The Robert Larner, M.D. College of Medicine
THE UNIVERSITY OF VERMONT

Department of Orthopaedics and Rehabilitation
McClure Musculoskeletal Research Center

Annual Research Day
Friday, June 23, 2023

UVM Robert T. Stafford Hall
Room 101

via Zoom
https://uvmcom.zoom.us/j/108497630

6:30-7:00 am Continental Breakfast

7:00 am Research Program Begins

Visiting Professor:

Benjamin Geer, MD
Orthopaedic Trauma Surgeon
DHMG Orthopaedics
Chandler, AZ

UVM Resident Alumni 2006-2011

Program

7:00 AM	***Keynote Presentation: Benjamin Geer, MD***
Introduction:	***Bruce D. Beynnon, PhD***

7:05 – 7:35	Title: "Life Needs a Preop Plan" By: Benjamin Geer, MD	
7:35 – 7:45	Questions	

SESSION 1	***PGY 5 Final Research Project Presentations***
Moderator:	***Chason Ziino, MD***
Lead Discussant:	***Benjamin Geer, MD***

7:45 – 8:00	Title: "Association of Geometric Characteristics of Knee Anatomy (Alpha Angle and Intercondylar Notch Type) With Noncontact ACL Injury" By: Evan Boyd, MD; PGY-5 (Bruce Beynnon, PhD)	3
8:00 – 8:10	Questions	
8:10 – 8:25	Title: "Outcomes of Nonoperatively Treated Vancouver B1 Fracture: Is Failure Common?" By: William Efird, MD; PGY-5 (Michael Blankstein, MD)	4
8:25 – 8:35	Questions	
8:35 – 8:50	Title: "The Intermalleolar Method for Intraoperative Rotational Assessment of the Tibia – A Prospective Clinical Validation Study" By: Michael Roberts, MD; PGY-5 (Patrick Schottel, MD)	5-6
8:50 – 9:00	Questions	
9:00 – 9:10	10 Minute Break	

SESSION 2	***PGY 3 Research Presentations***
Moderator:	***Andrew Geeslin, MD***

9:10 – 9:20	Title: "Using Machine Learning to Predict Major Complications Following Cervical Spine Decompression" By: Shawn Best, MD, PGY3 (Chason Ziino, MD)	7-8
9:20 – 9:25	Questions	
9:25 – 9:35	Title: "Trends in Orthopaedic Departmental Resident Research Support: A Survey of Program Directors" By: Jordan Conroy, MD, PGY3 (Chason Ziino, MD)	9
9:35 – 9:40	Questions	
9:40 – 9:50	Title: "Gardner-Wells Tongs are Safe and Effective for Intraoperative Positioning in Spine Surgery" By: Greg Roy, MD, PGY3 (Chason Ziino, MD)	10
9:50 – 9:55	Questions	
9:55 – 10:05	10 minute break	

SESSION 3	***Medical Student Research Presentations***	
Moderator:	***Niccolo Fiorentino, PhD and Patrick Schottel, MD***	
10:05 – 10:20	Title: "Quantifying Cartilage Composition and Arthrokinematics: Application to Short-Term Biomechanical Outcomes After Sports-Related Knee Injury and Surgery" By: Sadegh Khodabandeloo, BS (Niccolo Fiorentino, PhD)	11
10:20 – 10:30	Questions	
10:30 – 10:45	Title: "Preoperative Vitamin D Supplementation is a Cost-Effective Intervention in Arthroscopic Rotator Cuff Repair" By: Dhiraj Patel, MS3 (Chason Ziino, MD)	12
10:45 – 10:55	Questions	
10:55 – 11:10	Title: "Vitamin D Supplementation is a Cost-Effective Intervention for Posterolateral Lumbar Fusion" By: Dhiraj Patel, MS3, and Matthew Lippel, MS3 (Chason Ziino, MD)	13
11:10 – 11:20	Questions	
11:20 – 11:35	Title: "Acute Changes in Thigh Muscle Cross-Sectional Area Following ACL Injury in Males and Females" By: Kate French, BS, MS3 (Bruce Beynnon, PhD)	14
11:35 – 11:45	Questions	
11:45 – 12:00	Title: "Assessing early changes in cartilage water content and distribution in ACL-injured patients with T2* MRI" By: Taylor Walker, BS MS3 (Bruce Beynnon, PhD)	15
12:00 – 12:10	Questions	
12:10 – 12:25	Title: "T1rho mapping of articular cartilage following anterior cruciate ligament (ACL) injury" By: Emily Battle, BS, MS3 (Bruce Beynnon, PhD)	16
12:25 – 12:35	Questions	
12:35	Lunch and award presentations, Stafford Hall, 4th floor lobby	

Raymond F. Kuhlmann, MD Resident Research Award
- Awarded to the Outstanding Presentation by a Chief Resident

McClure Musculoskeletal Research Award *- Awarded to the Outstanding Presentation by a Researcher (non-faculty)*

Abstracts

Association of Geometric Characteristics of Knee Anatomy (Alpha Angle and Intercondylar Notch Type) With Noncontact ACL Injury

Michael S. Barnum, BS, **Evan D. Boyd, MD**, Pamela Vacek, PhD,
James R. Slauterbeck, MD, and Bruce D. Beynnon, MS, PhD

Background: The femoral intercondylar notch type and the alpha angle (the angle between the femoral notch roof and the long axis of the femur) are easily measured in clinical settings; however, their associations with anterior cruciate ligament (ACL) injury remain unclear.

Hypothesis/Purpose: The purpose was to determine if the alpha angle and the femoral notch type are associated with noncontact ACL injury univariately and in combination with previously identified knee geometric risk factors. We hypothesized that the alpha angle and the femoral notch type are associated with noncontact ACL injury and that the association differs between men and women.

Study Design: Case control study; Level of evidence, 3.

Methods: The alpha angle and the femoral notch type were measured via 3T magnetic resonance imaging (MRI) acquired from 61 women and 25 men with a first-time noncontact ACL injury. Each injured patient was matched with a control participant based on age, sex, and participation on the same sports team. A conditional logistic regression was used to assess univariate associations with ACL injury as well as multivariate associations using MRI-based risk factors of knee geometry identified in previous analyses: femoral intercondylar notch width at the anterior outlet, femoral intercondylar notch anteromedial ridge thickness, volume of the ACL, tibial plateau lateral compartment subchondral bone slope, lateral compartment middle articular cartilage slope, lateral compartment meniscus-cartilage height, lateral compartment meniscus-bone angle, and medial tibial spine volume.

Results: For female athletes, the alpha angle (odds ratio, [OR], 1.82 per 1-degree increase; P = .001), the tibial lateral compartment articular cartilage slope (OR, 1.25 per 1-degree increase in the posterior-inferior directed slope; P = .022), and the femoral notch anteromedial ridge thickness (OR, 3.36 per 1-mm increase; P = .027) were independently associated with ACL disruption. For men, no other variables entered the models after the alpha angle was inputted as the first step (OR, 2.19 per 1-degree increase; P = .010).

Conclusion: For women, ACL injury was most strongly associated with increased alpha angle, increased tibial plateau slope, and increased femoral notch ridge thickness. For men, increased alpha angle was the most significant factor associated with ACL injury. The mechanism of injury might be associated with a combination of impingement of the ACL against the bone and increased ligament loading.

Keywords: anterior cruciate ligament; injury; knee; anatomy; alpha angle

Outcomes of Nonoperatively Treated Vancouver B1 Fractures: Is Failure Common?

William M. Efird, MD, Evan D. Boyd, MD, Patrick C. Schottel, MD, Nathaniel J. Nelms, MD, Michael Blankstein, MSc, MD

Background: Periprosthetic fractures (PPFx) are a severe complication of total hip and hemiarthroplasty. Surgical treatment is typically performed but can result in major morbidity. Nonoperative PPFx management may provide a successful treatment alternative in select patients.

Methods: Vancouver B1 PPFx patients treated over a 10-year period were identified. Patient demographic data were retrospectively recorded. Injury and postoperative radiographs were reviewed. There were 48 patients who met the study criteria. Patients were divided into operative and nonoperative comparative cohorts. Outcome comparisons between the 2 cohorts included 1-year mortality, unplanned surgery within 24 months of injury, fracture union rate, and return to preinjury ambulation status.

Results: There was no difference in 1-year mortality between the nonoperative and operative cohorts (17 versus 8%; *P* ¼ .32). We found no significant difference in unplanned surgery between the nonoperative and operative groups (8.7 versus 12%; *P* ¼ .71), fracture union (100 versus 96%, *P* ¼ .34), or return to ambulation status (86 versus 91%; *P* ¼ .86). Nonoperative fractures were minimally displaced and within the metaphyseal region of the proximal femur without stem subsidence. Nonoperative fractures with subsequent treatment failure had initial fracture extension closer to the tip of the stem compared to successfully treated nonoperative fractures (5.5 versus 10.2 centimeters; *P* ¼ .02).

Conclusion: Select nonoperatively treated patients had infrequent need for unplanned surgery, high union rate, and return to their preinjury ambulation status. Nonoperative management is not appropriate for all Vancouver B1 PPFx, but those patients who have minimally displaced meta-diaphyseal fractures and partial remaining distal fixation can be successfully treated.

The Intermalleolar Method for Intraoperative Rotational Assessment of the Tibia – A Prospective Clinical Validation Study

Michael S. Roberts, MD, Jordon P. Conroy, MD; Michael Desarno, MS; Michael Blankstein, MD, MSc, FRCSC; Jesse C. Hahn, MD, MPH; Craig S. Bartlett, MD; Patrick C. Schottel, MD

Aided by a grant from the Orthopaedic Trauma Association (OTA)

Introduction: The goal of treatment for diaphyseal tibia fractures is to restore length, alignment, and rotation. Despite surgical advancements, restoring anatomic rotation remains a challenge. The prevalence of tibial malrotation following intramedullary nail fixation is as high as 19-41%. To date, several fluoroscopic methods for assessing tibial rotation have been proposed, although none have been widely adopted or rigorously tested in the setting of an acute fracture. We developed a novel fluoroscopic technique, termed 'the intermalleolar method', which has clear anatomical landmarks and is easily performed intraoperatively. In our preliminary cadaveric proof of concept study, we found this method to be both accurate and reliable, even when performed by surgeons with varying degrees of experience. The purpose of this clinical validation study is to assess the accuracy of this method in patients with tibial shaft fractures undergoing intramedullary fixation by comparing it to the gold standard, CT.

Methods: Prospective cohort study of 20 consecutive patients with unilateral tibial shaft fractures who underwent intramedullary fixation. Intraoperatively, measurements were performed using the intermalleolar method on both the uninjured and injured limbs after the implant was locked. A total of 40 limbs were measured. Postoperatively, patients underwent bilateral low-dose lower extremity rotational CT scans. CT measurements were obtained by four blinded observers. Mean absolute rotational differences and standard errors were calculated.

Results: Of the 20 tibia fractures, the mean patient age was 43.4 years. The most common AO/OTA fracture pattern was 42-A1 (35%; 7/20), and 40% (8/20) of fractures had ankle extension requiring separate fixation. The intermalleolar method had a mean absolute rotational difference of 5.1 degrees compared to CT (SE 0.6; range 0 – 13.7 degrees). The mean absolute rotational difference of the injured, operative limbs was 4.2 degrees (SE 0.7; range 0.3 – 10.9 degrees), while in the uninjured, nonoperative limbs had a mean absolute rotational difference was 6.1 degrees (SE 0.9; range 0.7 – 13.8 degrees). Ninety percent (36/40) of the measurements were within 10 degrees of the CT and 100% (40/40) were within 15 degrees. The accuracy of the intermalleolar method was not significantly influenced by patient BMI >35, simple versus comminuted fracture pattern, fibular fracture location, tibial fracture location, distal intra-articular fracture extension requiring separate fixation, or time since the onset of the study.

Discussion and Conclusion: The intermalleolar method for measuring tibial torsion is accurate and consistently provides a torsion value within 10 degrees of the mean CT measurement. This technique may be employed in the operating room to accurately quantify tibial torsion and assist with intra-operative rotational corrections.

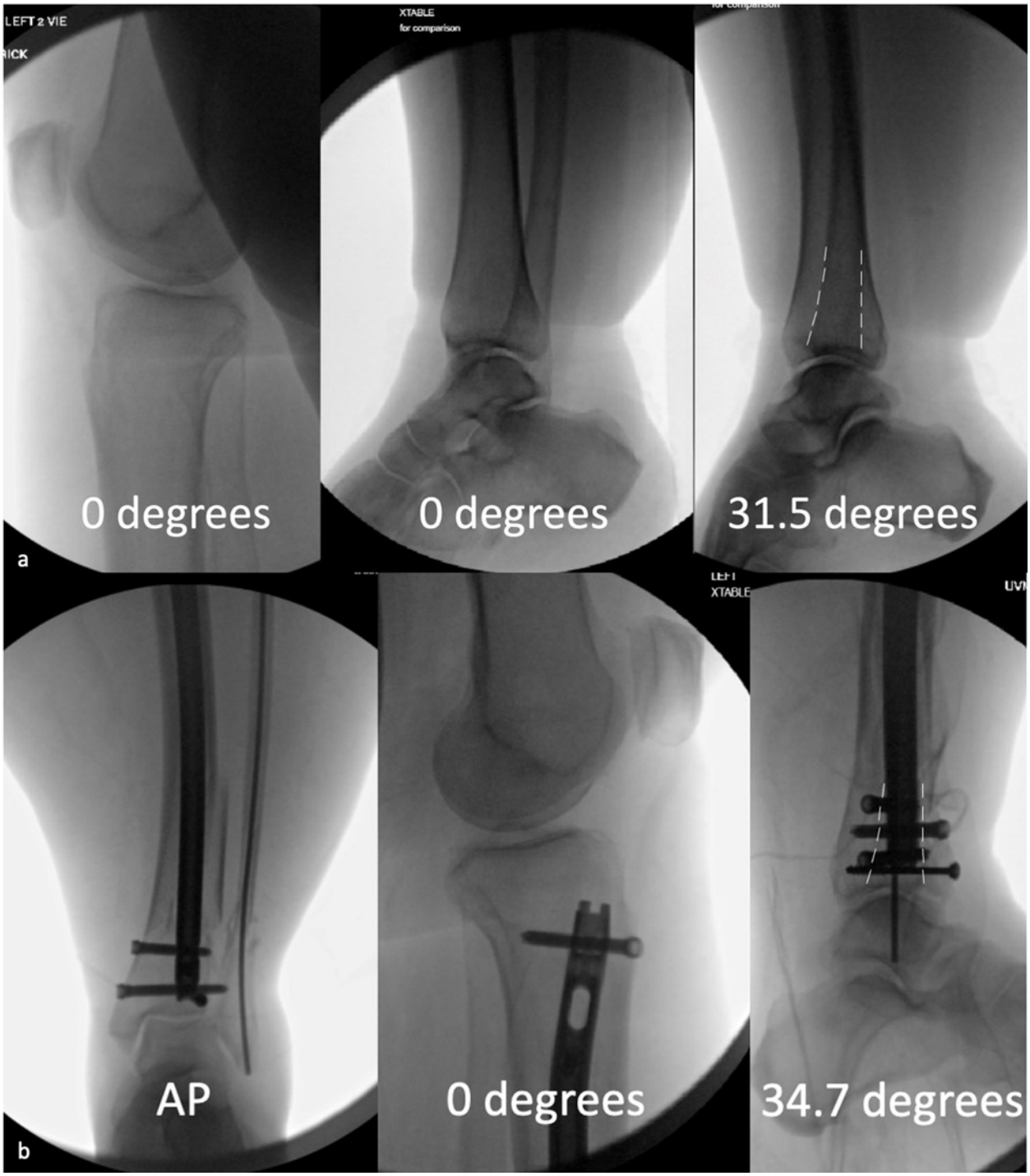

Figure 1a, 1b: Demonstration of the intermalleolar method on the nonoperative and operative limbs. A perfect lateral of the knee is performed with the posterior femoral condyles centered within the fluoroscopic beam and the C-arm positioned at zero degrees. The C-arm is the positioned centered at the ankle and rotated until the fibula perfectly bisects the tibia at the physeal scar.

Using Machine Learning to Predict Major Complications Following Cervical Spine Decompression

Shawn Best, MD, Chason Ziino, MD

Purpose: The purpose of this study is to assess the ability of various machine learning models to predict the occurrence of major medical complications following cervical decompression.

Study Design: Cross- sectional Database Study. Patient Sample: All patients (n=7743) undergoing cervical spine decompression (not including anterior cervical discectomy) in 2019 as identified in the National Inpatient Sample as sponsored by the Agency for Healthcare Research.

Quality Outcome Measures: Postoperative major medical complications: death, pulmonary embolism, deep vein thrombosis, respiratory failure, myocardial infarction, and cerebrovascular accident.

Methods: Underlying patient demographic factors and comorbidities were utilized to train multiple machine learning algorithms to predict major post-operative complications. Training data was used to generate classifiers in a 10-fold cross-stratified manner. A randomly generated subset of 20% of the initially identified patients were withheld as a test set to generate final error values and confusion matrices. These groups were then analyzed with the Waikato Environment for Knowledge Analysis (WEKA) software using the classifiers logistic regression and random forest, as well as the meta-classifier vote.

Results: The random forest model was most precise overall in discriminating between those patients who did and did not suffer major post-operative complications following cervical decompression, followed by the logistic regression model. The higher-order meta- classifier (vote) failed to predict any occurrences of major complications. Conclusion: A random forest machine-learning algorithm was the most successful at predicting major post-operative complications, followed by a logistic regression model, with both of these outperforming the higher-order metaclassifier. This demonstrates that increasing sophistication of a machine-learning model does not necessarily correlate with improved predictive power. As the influence and complexity of these models continue to expand, both within medicine and society writ large, it will be important to continue to hold their results under close scrutiny.

See figures next page.

Confusion Matrix (Logistic regression)

	Outcome +	Outcome -
Prediction +	1	3
Prediction -	99	1446

Confusion Matrix (Random Forest)

	Outcome +	Outcome -
Prediction +	7	14
Prediction -	93	1435

Confusion Matrix (Vote)

	Outcome +	Outcome -
Prediction +	0	0
Prediction -	100	1449

Trends in Orthopaedic Departmental Resident Research Support: A Survey of Program Directors

Jordan Conroy, MD

Background: There is a wide variability in protected time for resident research despite the fact that 97.5% of orthopaedic program directors report requiring research for graduation based on a recent study by Barghi et al in 2022. Through this work, the greatest obstacle identified was "faculty and resource commitment." No guidelines currently exist for leadership related to financial support of resident research, and to date, there is no clear analysis or summary of the current departmental practices among orthopaedic residency programs.

Purpose: To clarify departmental financial support for resident research by surveying all ACGME accredited orthopaedic programs directors as a first step towards establishing best practices for resident research policy development.

Methods: Survey of all orthopaedic program directors related to specific amounts of financial support for resident research. Analysis of responses will investigate the differences in amount of financial support, faculty use of CME/additional funds, percentage of faculty involvement and support, as well as regional variations.

Hypothesis: More than 50% of orthopaedic faculty are involved in resident research and an average annual department/faculty financial support per resident is between $1000-3000.

Results: Surveys currently in the process of distribution. Pending data collection and analysis.

Conclusion: Pending data collection and analysis.

Gardner-Wells Tongs are Safe and Effective for Intraoperative Positioning in Spine Surgery

Chason Ziino, MD, **Greg Roy, MD**, Dhiraj Patel, MS3

Background: There is an extreme paucity within the literature on the topic of complications following the use of GWT. Traditionally, GWT are used during spinal trauma cases to aid in fracture reduction through positioning and axial traction (Lerman, Loeser). less commonly it is used during non-trauma cases for position, instead, positioning devices such as the Mayfield tongs, horseshoe headrest, and mirrored foam headrest are used. These other modalities have their own set of known complications including partial or complete vision loss, arteriovenous fistula, skull fracture, tension pneumocephalous, CSF rhinorrhea, skin pressure sores and venous air embolism (Thijs, Grossman, Jain, Myers, Kamel). Many of these complications are rare and their true rates are unknown as most are reported through single or a few case reports. Nevertheless, these complications result in severe morbidity for the patient if encountered. Although there are known complications with GWT, they are generally minor and rare. One meta-analysis reported a high complication rate of 37.5%, consisting of loosening pins, asymmetric pins and infection; however, they had only one superficial infection and no severe complications reported. True rates of severe complications such as brain abscess, medial table penetration, neurovascular injury, are largely unknown as they are rare. Most reports are through case reports. This study will hope to further elucidate the complications and their rates in a broader application of GWT in traumatic and non-traumatic surgical procedures at a single institution by a single surgeon.

Purpose: Due to the paucity of literature regarding complications, especially major complications with the use of Gardner-Wells Tongs, their use is generally limited to spinal trauma. Gaining a better understanding of the complications and their incidence will inform the safety profile of their use and possibly expand their utility to other applications. It will also seek to confirm the work of other investigators in that complications associated with Gardner-Wells tongs are minor and rare. This is important information as there are described complications with major morbidity and possible mortality with little information on the incidence of these complications, especially in the elective, non-trauma setting.

Study Design: The study will be a retrospective case series

Methods: A retrospective chart review will be performed on all cases performed by a single surgeon (CZ) at a single institution to assess for post-operative complications. Chart review will include evaluation of operative reports, progress notes, clinic follow-up notes, etc. complications will be identified and categorized accordingly for analysis.

Data collection: Chart review will be performed and all complications will be recorded. Complications will be classified as major (medial table breach, deep abscess, neurovascular injury, pin pullout, increased intra-occular pressure) or minor (minor bleeding requiring staples, superficial infection, pin loosening). Complications will be included across all current follow up

Eligibility criteria: Patients will need to be 18 years old or greater and require use of GWT during a spine procedure in the operating room. Exclusion criteria include use of positioning device other than GWT.

Analysis: Analysis will be performed in Excel to find incidence (#complications/ (total cases using GWT*timeframe)) of both major and minor complications. Subanalysis looking at the incidence of each subtype of complication will also be performed.

Quantifying Cartilage Composition and Arthrokinematics: Application to Short-Term Biomechanical Outcomes After Sports-Related Knee Injury and Surgery

Sadegh Khodabandeloo, PhD Candidate, Niccolo Fiorentino, PhD
College of Engineering and Mathematical Sciences
in collaboration with the Department of Orthopaedics and Rehabilitation

Post-traumatic osteoarthritis (PTOA) is a prevalent long-term repercussion of ACL injury, especially when ACL disruption is combined with meniscal lesions. While ACL reconstruction restores stability of the joint, studies have shown it fails to ameliorate the progression of OA following surgery. Target therapies to reduce PTOA are desperately needed since more than 200,000 ACL injuries occur annually in the United States. However, the driving mechanism by which the PTOA initiates has yet to be determined.

A common hypothesis is that the onset of this degenerative process is due to alterations in the kinematics and arthrokinematics (the way femoral cartilage and tibial cartilage articulate) of the injured knee. Abnormalities in cartilage mechanics induce decomposition and changes in the composition of cartilage. Even though several studies determined the long-term effects of ACL reconstruction on the joints' arthrokinematics or cartilage composition, the existence of these alterations shortly after surgery and their relationship have yet to be investigated due to the lack of accurate imaging methods.

Musculoskeletal Imaging and Orthopedics Biomechanics laboratory is executing a NIH funded study to investigate arthrokinematics and cartilage composition changes after the ACL reconstruction (ACLR) surgery. The goal of this study is to utilize model-based tracking (MBT) approach to study joint arthrokinematics and quantitative MRI (qMRI) to investigate cartilage composition at two different timepoints (1-2 years after surgery and 2-3 years after surgery). Overall, the outcomes of the lab's work define the capacity of our measurement systems to detect abnormalities in arthrokinematics and qMRI measurements. Ultimately, the results of the NIH-funded study will provide a better comprehension of PTOA initiation and inform future therapeutics, such as new rehabilitation programs, aimed at slowing down or eliminating early changes in patients at high risk for PTOA.

Preoperative Vitamin D Supplementation is a Cost-Effective Intervention in Arthroscopic Rotator Cuff Repair

Dhiraj Patel, MS3, Gregory Roy, MD, Nathan Endres, MD, Chason Ziino, MD

Background: This study investigates the potential role of preoperative 25(OH)D supplementation as a cost-effective strategy to decrease revision rotator cuff repair (RCR) rates and lower the total healthcare burden from patients undergoing primary arthroscopic RCR. Previous literature has emphasized the importance of vitamin D on bone health and maintenance, soft tissue healing and outcomes in RCR. Inadequate preoperative vitamin D levels may increase revision RCR rates following primary arthroscopic RCR. Although 25(OH)D deficiency is common in RCR patients, serum screening is not routinely performed.

Methods: A cost-estimation model was developed to determine the cost-effectiveness of both preoperative selective and nonselective 25(OH)D supplementation in RCR patients in order to reduce revision RCR rates. Prevalence and surgical cost data was obtained from published literature through systematic reviews. Cost of serum 25(OH)D assay and supplementation were obtained from public-use data. Mean, lower and upper bounds of one year cost-savings were calculated for both the selective and nonselective supplementation scenarios.

Results: Preoperative 25(OH)D screening and subsequent selective 25(OH)D supplementation was calculated to result in a mean cost-savings of $6,099,341 (range: $-2,993,000 - $15,191,683) per 250,000 primary arthroscopic RCR cases. Nonselective 25(OH)D supplementation of all arthroscopic RCR patients was calculated to result in a mean cost-savings of $11,584,742 (range: $2,492,401 - $20,677,085) per 250,000 primary arthroscopic RCR cases. Univariate adjustment projects that selective supplementation is a cost-effective strategy in clinical contexts where the cost of revision RCR exceeds $14,824.69 and prevalence of 25(OH)D deficiency exceeds 6.67%. Additionally, nonselective supplementation is a cost-effective strategy in clinical scenarios where revision RCR cost ≥ $4,216.06 and prevalence of 25(OH)D deficiency ≥ 1.93%.

Conclusions: This cost-predictive model promotes the role of preoperative 25(OH)D supplementation as a cost-effective mechanism to reduce revision RCR rates and lower the overall healthcare burden from arthroscopic RCR. Nonselective supplementation appears to be more cost-effective than selective supplementation, likely due to the lower cost of 25(OH)D supplementation compared to serum assays.

Vitamin D Supplementation is a Cost-Effective Intervention for Posterolateral Lumbar Fusion

Dhiraj Patel, MS3, **Matthew Lippel, MS3**, David Lunardini, MD,
Robert Monsey, MD, Chason Ziino, MD

Background: This study investigates the role of preoperative 25(OH)D supplementation as a cost-effective strategy to decrease pseudarthrosis rates and overall healthcare burden following posterolateral fusion (PLF). Previous literature has emphasized the importance of vitamin D in bone health maintenance, spinal health, and outcomes in spinal fusion. Inadequate preoperative 25(OH)D levels may increase pseudarthrosis rates following PLF. Thus, a cost-estimation model was developed to determine the cost-effectiveness of both selective and nonselective 25(OH)D supplementation in PLF.

Methods: Prevalence and cost data were obtained from published literature through systematic reviews. Cost of serum 25(OH)D assay and supplementation were obtained from public-use data. Mean, lower and upper bounds of one year cost-savings were calculated for both supplementation scenarios.

Results: Preoperative 25(OH)D screening and subsequent selective 25(OH)D supplementation was calculated to result in a mean cost-savings of $10,978,440 ($9,969,394-$11,987,485) per 10,000 PLF cases. Nonselective 25(OH)D supplementation of all PLF patients was calculated to result in a mean cost-savings of $11,213,318 ($10,204,272-$12,222,363) per 10,000 cases. Univariate adjustment projects that selective supplementation is a cost-effective strategy in clinical contexts where revision PLF costs exceed $781.89 and prevalence of 25(OH)D deficiency ≥ 0.612%. Nonselective supplementation is cost-effective in clinical scenarios where revision PLF cost ≥ $198.09 and prevalence of 25(OH)D deficiency ≥ 0.1645%.

Conclusions: This cost-predictive model promotes the role of preoperative 25(OH)D supplementation as a cost-effective mechanism to reduce overall healthcare burden following PLF. Nonselective supplementation appears to be more cost-effective than selective supplementation, likely due to the relatively lower cost of 25(OH)D supplementation compared to serum assays.

Acute Changes in Thigh Muscle Cross-Sectional Area Following ACL Injury in Males and Females

Kate A. French, MS3, Bruce Beynnon, PhD, Pamela Vacek, PhD, Andrew Borah, ATC, Mickey Krug, ATC, Mack Gardner-Morse, MS, Rebecca Choquette, ATC, Timothy Tourville, PhD, Michael Toth, PhD, Mathew Failla, PhD, Andrew Geeslin, MD, Matthew Geeslin, MD, Nathan Endres, MD

Background: Injury to the ACL greatly increases an individual's risk of developing post-traumatic osteoarthritis (PTOA), a debilitating disease. Understanding the early mechanisms of PTOA is critical, as late intervention, after damage to the articular structures has occurred, does not modify the disease course and only provides symptomatic relief. Quadriceps strength loss that occurs soon after injury is associated with tibiofemoral joint space width (JSW) narrowing, characteristic of the early onset of PTOA. To date, no study has characterized the acute response of thigh muscle cross-sectional area (CSA) to ACL injury in females and males, nor how that response is modified by the subject's body mass index (BMI) and concomitant injury to the menisci.

Objectives: Establish side-to-side symmetry of thigh muscle CSA in normal, uninjured subjects, and characterize acute changes in thigh muscle CSA following first-time ACL rupture, pre-reconstruction.

Methods: 69 individuals (43 females, 26 males) aged 14 to 34 years old (mean 22.6) with a first-time ACL rupture with or without concomitant meniscus injury (39 and 30, respectively) underwent mid-thigh Axial T1 FFE MRI prior to reconstruction. Bilateral extensor and flexor muscle groups were manually segmented, and CSA values calculated using a MATLAB program developed by our research team. A within-subjects design was used by comparing within-person injured-to-contralateral normal side changes. In addition, 9 healthy control subjects (5 females, 4 males) with no history of lower extremity injury underwent the same protocol to establish a normal range of difference within subjects and corresponding 95% confidence intervals. Independent t-tests and ANOVA were used to evaluate for differences in muscle group CSA ($P<.05$).

Results: Control subjects had insignificant mean right-to-left differences in thigh muscle CSA of 0.28 cm2 (95% CI -1.70-2.27) and 0.52 cm2 (95% CI -1.45-2.49) in extensor and flexor muscle groups, respectively. In ACL-injured female and male subjects with or without concomitant meniscus injury, both groups had significant decreases in extensor muscle CSA of the injured leg (females: mean -7.03 cm2, $P<.001$; males: mean -8.41 cm2, $P=.01$) and no significant differences in flexor muscle CSA; adjusting for time between injury and MRI acquisition did not have a significant effect on these findings. Females with concomitant meniscus injury had a significantly greater decrease in extensor muscle CSA in the injured leg than those with ACL injury alone (mean -9.07 cm2 vs -4.20 cm2, $P<.001$); no such difference was found in male subjects ($P=.84$). In addition, there was a significant decrease in extensor muscle CSA in the injured leg of overweight males (BMI $\geq$25 to <30) compared to healthy weight males ($P=.02$); no significant differences in muscle CSA between injured and uninjured legs by BMI category were found in females. Lastly, our method of muscle segmentation and CSA calculation had high test-retest reliability with ICCs between 0.97 and 0.98 for both muscle groups.

Conclusions: Extensor muscle CSA of the injured leg decreased significantly in both males and females following ACL rupture prior to reconstruction, while flexor muscle CSA did not change significantly. This decrease was even more dramatic when looking at females with a concomitant meniscus injury. The decrease in extensor muscle CSA is likely to persist and worsen post-reconstruction and may contribute to the increased development of PTOA in ACL-injured individuals. As an interim analysis of a study with an enrollment goal of 80 subjects, the smaller sample size was only a minor limitation as covariate analyses with variables such as time between injury and MRI acquisition, BMI and concomitant meniscus injury were still able to occur.

Assessing early changes in cartilage water content and distribution in ACL-injured patients with T2* MRI

Taylor R Walker, MS3, Bruce Beynnon, PhD, Pamela Vacek, PhD, Andrew Borah, ATC, Mickey Krug, ATC, Mack Gardner-Morse, MS, Rebecca Choquette, ATC, Timothy Tourville, PhD, Michael Toth, PhD, Mathew Failla, PhD, Andrew Geeslin, MD, Matthew Geeslin, MD, Nathan Endres, MD

Articular cartilage (AC) is hydrated specialized connective tissue with viscoelastic properties. It reduces transmitted loads to underlying subchondral bone in joints such as the knee. The mechanical properties of cartilage depend on the integrity of its structure and an appropriate distribution of water, proteoglycan, and collagen throughout its matrix. Unfortunately, a severe joint injury can initiate post-traumatic osteoarthritis progression, and this has been observed in greater than 80% of ACL-injured patients at 10-15 year follow up.

Previous research has also shown that T2* MRI can be useful in detecting changes in cartilage water content and distribution within cartilage soon after severe joint trauma and that early T2* changes correlate with later cartilage loss and osteoarthritis progression. Thus, this imaging modality has increasingly been utilized in research as an image-based biomarker to assess osteoarthritis progression in pre-symptomatic patients following ACL injury.

This study aims to assess and compare pre- operative changes in cartilage water content and distribution in ACL-injured patients with and without concomitant meniscal injury. Meniscus tears are observed in more than 50% of patients with ACL injuries, and meniscal injury modifies risk for PTOA. Assessing early, sex-specific changes in water content and collagen organization in ACL- injured patients with and without concomitant meniscal injury can help identify whether these factors influence disease progression and risk.

20 participants were included in the study (5 males and 5 females with and without concomitant lateral meniscal injury) and underwent bilateral pre-operative 3T MRI scans with acquisition of T2* sequences. The tibiofemoral cartilage was segmented manually in each sagittal image slice to establish 3-dimensional articular cartilage thickness and T2* relaxation time maps for the injured and contralateral normal knees.

A paired t-test will be used to identify injured to contralateral normal side differences in T2* relaxation times across the articular cartilage. A non-paired t-test will be used to determine whether patterns of injury-related changes in cartilage water content (demonstrated by T2* relaxation time) varies in these regions based on injury type (ACL tear with or without meniscal injury) and patient sex. This data will confirm or refute our hypothesis that injury severity and patient sex are factors that modify the effect of ACL-injury on cartilage water content and distribution and in turn impact risk for developing PTOA.

Citations

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T1rho mapping of articular cartilage following anterior cruciate ligament (ACL) injury

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Anterior cruciate ligament (ACL) trauma is a common injury that significantly alters the cartilage composition of the knee, ultimately putting individuals at risk of developing post-traumatic osteoarthritis (PTOA). In the time shortly following injury, it is unclear how exactly cartilage matrix components adapt at different depths and within different regions of the knee. Collection of T1rho relaxation times by MRI allows for 3D mapping of cartilaginous change.

T1rho quantifies the loss of proteoglycan content from cartilage, providing a marker of degeneration. This study aims to better understand patterns of proteoglycan change throughout the knee, and how this may differ depending on the sex of the subject and the extent of injury. Previous studies have shown that there are significant sex-specific differences in cartilage thickening and thinning following injury, thus necessitating separate analysis of male and female data. Additionally, more extensive trauma involving the meniscus has demonstrated a greater effect on articular cartilage, thus necessitating separate analysis of isolated ACL injury and ACL injury with concomitant meniscus trauma.

In this study, pre-operative bilateral knee MRIs were obtained from 16 subjects (8 males and 8 females). Of each sex-specific cohort, 4 had suffered isolated ACL injury, and 4 had suffered combined ACL and lateral meniscus injury. Manual segmentation of sagittal MRI slices defined the bounds of femoral and tibial cartilage.

Currently, superficial (superior 50%) and deep (inferior 50%) cartilage are being analyzed in the trochlea, tibia, and femur. T1rho mapping of these regions of interest will help discern patterns of cartilage response to injury unique to these patient populations. The results of this data analysis may offer foundational information for T1rho mapping as an early biomarker of PTOA and may guide further research into targeted treatment plans for men and women.