UNIVERSITY OF PITTSBURGH

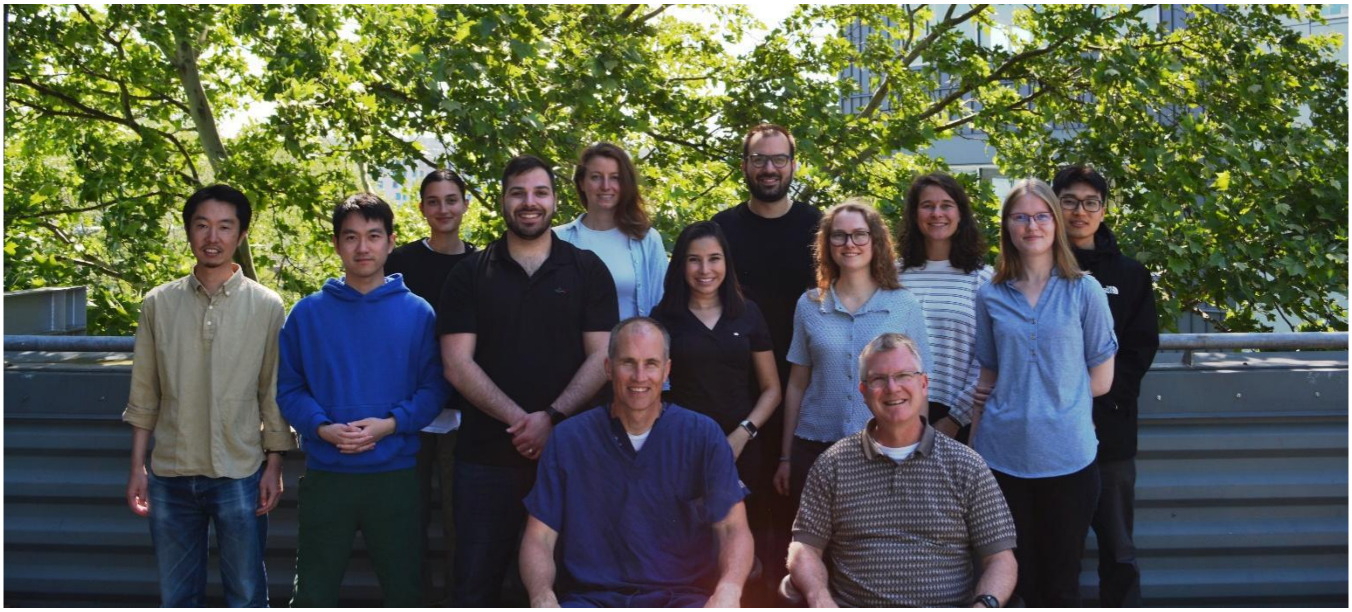
ORTHOPAEDIC ROBOTICS LABORATORY

2024 SUMMER STUDENT ABSTRACT BOOKLET

FOREWARD

The Orthopaedic Robotics Laboratory is the University of Pittsburgh's newly formed collaborative effort between the Department of Bioengineering and the Department of Orthopaedic Surgery. The mission of the ORL is the prevention of degenerative joint diseases by improving diagnostic, repair, and rehabilitation procedures for musculoskeletal injuries using state-of-the-art robotic technology. The ORL would like to commend the work of the students during the summer of 2024. Students made significant impacts in the study of shoulder and knee degenerative joint diseases. The work of our students, with the help of our mentors, contributes greatly to the field of Orthopaedic Research and to all patients who benefit.

OUR TEAM



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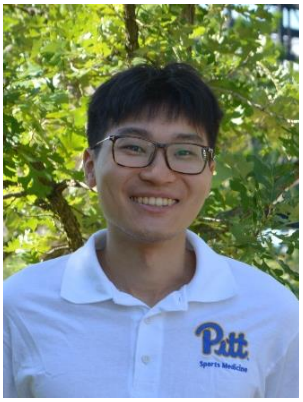

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TABLE OF CONTENTS

Glenohumeral Anterior-Posterior Translation Range Is Not Associated with Rotator Cuff Muscle Strength Ratio in Individuals with Symptomatic Isolated Supraspinatus Tears Prior to Exercise Therapy

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INTRODUCTION: The dynamic stabilizers of the glenohumeral joint, particularly the rotator cuff muscles, play a crucial role in maintaining joint stability during shoulder motion. For example, in the transverse plane, the subscapularis translates the humeral head anteriorly and medially, while the infraspinatus and teres minor translate the humeral head posteriorly and medially in relation to the glenoid, forming the transverse force couple of the rotator cuff[1,2]. A balanced transverse force couple might minimize glenohumeral anterior-posterior translation, potentially informing clinicians in the design of nonoperative treatment protocols for individuals with shoulder muscle strength deficits caused by rotator cuff tears[4]. Therefore, the objective of the study was to investigate the relationship between the strength ratio of the transverse force couple (i.e. [infraspinatus + teres minor]/subscapularis) and the range of glenohumeral anterior-posterior translation during scapular plane abduction in individuals with partial- or full-thickness symptomatic rotator cuff tears isolated to the supraspinatus tendon prior to an exercise therapy program. It was hypothesized that there would be a non-linear relationship between the strength ratio and the range of glenohumeral anterior-posterior translation in groups of individuals with partial- or full-thickness supraspinatus tears.

METHODS: Seventy-nine subjects with a symptomatic rotator cuff tear isolated to the supraspinatus tendon (age 59.4 ± 9.2 years; BMI 28.1 ± 4.9 kg/m²; 28 with partial tears, 51 with full-thickness tears) provided IRB-approved consent before participating in any research procedures. Subjects' isometric strength and in-vivo glenohumeral kinematics were measured prior to a personalized exercise therapy program. Isometric shoulder external and internal rotation strength was assessed by a physical therapist using a hand-held dynamometer with the subjects seated and their affected arm positioned at 0° of humerothoracic abduction and 90° of elbow flexion. Internal rotation strength testing assessed the strength of the subscapularis, while external rotation strength testing assessed the strength of the infraspinatus and teres minor[5,6]. The average strength ratio of the transverse force couple ([infraspinatus+teres minor]/subscapularis)*100% was then calculated across three trials. In-vivo glenohumeral translations during scapular plane abduction were collected using bi-plane radiography and a previously validated model-based tracking technique, with an accuracy of ±0.4 mm[3,4]. The glenohumeral anterior-posterior translation range was then calculated by summing the maximum anterior and posterior glenohumeral translations during the entire movement. Glenohumeral translations were normalized to glenoid width to account for differences in bony morphology between individuals. Polynomial regressions were utilized to determine the associations between the strength ratio and the range of glenohumeral anterior-posterior translation. Significance was set at $p < 0.05$.

RESULTS: The strength ratio for cohorts with partial- and full-thickness supraspinatus tears was 80.9 ± 37.2% (range: 25% to 208%) and 69.4 ± 21.2% (range: 29% to 123%), respectively. In 90% of the subjects (71/79), the strength ratio was less than 100%. The range of glenohumeral anterior-posterior translation for cohorts with partial- and full-thickness supraspinatus tears was 9.3 ± 3.6% (range: 2.1% to 17.4%) and 9.3 ± 5.4% (range: 0% to 26.8%) of glenoid width, respectively. Polynomial regression results indicated that the range of glenohumeral anterior-posterior translation was not associated with the strength ratio in those with partial tears [$F(2,25) = 0.380$, $p = 0.688$] or full-thickness tears [$F(2,48) = 1.929$, $p = 0.156$] (Figures 1 and 2).

DISCUSSION: The major finding of the current study was that the range of glenohumeral anterior-posterior translation was not associated with the strength ratio of the transverse force couple during scapular plane abduction in individuals with a partial- or full-thickness symptomatic tear isolated to the supraspinatus prior to exercise therapy. Thus, the current finding refutes our hypothesis. A possible explanation for the lack of association is that, with an isolated supraspinatus tear and the transverse force couple intact and not seriously deficient, the humeral head remains well-compressed centrally in the glenoid, resulting in minimal glenohumeral anterior-posterior translation, similar to that observed in healthy shoulders[3,4]. A wide variability in translation range could be explained by the complexity of the shoulder girdle (e.g. bony geometry), as well as the inevitable impact of other shoulder musculature on isometric strength tests. Since our study concluded that glenohumeral anterior-posterior translation is not affected by the strength ratio of the transverse force couple, previous studies on healthy shoulders suggesting an approximately 70% strength ratio might be instructive when designing nonoperative treatment protocols[7,8], ensuring it does not exceed 100% when considering the volume of the subscapularis relative to the infraspinatus and teres minor[9]. Most importantly, clinicians should emphasize enhancing overall shoulder strength and function relative to the contralateral arm. Future work will investigate this relationship in cohorts with serious shoulder strength deficits, where a balanced transverse force couple might be key to maintaining shoulder stability.

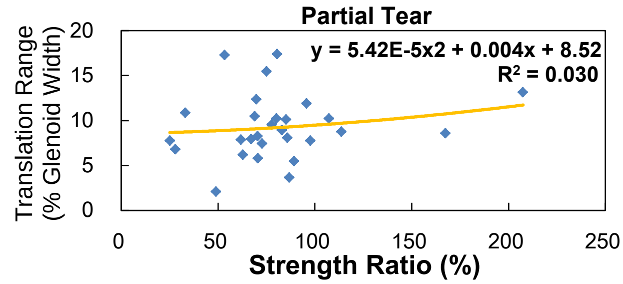

Figure 1. Relationship between the strength ratio ([infraspinatus+teres minor]/subscapularis)*100% and the range of glenohumeral anterior-posterior translation in subjects with partial supraspinatus tears.

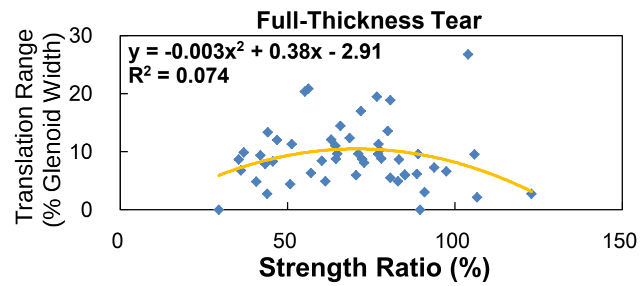

Figure 2. Relationship between the strength ratio ([infraspinatus+teres minor]/subscapularis)*100% and the range of glenohumeral anterior-posterior translation in subjects with full-thickness supraspinatus tears.

CLINICAL RELEVANCE: When designing nonoperative treatment protocols for individuals with rotator cuff tears isolated to the supraspinatus tendon, clinicians should emphasize enhancing overall shoulder strength and function relative to the contralateral arm, since glenohumeral anterior-posterior translation is not affected by the strength ratio of the transverse rotator cuff force couple.

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ACKNOWLEDGEMENTS: Support from the National Institutes of Health grant 5R01AR069503 is gratefully acknowledged.

Evaluating the Accuracy of the Current Algorithm for Planning Anterior Closing Wedge High Tibial Osteotomies

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INTRODUCTION: An anterior closing wedge high tibial osteotomy (HTO) is an orthopedic procedure which corrects excessive posterior tibial slope (PTS) by removing a wedge of bone in the anterior proximal tibia. High PTS is associated with increased risk of anterior cruciate ligament (ACL) injury and failure of ACL reconstruction [1-2]. For these reasons a closing wedge anterior HTO can be performed to potentially prevent repeated ACL injury. Anterior HTOs are usually planned geometrically on a strict lateral radiograph with some algorithms using the relationship that 1 mm of wedge removed equates to 1° of correction [3- 4]. Recently researchers and companies have been developing planning software and patient specific instruments to improve the accuracy of angle corrections [5-6]. However, these methods sometimes result in undesired corrections [7]. The objective of this study was to assess the accuracy of the algorithm used to plan anterior closing wedge HTOs, assuming that the tibia acts as a rigid body. It was hypothesized that the current planning techniques will result in an accurate correction on rigid body models.

METHODS: The geometry of eight tibias (all left knees) was utilized from a previous study that constructed the geometry from computed tomography (CT) scans (Mimics, Materialize) [8]. The tibias were aligned with a rotation matrix using the most medial and lateral points on the condyles and center of shaft (MATLAB, MathWorks) to obtain a lateral image. The initial medial and lateral PTSs were measured using the double circle method previously established [9]. The cuts were planned for a supra-tubercle osteotomy with preservation of the posterior hinge (Figure 1) [10]. The target was to reduce the mean of the medial and lateral PTS to 0° for each bone model. The models were cut along the planned lines, the wedge was removed, and the superior portion of the tibia was rotated about the axis of rotation until the upper and lower cut planes met (3-matic, Materialize). The corrected PTS was measured using the same method stated above (Figure 2). The anterior height of the removed wedge was measured. The corrected medial and lateral PTSs were averaged to find a mean slope for each tibia model. Correction error was defined as deviation of the average slope from 0°. The wedge height ratio was taken as the anterior height of the wedge over the measured correction. One sample t-tests were used to test if the corrections were significantly different from the target of 0° and if the ratio was different from 1 mm/ 1°. Significance was set at $p<0.05$.

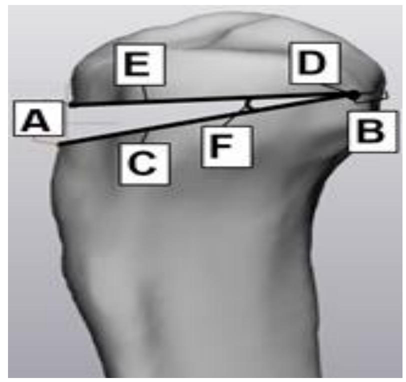

Figure 1. A) Wedge height; B) posterior hinge; C) Lower cut plane planned from point directly above tubercle to axis of rotation (AOR); D) Location of hinge is approximately 1 cm from posterior cortex in 2 directions; E) Upper cut plane planned from AOR; and F) rotated target angle from the lower cut plane.

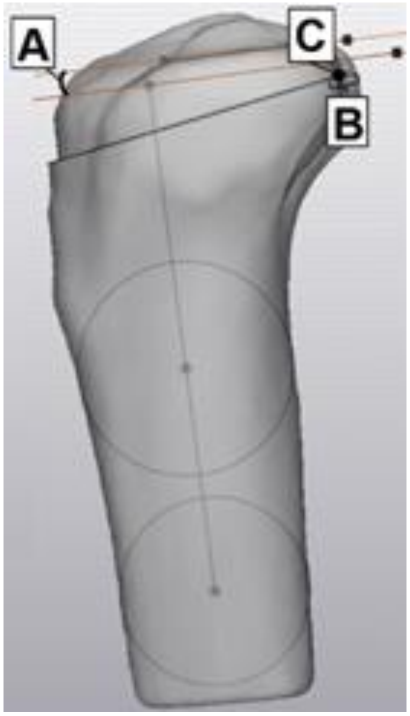

Figure 2.
A) Posterior Tibia Slope;
B) Posterior hinge; and
C) Axis of rotation (AOR) at center of hinge

RESULTS: The initial PTS ranged from 2° to 10°. The PTS following correction ranged from -0.6° to 0.8° with 2 tibias overcorrected and 5 under- corrected. The correction error was 0.3° ± 0.3°. The mean wedge height ratio was 1 mm/degree ± 0.1 mm/degree. The wedge ratios ranged from 0.8 to 1.1 mm/degree (Table 1). A statistically significant difference was found between the correction error and 0° ($p=0.006$) and no statistically significant difference was found between the sample wedge height ratio and 1 mm/degree ($p=0.732$).

Table 1. Average posterior tibial slope of both compartments for each tibia model after correction

Tibia	Average Slope (°)	Measured Correction (°)	Wedge Height (mm)	Wedge Ratio (mm/ °)
1	0.2	9.8	10.1	1.0
2	0.2	7.5	7.2	1.0
3	0.8	8.1	8.6	1.1
4	-0.1	9.0	7.4	0.8
5	0.0	4.2	3.8	0.9
6	0.3	1.7	1.9	1.1
7	0.3	9.7	9.4	1.0
8	-0.6	7.5	7.4	1.0

DISCUSSION: The findings support the use of the current algorithm for planning anterior closing wedge HTOs supra-tubercle with preservation of the posterior hinge assuming the tibia is rigid. Although a statistically significant error was found in the corrections, the mean correction error was only 0.3°. This error is lower than the repeatability of measuring PTS [11]. The assumption of 1 mm/degree for the wedge height ratio was also upheld for supra-tubercle HTOs. Factors that may affect this ratio's applicability include surgical differences such as the amount of posterior cortex remaining intact and patient-related differences such as tibia size. Discrepancy in the correction angle observed clinically may be the result of assuming the tibia acts as a rigid body. Deformation may occur at the hinge changing the accuracy of corrections. Thus, future studies will use finite element analysis to examine deformation in the proximal tibia during anterior HTOs and the effect of this deformation on the slope correction.

CLINICAL RELEVANCE: Assuming that the tibia acts as a rigid body, the current planning techniques for closing wedge HTO should result in accurate corrections. Inaccurate corrections during this procedure may be the result of tibia acting as deformable body.

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Changes in Tibial Articular Cartilage Thickness in a Porcine Model Through Skeletal Maturation

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INTRODUCTION: Chondral lesions are the most prevalent injuries in skeletally immature patients who have experienced acute knee trauma and considerably increase the risk of developing osteoarthritis as an adult[1,2]. In order to evaluate and treat osteochondral and chondral lesions, it is important to understand the morphology of the cartilage. Osteochondral allografts are a restoration procedure for osteochondral lesions and require matching a graft to a donor site with consideration of both size and topography to maintain a normal contact pressure[3]. Thus, it is crucial to determine the site for allograft extraction with appropriate morphological factors such as thickness. However, not many studies have been conducted on how the thickness of tibial articular cartilage changes in children and adolescents as they age. The objective of this study is to determine how the cartilage thickness at the tibial plateau changes through skeletal maturation in a porcine model and create a comparison between the lateral and medial condyles.

METHODS: This study used 47 MRI data sets for porcine knees from previously published data generated from an NIH grant, taken at 1.5, 3, 4.5, and 18 months of age. Each age group consisted of approximately 6 male and 6 female pigs. For each specimen, a 3D model was generated from the articular cartilage located on the tibial plateau in Materialize Mimics version 25. The lateral and medial plateaus were identified and labeled for each knee. The 3D model of the cartilage was then exported into MeshLab version 2020.07 where the Shape Diameter Function was applied with an opening angle of 60° to measure the thickness of the cartilage. In MATLAB, the tibia cartilage model was imported as a mesh and divided into four quadrants: Anterior Lateral (AL), Anterior Medial (AM), Posterior Lateral (PL), and Posterior Medial (PM). The maximum and average thickness were calculated for each quadrant. The locations of maximum thicknesses were determined and marked on the 3D model of the tibial plateau.

RESULTS: The locations of the maximum thickness were all consistently on the outer edges of the plateaus (Figure 1) and ranged from 3 to 10 times greater than the average thickness of their respective quadrant. The average cartilage thickness of the lateral condyle ranged from 4.5 mm in the anterior lateral quadrant at 1.5 months to 1.3 mm in the posterior medial quadrant at 18 months (Figure 2). The cartilage thickness of the medial plateau ranged from 3.3 mm in the posterior lateral quadrant at 1.5 months to 1.3 mm in the posterior lateral quadrant at 18 months. However, on the medial plateau, the thickness of both the AM and PM quadrants increased slightly between 4.5 months and 18 months. For both the medial and lateral plateau, the lateral halves of the plateau are thicker than the medial halves at all ages other than 18 months. The cartilage on the anterior halves of the plateaus is also thicker than the cartilage on the posterior for the first three age groups with the exception of the AM and PM quadrants on the medial plateau at 3 months. The order from thickest to thinnest remains AL, PL, AM, PM for the first three age groups.

DISCUSSION: These results show both an inverse relationship between cartilage thickness and age and that the lateral plateau has a higher cartilage thickness. This indicates that a younger subject would experience smoother movement and more shock absorption because of the thicker layer of cartilage, making them less prone to injury. The lateral plateau likely has a higher thickness due to the load distribution of the joint. At earlier stages of maturation, the lateral tibial plateau may experience greater or more variable loads, leading to a thicker layer of cartilage being required to absorb them and protect the joint. The result also demonstrates that cartilage thickness is not the same along the four quadrants on each plateau during childhood and adolescence in a porcine model but becomes evenly distributed when matured. This means that trends about knee joint function found in studies conducted on fully mature subjects may not apply to children or adolescents.

CLINICAL RELEVANCE: When performing an osteochondral allograft, it would be important to find a donor from the same age group as the recipient and matching the laterality of the plateau for the best topographical match.

REFERENCES: 1. Oeppen et al. AJR, 2004 2. Gelber et al. AIM, 2000 3. Wang et al. AJSM, 2018

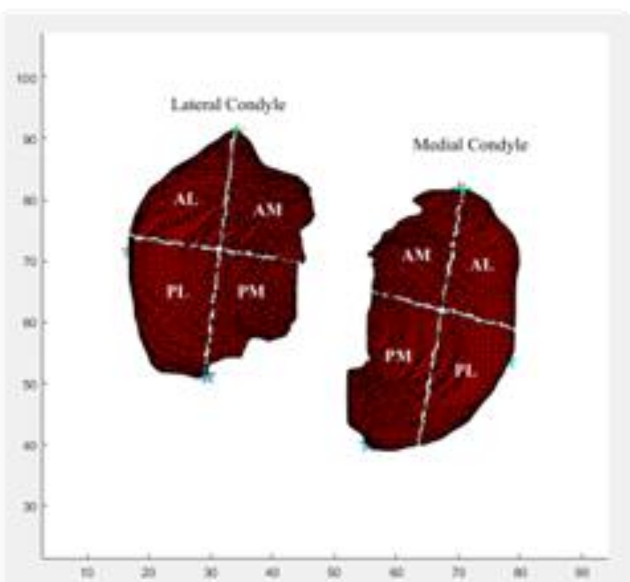

Figure 1. Mesh of tibial plateau cartilage with labeled condyle quadrants and locations of maximum thickness

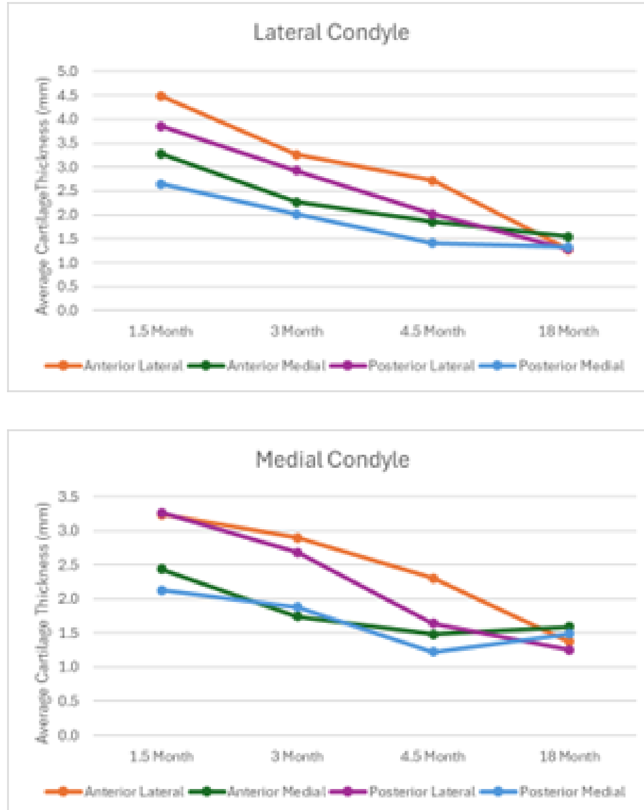

Figure 2. Average cartilage thicknesses of the four quadrants of the lateral and medial condyle at each time point

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