation protocol with faster return to work and sport related activities. Overall, this study demonstrates that with appropriate technique and post-procedural management USGT is a safe procedure.

CONCLUSION

To date, this is the largest study exploring the safety of USGT with a total of 262 patients and 289 procedures. This procedure was found to be safe as there was a low complication rate of 0.7%. Patients also experienced reduced pain and improved physical function at short term and long term follow up. This study supports future research of USGT including prospective studies comparing USGT to the accepted standard of care.

ACKNOWLEDGMENTS

Study data was collected and managed using REDCap electronic data capture tools hosted at University of Iowa (supported by NIH 54TR001013). Two subsets of this data have been previously published by the same authors (Insertional Achilles, N = 34; elbow, N = 131) and is reproduced with permission as discussed in the text. A preprint of this manuscript can be found at https://www.researchsquare.com/article/rs-32408/v1.

AVAILABILITY OF DATA AND MATERIALS

Individual participant data that underlie the results reported in this article after deidentification will be available to immediately following publication and ending 5 years following publication. This data will be shared with researchers who provide a methodologically sound proposal and will use the data to achieve aims specified in the proposal. Proposals should be directed to Mederichall@uiowa.edu. To gain access, data requestors will need to sign a data access agreement.

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CONSERVATIVE TREATMENT OF A NONDISPLACED INTERTROCHANTERIC FEMUR FRACTURE: A CASE REPORT AND REVIEW OF THE LITERATURE

Jason E. Mascoe, BS[1]; Paul K. Herickhoff, MD[2]

ABSTRACT

A 21-year-old otherwise healthy male sustained a nondisplaced, intertrochanteric fracture of the left femur after being "rear-ended" by a motor vehicle while riding his bicycle. His fracture was managed with protected weight-bearing and progressive mobilization. No traction was utilized. The patient had an excellent clinical outcome at two-year follow-up, reporting modified Harris Hip Score 85, Hip Outcome Score-Activities of Daily Living 88, Hip Outcome Score-Sport Specific 89, and International Hip Outcome Tool-33 of 77.

Conclusion: Nonsurgical treatment, consisting of restricted weight-bearing, for non-displaced intertrochanteric femur fracture in young, healthy patients can provide a successful result.

Level of Evidence: V

Keywords: conservative management, hip, trauma, orthopaedic surgery

INTRODUCTION

Less than 3% of all intertrochanteric femur fractures occur in patients under age 50.[1] The infrequent nature of this injury, as well as the "universal agreement" among orthopaedic surgeons in the 1960's that all intertrochanteric femur fractures are best treated by internal fixation[2] has resulted in a dearth of literature on conservative treatment of intertrochanteric femur fractures, particularly in younger patients. Surgical treatment of intertrochanteric femur fractures in young patients has significant risks, with reported complication rates ranging from 9-57%.[1,3] Although displaced intertrochanteric femur fractures are unlikely to achieve a successful result with conservative treatment, a nondisplaced intertrochanteric femur fracture has greater stability, with an increased likelihood of achieving union in acceptable alignment.[4] Therefore, the rationale for conservative treatment of stable intertrochanteric femur fractures in young patients is avoidance of risks associated with surgical treatment, the fracture is more likely to heal in acceptable position, higher likelihood of an successful clinical outcome,[5–7] and the complications of non-surgical treatment seen in the elderly[8] are less likely to be experienced by younger patients. The purpose of this study was to report on successful conservative treatment of a nondisplaced, intertrochanteric fracture in a young patient.

Statement of Informed Consent

The patient consented to publication of his case, and Institutional Review Board (IRB) approval was obtained for this study.

CASE REPORT

A 21-year old male was thrown from his bicycle when he was "rear-ended" by a motor vehicle and landed on the left side of his body. He had immediate onset of pain in his left hip with the inability to ambulate. He was transported to the emergency room for evaluation, where x-rays (Figures 1.1 and 1.2) and a CT scan were performed (Figure 1.3). These demonstrated a left nondisplaced, intertrochanteric femur fracture. The remainder of his evaluation was unremarkable, except for a small laceration at his left elbow.

Examination of the left lower extremity demonstrated superficial abrasions on his left buttock and lateral aspect of his left knee. He was tender to palpation over the greater trochanter with mild swelling. He was able to actively perform logroll with his left leg and tolerated gentle passive flexion and abduction of the hip without significant discomfort. He was neurovascularly intact.

The patient was counseled about treatment options for this injury, including fixation with a sliding hip screw and conservative treatment, and a joint decision was made to proceed with nonsurgical treatment. He was admitted to the hospital with non-weightbearing restrictions in place for the left lower extremity. Enoxaparin and TED stockings/foot pumps were initially prescribed for DVT prophylaxis. However the patient was switched to Rivaroxaban 10 mg daily after he did not tolerate the needle sticks. No traction devices were utilized. He

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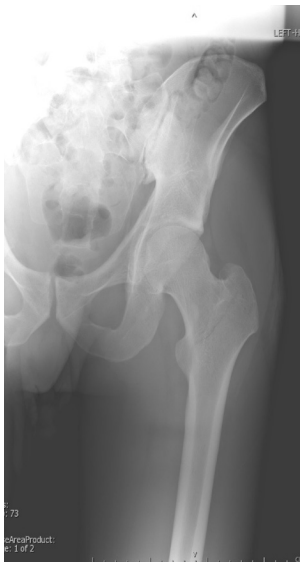

Figure 1.1. X-ray A/P view of the Left Hip, day of injury.

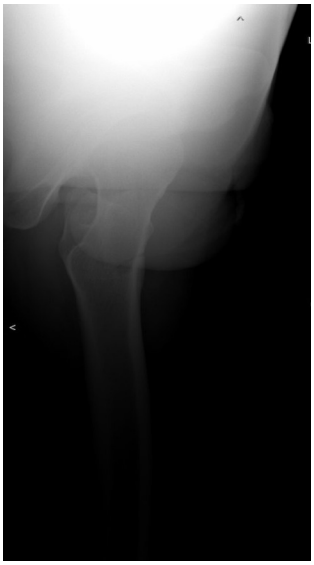

Figure 1.2. X-ray, Cross Table Lateral view of the Left Hip, day of injury.

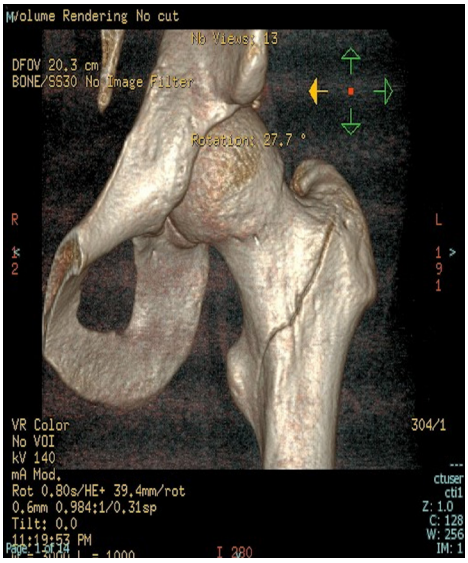

Figure 1.3. 3-D Reconstructed Computed Tomography- Frontal view of the Left Hip, day of injury.

worked with physical therapy and occupational therapy daily. On hospital day one, he transferred from bed to a chair with a walker and assistance. By hospital day four, he was able to ambulate to the bathroom with a walker and no assistance. By day seven he could independently transfer out of bed, ambulate over 150 feet with crutches, achieved acceptable pain control with oral analgesics, and was discharged to home with in-home physical therapy appointments three times per week.

He was subsequently evaluated at two weeks following his injury and continued to experience mild pain localized to his left hip. X-rays demonstrated blurring of the fracture line and no interval displacement. He was advanced to toe-touch weightbearing. At the six-week evaluation, he had full strength and x-rays demonstrated near-complete healing of the fracture (Figures 2.1 and 2.2). Weight-bearing was advanced, and he was instructed to wean off his crutches. At the three-month evaluation, he reported ability to walk long distances without pain and had returned to swimming and bicycling. He was cleared to begin running and return to sport.

At the two-year follow-up visit, he could perform all activities without limitation. He reported rare discomfort on the lateral aspect of his left hip, managed with stretching and use of a foam roller. X-rays demonstrated complete healing and remodeling of his fracture with a well-preserved joint space (Figures 3.1 and 3.2). Patient-reported outcome scores were obtained: modified Harris Hip Score (mHHS) was 86, Hip Outcome Score for Activities of Daily Living (HOS-ADL) was 88 and Sport Specific (HOS-SS) was 89 (Sport-Specific) International Hip Outcome Tool-33 score (IHOT-33) was 77.

DISCUSSION

This case report describes successful conservative treatment of a stable, nondisplaced intertrochanteric femur fracture in an otherwise healthy 21-year-old male. Historically, conservative treatment for intertrochanteric fractures involved bedrest and traction for 6-12 weeks, followed by advancing to rehabilitation. Because these fractures are uncommon in younger patients, the reports of conservative treatment of intertrochanteric femur fractures has overwhelmingly consisted of elderly patient populations.[9] In older patients, multiple studies have demonstrated early reduction and internal fixation improves patient comfort, facilitates nursing care, facilitates early mobilization, and decreases the duration of hospitalization.[8,10–13] Conversely, other studies have reported acceptable results with nonsurgical treatment of intertrochanteric femur fractures in elderly patients.[5-7,13–15]

Horn and Wang reported on their experience treating 170 patients with intertrochanteric fractures and over age 50 with traction. Ambulation was restored in all patients who were previously able to ambulate and there were low reported complication rates (5.3% mortality, 3% pneumonia and 2% decubitus ulceration).[5] Scott reported on treatment of intertrochanteric femur fractures with either traction or surgery over a two year period. The non-surgical treatment has a higher prevalence of good outcomes and there was greater mortality observed in the surgical group.[14] Bong and colleagues reported on 150 unstable intertrochanteric fractures treated by one of three methods: traction, surgery with medial displacement of the shaft and fixation with a McLaughlin pin and side plate, or valgus osteotomy followed by a McLaughlin

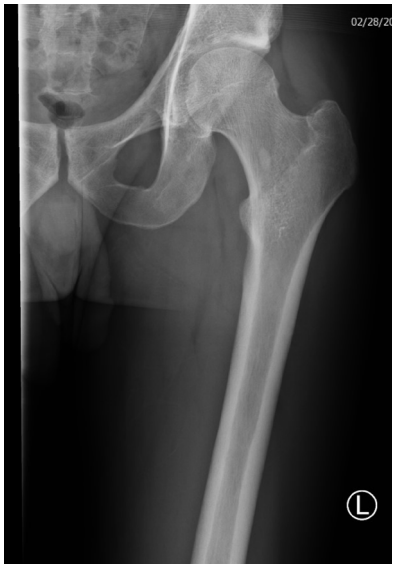

Figure 2.1. X-ray A/P view of the Left Hip, 6 weeks post-injury.

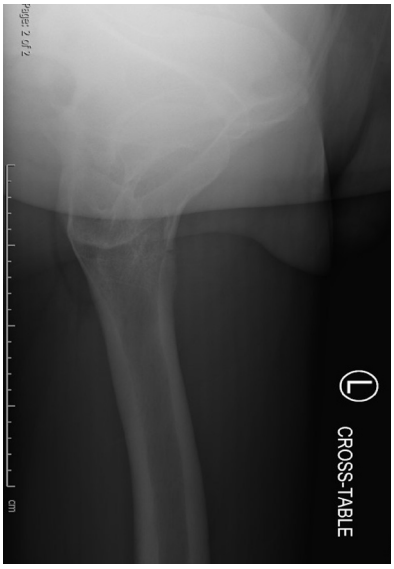

Figure 2.2. X-ray, Cross Table Lateral view of the Left Hip, 6 weeks post-injury.

pin and plate. The authors found that patients who were younger, previously active, and had adequate nursing care responded the best to conservative management, however similar functional outcomes were noted in all three groups.[7]

The results of surgical treatment of intertrochanteric femur fracture in young patients, to our knowledge, is limited to two case series. Hwang et al reported on 66 intertrochanteric femur fractures in patients under 40 years old treated with a dynamic hip screw or gamma nail.[3] The patients were 70% male and 71% of injuries occurred through high-energy trauma. There were no reported non-unions and radiographic fracture union was achieved a mean of 70.5 days (range 31-213 days). Nine percent of the patients in this study sustained a complication, including infection, aspiration pneumonia, and hardware loosening.

Robinson et al reported on the results of operative treatment of intra- and extracapsular hip fractures in patients under age 50.[1] Internal fixation of extracapsular hip fractures was performed using a Richards compression screw with a three- or four-hole plate. Among patients with extracapsular hip fractures, 57% of patients experienced a complication, including fixation failure, infection, adult respiratory distress, and pneumonia.[15]

There are several notable aspects of this case. The risks of surgery were avoided, and the patient did not sustain a complication resulting from the non-surgical treatment. The patient was hospitalized for only seven days, which was significantly less than 6 weeks of greater reported by previous studies of conservatively treated patients. No traction was required since a non-displaced intertrochanteric femur fracture is a stable pattern injury.

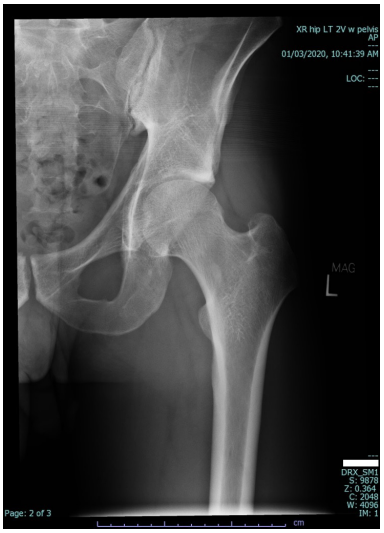

Figure 3.1. X-ray, A/P view of the Left Hip, 2 years post-injury.

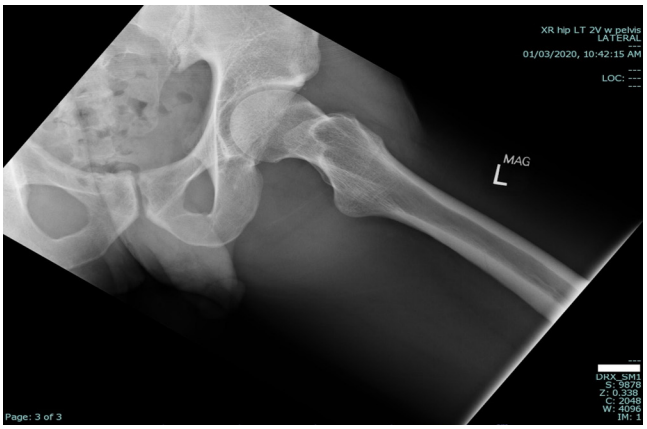

Figure 3.2. X-ray, Cross Table Lateral view of the Left Hip, 2 years post-injury.

Patient reported outcome scores were collected and demonstrated an objectively successful result. Our patient scored above the Patient Acceptable Symptomatic State score (PASS) as determined by Chahal and Maxwell.[16,17]

There are limitations to this case report. The outcome scores utilized were not available at the time of the Robinson and Hwang studies and we cannot directly compare the clinical outcome of our patient to these historical, surgically treated cohorts. The mHHS, HOS-ADL, HOS-SS, and IHOT-33[18] were originally developed to evaluate the outcomes of hip arthroscopy and have not been validated in a hip fracture population. However, since hip arthroscopy is typically performed on young patients, we believe these scores are the most relevant functional outcome scores available for this patient.

In conclusion, we report on a case of a nondisplaced intertrochanteric femur fracture managed with conservative treatment with restricted weight-bearing and achieving an excellent result. While successful conservative treatment of this injury is reported, operative treatment remains the standard of care for many patients with similar injuries, including unstable intertrochanteric femur fractures and in patients over the age of 40.

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FOUR ANCHOR REPAIR OF JERSEY FINGER

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ABSTRACT

Background: Various surgical techniques for treating avulsions of the flexor digitorum profundus tendon at the distal phalanx have been published but no ideal technique has emerged. We introduce a new all-internal 4-anchor flexor tendon repair technique and evaluate outcomes in three clinical cases.

Methods: In this retrospective case series, we reviewed three patients that sustained an avulsion of the flexor digitorum profundus tendon at the distal phalanx. All patients were surgically treated with the four-anchor repair technique. Two titanium anchors were inserted into the distal phalanx and two all-suture anchors were inserted distal to the first set of anchors. The tendon was then attached to these four anchors using a Krackow stitch pattern and the anchors were sown to each other. Active flexion and extension of the proximal and distal interphalangeal joint were measured at 3-month, 12-month, and 5-year follow-up. Postoperative complications were documented.

Results: All patients achieved excellent clinical outcomes according to assessment criteria. At 3-month follow-up, all patients regained full flexion; two patients had full extension, while one patient was 3 degrees short of full extension. At 12-month follow-up, all patients had full flexion and extension. Five-year follow-up demonstrated the same results with no loss of function, sensation or grip strength. The repairs healed without rupture, and no complications were reported.

Conclusion: The 4-anchor flexor tendon repair is a viable surgical technique for zone 1 flexor digitorum profundus tendon repair or reconstruction. Further studies are needed to replicate these promising results and biomechanically validate this technique.

Level of Evidence: IV

Keywords: bone anchor repair, flexor digitorum profundus, jersey finger, surgical technique, zone 1

INTRODUCTION

Jersey finger is an avulsion of the flexor digitorum profundus (FDP) tendon from its insertion site on the distal phalanx. These injuries commonly occur in sports such as American football and rugby when a player grabs the jersey of an opponent during the tackling motion. The mechanism of injury involves a flexed distal interphalangeal (DIP) joint that is suddenly and forcefully hyperextended during FDP contraction, causing the FDP tendon to rupture at its insertion on the distal phalanx (zone 1). Zone 1 flexor tendon injuries account for 4% of all acute traumatic tendon injuries of the hand.[1] The ring finger is most commonly affected because it is where FDP insertion is weakest.[2] Furthermore, jersey finger injuries require immediate recognition and treatment to avoid permanent disability of the affected finger.[3] Unfortunately, many of these injuries have delayed presentation.

A pull-through technique with a dorsal button over the nail is the classic surgical repair technique.[4] However, this technique has the potential problems of infection and nail plate deformities.[5,6] A variety of other surgical treatments have been reported in the literature. Techniques include two-anchor repair,[7] combined anchor with buried back-up fixation,[8] and repair of the tendon with the volar plate.[9] Another technique described and biomechanically tested used anchors combined with a dorsal button technique.[10]

In this paper, we describe a new all-internal 4-anchor repair technique for treating FDP avulsions in zone 1 and describe the course of three patients who underwent this technique (Figure 1).

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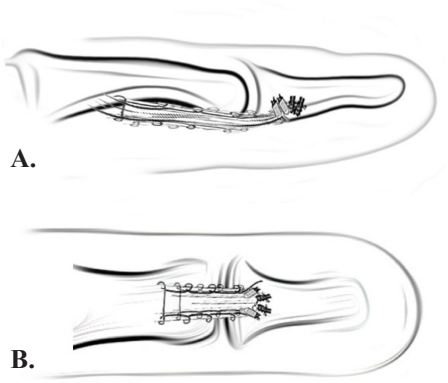

Figure 1. 4-Anchor Repair Technique. The 4-anchor repair technique is a 2-part repair: a locking Krackow suture is fixed to two retrograde anchors in a proximal row, and a locking Krackow suture is fixed to two all-suture anchors in a distal row. The ends of the anchor sutures are sown to each other. A. Lateral view. B. AP view

METHODS

Three patients who sustained an avulsion of the FDP tendon in zone 1 were included in this retrospective case series. Preoperative diagnosis of jersey finger was made based on clinical and radiographic findings. Patients were counseled about the procedure, including the rationale, risks, complications, and alternative forms of treatment, before consenting to surgery. The first two cases described in the following sections underwent direct FDP tendon repair, while the third case required a one stage allograft reconstruction of the FDP tendon.

The case series was written in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to ensure accurate reporting of the case series. The case series involved three or fewer patients and did not meet the criteria for IRB approval. Patient confidentiality was respected with the de-identification of protected health information.

Clinical Cases

I. Case 1

A 17-year-old, left-hand dominant male injured his left ring finger when he grabbed the jersey of an opposing player during a high school football game. Initially, he thought he had just "jammed" the finger. He presented to our office six weeks post-injury complaining of an inability to flex the finger. On examination, there was a visible alteration to the natural flexion cascade of the hand, with his left ring finger found in an extended position. FDS function was present in the ring finger, but he was unable to actively flex the DIP joint. He had full passive range of motion of all the joints. MRI confirmed an FDP rupture at the level of the PIP joint without collapse of the A4 pulley (Figure 2).

Figure 2 . Pre-op Images in Case #1. Two radiographic views of the left ring finger showed a small sliver of bone was avulsed from the volar plate of the PIP joint. MRI demonstrated an FDP rupture at the level of the PIP joint without collapse of the A4 pulley. A. PA view B. Lateral view C. MRI

II. Case 2

A 16-year-old, left-hand dominant male injured his left ring finger during a football game when the ball directly hit the tip of his left ring finger. Afterward, he had difficulty flexing the finger. The patient presented to our office three and a half weeks post-injury. His chief complaint was difficulty bending the DIP joint. On examination, his left ring finger demonstrated mild swelling. Flexion at the PIP joint was intact, but the patient was unable to flex the DIP joint of his left ring finger. He had full passive range of motion of all fingers. There was no evidence of a fracture seen on radiographs, but non-fused, open growth plates were present in all of the phalanges. At the preoperative evaluation, we presented him with the option to observe his condition or proceed with surgery to repair or reconstruct his flexor tendon. We discussed the possibility that surgery may result in growth plate arrest. Since the distal phalangeal physis were near to complete closure and had minimal growth remaining, he ultimately decided to proceed with the 4-anchor repair procedure.

III. Case 3

A 34-year-old, right-hand dominant male, on active duty in the military, injured his right ring finger while restacking weights at the gym. The patient went to the hospital eight weeks after the injury, where he was put in a splint that he used irregularly. He presented to our office ten weeks post-injury. His chief complaint was difficulty holding the wheel and shifting gears while driving due to the inability to bend the tip of the right ring finger. On examination, his right ring finger demonstrated mild swelling, with tenderness to palpation over the proximal interphalangeal (PIP) joint, and a palpable soft tissue defect was present over the middle phalanx. Flexor digitorum superficialis (FDS) function was intact, but he was unable to actively flex the DIP joint. Active extension

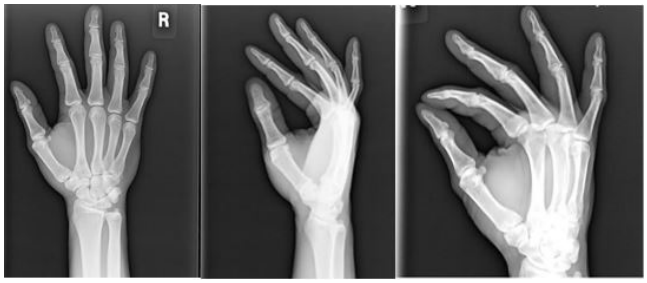

Figure 3. Pre-op Radiographs in Case #3. Three views of the right hand demonstrated no fractures and no malalignments.

was full in the metacarpophalangeal (MCP), PIP, and DIP joint. There was no evidence of an avulsion fracture on radiographs (Figure 3). Due to the late presentation, we planned for both a one stage reconstruction of his flexor tendon, and a two stage reconstruction with a reconstruction of the A4 pulley and Hunter rod placement, followed by a later reconstruction of his flexor tendon.

Surgical Procedure

The procedures were performed under regional anesthesia with all patients in the supine position. A pneumatic tourniquet was applied. The arms were prepped and draped in a typical sterile fashion. Preoperative antibiotics were administered for all of the patients. The arms were elevated and exsanguinated before tourniquets were inflated to 250 mmHg.

Surgical exploration began with a mid-lateral incision over the middle and proximal phalanges of the ring finger. The incision was then extended across the DIP joint and obliquely across the distal phalanx. Dissection was performed down through the subcutaneous tissue. Care was taken to preserve the integrity of the neurovascular bundle. A full-thickness skin flap was elevated, leaving the neurovascular bundle posterior to the volar flap. With the flexor tendon sheath exposed, the A5 pulley was opened to locate the ruptured FDP tendon. The decision to open the A1 and A3 pulley was determined intraoperatively. In order to identify the proximal end of the FDP tendon, a window was made at the A3 and then if necessary at the A1 pulley. Once identified, the flexor tendon ruptures were classified according to the Leddy and Packer classification system.[11] After removing adhesions, a temporary suture was passed through the FDP tendon using a modified Kessler technique. Using the suture ends, the tendon was passed through the flexor sheath in the proximal to distal direction and was pulled out to length to ensure proper tendon excursion and gliding. If necessary, the A4 pulley was dilated to facilitate passage of the tendon. Once the tendon was adequately mobilized, it was held in place with a twenty-five-gauge needle in preparation for bone anchor insertion. Before placing the anchors, the bone of the distal phalanx was cleaned and roughened to allow for better in-growth of the tendon.

We proceeded with the four-anchor repair. Two 2.2-mm Micro Corkscrew (Arthrex) titanium anchors, preloaded with 2-0 FiberWire suture, were inserted into the distal phalanx at deadman's angle.[12] Then, two 1.0-mm Juggerknot (Zimmer Biomet) all-suture anchors, preloaded with 3-0 MaxBraid suture, were inserted distal to the first set of anchors. The 2-0 FiberWire sutures were passed proximally on one side of the tendon and then distally on the opposite side using three locked Krackow stitches on each side. The starting point for the 2-0 FiberWire was not on the end of the tendon but rather starting 6-mm more proximal than the end of the tendon. The suture ends were tied together to pull the tendon distally. Similarly, the 3-0 MaxBraid sutures were woven into the tendon but starting from the end of the tendon using a Krackow stitch pattern and the suture ends were tied to each other distally. At the distal end, in order to maximize compression of the tendon down to the bone, the remnant suture strands from each anchor were sewn to each other. This created a mattress-type repair, similar to what would be used in a rotator cuff repair, to compress the FDP tendon at the footprint.

In case #3, the FDP tendon was found in the carpal tunnel, and was unable to stretch the full length to the distal phalanx due to extensive contraction. The A4 pulley was intact, albeit collapsed. Hence, we proceeded with a one stage reconstruction. The flexor tendon was excised at the level of the lumbricals to serve as the proximal attachment site for the tendon graft. After dilation of the A4 pulley, a silicone Hunter rod was used to pass a 4-mm allograft flexor tendon through the pulley system from the proximal to distal direction. Following bone anchor insertion and tendon attachment at the distal phalanx, the allograft tendon was secured to the proximal end of the FDP tendon with three Pulvertaft weaves. 2-0 FiberWire was used to suture the tendons together at the level of the palm.

Function of the tendon was reestablished with the tenodesis effect (passive wrist extension and flexion demonstrated appropriate flexion and extension of the fingers). The wounds were copiously irrigated, followed by the closure of the skin with 5-0 nylon. Xeroform hand dressing was applied, followed by bulky hand dressing. At the end of the surgery, a dorsal MCP joint block splint at 70 degrees of flexion was applied. Postoperatively, the patients were started on a flexor tendon protocol with passive flexion and active extension for one month. After one month, active flexion of the finger was allowed with place-and-hold exercises.

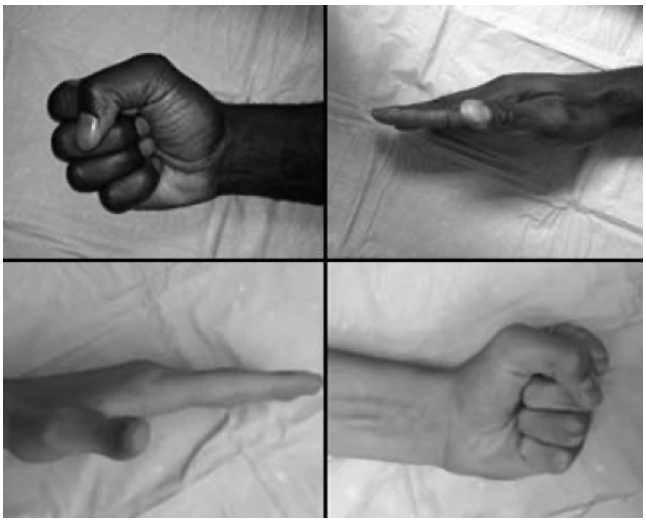

Figure 4. Post-op images of case #2 (top row) and case #1 (bottom row) at one year follow-up shows full active flexion and extension, with no loss of function.

Assessment

The primary outcome was active flexion and extension at the PIP and DIP joint of the injured finger. The range of motion was measured with a goniometer. The results were assessed using the Strickland-Glogovac criteria, which calculates the combined total flexion of the PIP and DIP minus any extension lag.[13] Outcomes were assessed 3-month, 12-month, and 5-year follow-up. We also documented any complications, such as infection or anchor failure. Radiographs were obtained to assess implant migration. Images and videos were recorded to assess the performance of tasks.

RESULTS

In our retrospective case series, the average age was 22 (range 16-34), and all three patients were males. All injuries occurred in the ring finger of the dominant hand after a forceful load was placed on the flexor tendon (i.e., weightlifting, football). One patient had a type I injury that required a staged allograft reconstruction of the FDP tendon. Two patients had a type II injury that underwent direct FDP tendon repair. In all three cases, the patients tolerated the procedure well and left the operating room uneventfully. The repairs healed without rupture, and no postoperative complications were reported. Radiographs obtained at follow-up showed that the anchor implants maintained stable position in all three patients. At 3-month follow-up, two patients obtained full active flexion and extension at the PIP and DIP joints. However, in case #3, active extension was 3 degrees short of full extension. No patients reported a loss in sensation or grip strength. Follow-up at approximately one year (13-month, 16-month, and 10-month, in the three cases, respectively) demonstrated the same results with no loss of function, and case #3 achieved full extension (Figure 4). At the final follow-up (7-year, 4.5-year, and 5-year, in the three cases, respectively), all patients maintained full flexion and extension (Figure 5). Based on the Strickland–Glogovac assessment criteria, all patients achieved excellent outcomes, with net range of motion of the DIP and PIP joint >149 degrees.

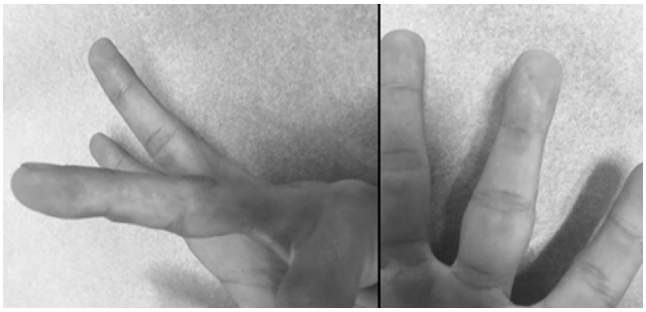

Figure 5. Post-op Images in Case #2. Long-term (4.5 years) follow-up demonstrated full active flexion and extension, with no loss of function.

DISCUSSION

In this case series, we presented three patients who ruptured their FDP tendon at the distal phalanx and underwent a 4-anchor repair technique. Despite the differences in injury classification and tendon repair (direct repair in case #1 and #2 versus allograft reconstruction in case #3), all patients achieved excellent clinical outcomes. At early and long-term follow-up, patients regained full flexion and extension at the PIP and DIP joint, with no loss in sensation or grip strength, and no postoperative complications.

Flexor tendon injuries present a distinct problem for hand surgeons due to the forces experienced by the repair sites. Schuind et al. demonstrated that the forces generated by tendons during active motion were around 34 N.[14] Thus, any repair must be able to withstand this level of force to be viable, especially in light of the trend toward active flexion rehabilitation protocols in other flexor tendon repairs. Our technique was designed in an attempt to exceed this force while avoiding the complications of pullout techniques.

In the literature, numerous studies have outlined surgical techniques to treat avulsions of the FDP tendon from the distal phalanx. Huq et al. compared outcome data for all available repair techniques and found that each technique presented its advantages, but no technique was superior in terms of patient outcomes.[15] The dorsal button technique and other pullout techniques are limited due to lower load to failure, gapping, nail deformity, and infections. Silva et al. demonstrated that loads of 20 N led to gapping of 8-mm in a cadaveric study of FDP avulsion injuries with pullout techniques.[6] 20 N is

below the force seen with active flexion and thus limits the use of active rehabilitation protocols with pullout techniques. Two anchor techniques are also limited due to load to failure similar to the levels seen in active flexion. The 2-anchor repair with Krackow stitch had load to failure of 34 N which is very close to the forces seen in active flexion.[10]

Lee et al. using a cadaveric model, compared the biomechanical properties of a combined anchor-button technique against a dorsal button and 2-anchor repair. The combined anchor-button technique was found to have increased load to failure.[10] The combined anchor-button technique had a 115 N load to failure. This approaches the native tendon load to failure described by Manske et al. of 118.6 N.[2] Despite the increased load to failure, the technique still has the potential for nail deformity and infection.

In this case series, a modification of the anchor-button technique was performed by using two additional internal all-suture anchors in place of the dorsal button (Figure 1). This technique was employed in an attempt to duplicate load to failure of the anchor-button technique while lowering the risk of infection and nail plate deformity by avoiding the button. The 1-mm Juggerknot hole is only slightly larger than the typical 0.037 inch (0.94 mm) diameter Keith needle often used to pass sutures in a pullout technique. Thus, the risk of fracture and bone loss should be no greater than the combined anchor-button technique. Other studies have demonstrated that replacing the dorsal button with internal sutures poses less risk for infection and offers a quicker return to work than a pullout suture[5] with the added benefit of no nail plate deformities.[3] The use of bone anchors is also advantageous because they allow the use of multistrand locking sutures, which are biomechanically stronger than pullout techniques, and also does not require removal.[6,7] Furthermore, increased stiffness and reduced gap formation favor bone anchor fixation in early active rehabilitation protocols,[7] which prevents flexion contractures and tendon adhesions.[10]

Our 4-anchor repair uses two 2.2-mm Micro Corkscrew (Arthrex) titanium anchors and two 1.0-mm Juggerknot (Zimmer Biomet) all-suture anchors. Each 1.0-mm anchor has approximately 26 N of load to failure,[16] and each 2.2-mm anchor has approximately 29 N of load to failure.[17] Although dependent on bone quality, suture tension to each anchor, and tendon grasping method among other factors, the potential load to failure of this technique could be close to load to failure of the Lee et al. described combined anchor-button technique and the native tendon's load to failure. Further biomechanical studies are needed to determine the ultimate load to failure and the amount of gapping produced by active flexion forces with our technique, but the technique has the potential to allow an active flexion rehabilitation protocol.

By using four separate anchors in a double-row, the insertion footprint can be better recreated since the FDP tendon insertion covers roughly 20% of the volar surface area of the distal phalanx.[18] One potential complication of all anchor repairs is anchor penetration through the distal cortex.[19] This complication did not occur in any of our patients. Other complications, such as adhesion formation, joint contracture, and quadrigia, did not occur either. Another potential problem unique to this technique is iatrogenic fracture of the distal phalanx by the placement of four anchors in such a small footprint. This was not observed and did not occur in our series, but we had young active patients with good bone quality. One contraindication to anchor repair includes loss of bone integrity, which is often seen in older adults with osteoporotic bone. As a result, in osteoporotic patients or patients with poor bone quality, anchor-bone fixation may be unstable, and the risk of failure or revision surgery is higher.[20,21,22]

The patients in our series achieved excellent outcomes and demonstrated minimal complications in early and long-term follow-up. We believe the 4-anchor repair technique achieves better restoration of the anatomic footprint. By nature of internalizing all fixation, it minimizes complications such as nail damage and infection associated with button techniques. The technique potentially maximizes the load to failure at the tendon-bone interface, but this needs to be confirmed with biomechanical studies. If biomechanical studies confirm reestablishment of the native load to failure and no gapping with serial loading, the technique also has the possibility of an early active postoperative therapy protocol. The cases presented suggest that the 4-anchor repair may be an excellent candidate for treating avulsions of the FDP tendon at the distal phalanx. The main limitation of our series was the small sample cohort (three patients) without a control group. Further studies are needed, including further clinical experience and biomechanical studies, to characterize the best use of this technique.

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