# UNIVERSITY OF PITTSBURGH

# ORTHOPAEDIC ROBOTICS LABORATORY

## 2019 SUMMER UNDERGRADUATE ABSTRACT BOOKLET

PITT | SWANSON ENGINEERING
BIOENGINEERING

ORL
Orthopaedic Robotics Laboratory

DEPARTMENT OF ORTHOPAEDIC SURGERY
UNIVERSITY OF PITTSBURGH

# FOREWORD

The Orthopaedic Robotics Laboratory is a collaborative effort between the Department of Bioengineering and 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 undergraduate students during the summer of 2019. Students made significant impacts in the study of shoulder and knee injuries. The work of the students, with the help of their mentors, contributes greatly to the world of Orthopaedic Research and to all patients who benefit.

# OUR TEAM
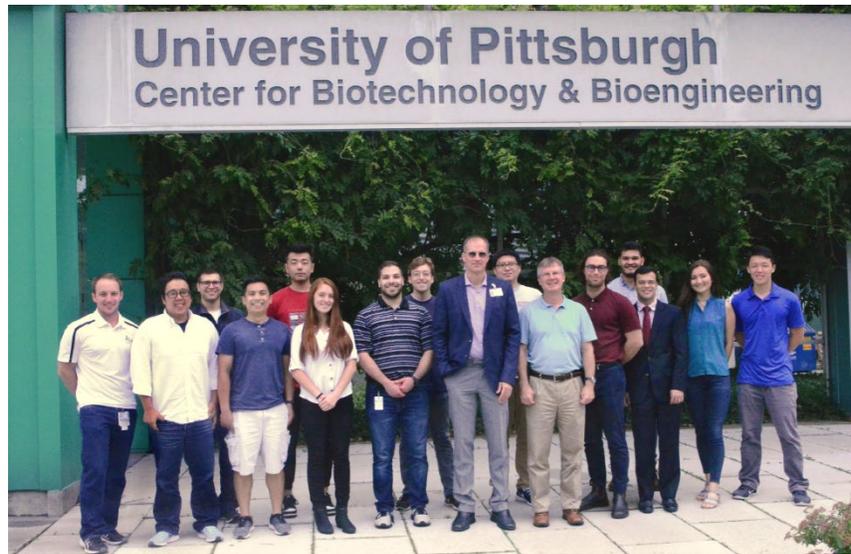




**Michael Kassabian**
Class of 2020
Bioengineering
University of Pittsburgh



**Jacqueline Mchale**
Class of 2021
Bioengineering
University of Pittsburgh



**Jocelyn Hawk**
Class of 2020
Bioengineering
University of Pittsburgh

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# Quantifying 3D Volume of Glenohumeral Capsule Following a Shoulder Dislocation from Clinical MR Arthrogram Data

Jocelyn L. Hawk[1], Robert T. Tisherman[2], Christopher M. Gibbs[2], Volker Musahl[2,1],
Albert Lin[2], Richard E. Debski[1,2]

University of Pittsburgh, [1]Department of Bioengineering and [2]Department of Orthopaedic Surgery

**Introduction:** The glenohumeral joint is the most commonly dislocated joint, usually by an anterior shoulder dislocation [1]. This type of injury can result in permanent deformation of the glenohumeral capsule, which causes greater capsular laxity and increased capsular volume [2]. A common surgical procedure to reduce capsular volume is capsular plication, but currently, how the capsule is plicated is largely subjective without taking into account the magnitude and location of non-recoverable strain in the capsule. Thus, there exists a need to quantify injury to the glenohumeral capsule and individualize surgical repair. It is currently unknown whether changes in capsular volume following a shoulder dislocation can be quantified using MR arthrogram. Therefore, the aim of this study is to reconstruct 3D models of the glenohumeral capsule from MR arthrogram to assess capsular volume in healthy patients and patients who have undergone one or more anterior shoulder dislocations.

**Methods:** MR arthrograms of the glenohumeral joint in healthy subjects (n=8) and subjects that had sustained at least one anterior shoulder dislocation (n=8) were acquired. The capsular space was defined as the space within the glenohumeral capsule filled with the contrast agent during the MR arthrogram. The capsular space, humerus, and glenoid were segmented in MIMICS (version 17.0, Materialise NV, Belgium) from the coronal, sagittal, and axial view for each subject. This created a mesh, a 3D model made up of triangles, for each view of each subject. Meshes created from each view were then combined in MeshLab by overlaying them (version 1.3.4, ISTI, Italy) to make a higher resolution mesh for each subject **(Figure 1)**, and the volume of the capsular space was determined using MeshLab. The volume of the capsular space was also calculated with the superior portion removed because the inferior region of the capsule was expected to experience the greatest injury. This was standardized between subjects by removing any capsular space above the greater tuberosity of the humeral head. These volumes were then normalized to the size of the humeral head by fitting a sphere to the humeral head and dividing the capsular volume by the radius of the sphere cubed. The capsular volumes of each group were compared with a two-sample t-test with significance set at $p<0.05$.
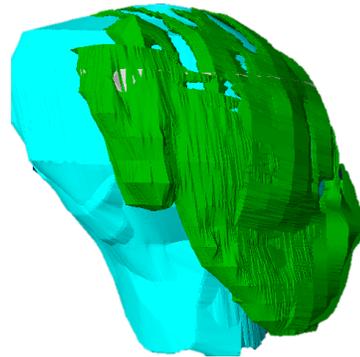


**Figure 1:** Posterior view of a 3D reconstruction of the glenohumeral capsular space (green) and humeral head (blue).

**Results**: The average total capsular volume of the injured group was found to be 65% larger than the capsular volume of the healthy group (p=0.027) **(Figure 2)**. There was no significant difference in capsular volume when the superior part of the capsule was removed **(Figure 3)**. A power analysis was conducted for capsular volume with the superior portion removed, and a total of 26 more subjects would be needed for the results to be significant.
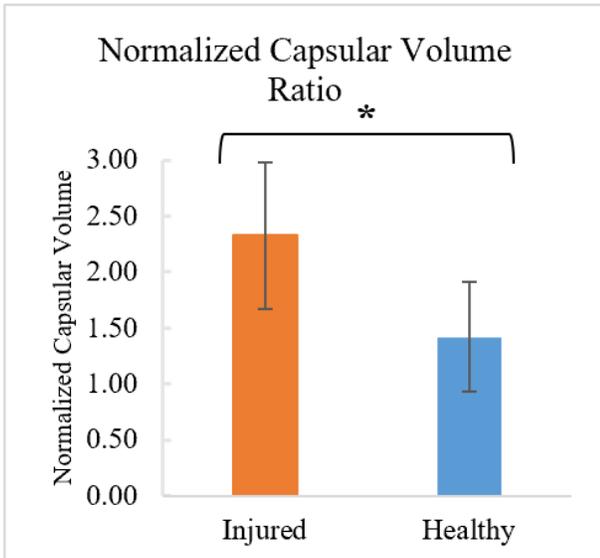
**Figure 1:** Total glenohumeral capsular volume in healthy and injured subjects calculated from 3D reconstruction of MR arthrogram. The normalized volume was 65% larger in the injured subjects than in the healthy subjects.
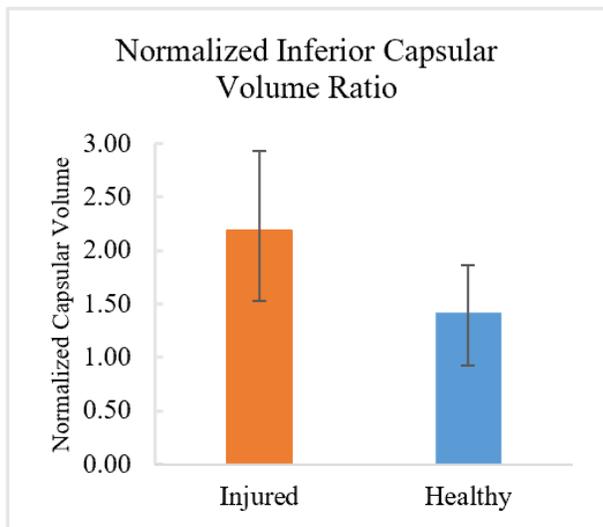


**Figure 2:** Glenohumeral capsular volume with superior portion removed in healthy and injured subjects calculated from 3D reconstruction of MR arthrogram. No significant difference in normalized volume was found between healthy and injured subjects

**Discussion:** 3D models of the capsular space for the glenohumeral joint were successfully reconstructed from MR arthrograms and were able to show a significant difference in capsular volume between healthy and injured subjects. The findings of this study are consistent with previous literature in that capsular volume was found to increase following a shoulder dislocation [3]. This is due to the capsule becoming stretched out and permanently deformed during the dislocation. This study has shown that capsular volume can be quantified by 3D reconstruction of MR arthrogram. This method was able to quantify total capsular volume but may not be ideal for examining injury to specific regions of the capsule due to the large slice thickness of the MR arthrograms that was used to create the models. Also, the joint position and amount of contrast agent injected into the joint was not standardized between subjects. Future studies should utilize a methodology to assess injury to specific regions of the capsule by determining the volume of each specific region of the capsule following a shoulder dislocation. By quantifying capsular injury using MRI, surgical repair to the glenohumeral capsule following a shoulder dislocation can be individualized from patient to patient. Injury specific repair could reduce the chance of recurrent shoulder instability, improving the life of the patient.

**References:** 1. Abrams et al. JBJS. 2014 2. Park et al. 2014. 3. Dietz et al. 2005. KSSTA

# How Bony Morphology Affects Tibiofemoral Contact Pressure Through Intact, ALCD, and LET States at Different Angles of Flexion

Jacqueline McHale[1], Sene Polamalu[1], Luke Mattar[1], Gerald Ferrer[1], Calvin Chan[1],
Volker Musahl[2,1], Richard Debski[1,2]

1. Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA, United States.
2. Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA, United States

**INTRODUCTION:** Injuries of the anterior cruciate ligament (ACL) have a high prevalence of approximately 200,000 cases each year, and 42% of ACL reconstructions lead to osteoarthritis [1]. There are many risk factors that can lead to this injury, such as individual level of activity, sex, age, and bony morphology [1]. The anterolateral capsule (ALC) is a complex system of tissue that provides rotational stability, much like the ACL. Injuries of the ACL are concomitant with ALC injuries, which often occur when increased rotational knee instability happens [2]. Lateral extra-articular tenodesis (LET) is done to provide further rotational stability post-injury [3]. This is a process of inserting graft to replicate anterolateral ligament anatomy. At 90° flexion, LET knees reduced contact area in the medial compartment relative to intact knees [3]. This could be attributed to tibiofemoral bony morphology. Studies show that males and females with increased lateral tibial plateau slope experienced more ACL injuries, and males with increased medial tibial plateau slope had more ACL injuries [4]. From this finding it can be observed that greater plateau slope increases risk of ACL injury [5]. The objective of this study is to determine the effect of lateral and medial tibial plateau slopes on tibiofemoral contact pressure in response to 134 N anterior load and 200 N axial compression at intact, anterolateral capsule deficient (ALC), and LET states at 0°, 30°, 60°, and 90° flexion.

**METHOD:** To investigate how tibial bony morphology affects contact pressure before and after LET, bone models must first be constructed. In this study, 8 cadaveric CT scans of tibias and femurs were used. They were then segmented using Mimics and tibial plateau slopes were measured. In order to segment bones, a mask was created from the CT scan that outlined the bone, which could be observed in the coronal, sagittal, and axial perspectives. After cavity filling, or automatically filling in each part of the bone where the perimeter mask was intact, there were still holes that needed to be manually filled in. This was done slice by slice, each slice thickness being 0.63 mm, in the axial view. After the mask was complete, a part was calculated from the mask. This develops a 3D model of the completely segmented bone. Lastly, the bone's contours were edited to become smoother and replicative of a healthy bone (Fig. 1).
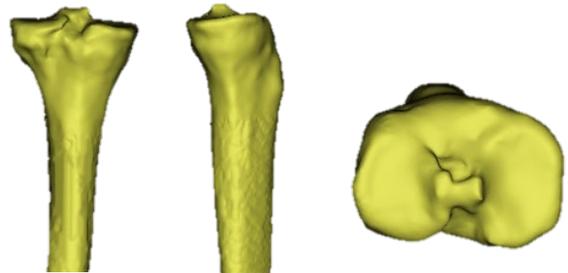


**Figure 1:** Coronal, sagittal, and axial views of the smoothed 3D tibia.

From the CT scan segments in the sagittal plane, the tibial plateau slopes can be measured (Fig. 2) [6]. This was done by determining the long axis and its orthogonal line for reference. Then, in both the bone's medial and lateral sides, the tangent line was created. This tangent line began at the peak of the lateral or medial rim and ended at the orthogonal line. The angle between this was the tibial plateau slope, and was recorded.

**Figure 2:** Axial and sagittal views of the tibia, including the medial and lateral angles that were taken [6].

A correlational analysis was carried out between medial plateau slope, lateral plateau slope, and plateau slope differential and peak contact pressure, mean contact pressure, and contact area at intact, ALCD, and LET states at 0°, 30°, 60°, and 90° ($p<0.05$). Normality was tested through Shapiro-Wilk W Test and transformations were performed to normalize the data.

**RESULTS:** The measurement angles that can be seen in Table 1 showed that the tibial lateral angles were on average 2.6° greater than the tibial medial angles.

| | Specimen 1 | Specimen 2 | Specimen 3 | Specimen 4 | Specimen 5 | Specimen 6 | Specimen 7 | Specimen 8 | Average Angles: |
|---|---|---|---|---|---|---|---|---|---|
| Sagittal view angle° (medial) | 4.1 | 5.7 | 2.9 | 7.3 | 7.7 | 1.7 | 6.5 | 2.9 | **4.8** |
| Sagittal view angle° (lateral) | 8.5 | 7.3 | 4.3 | 8.8 | 8.9 | 5.9 | 7.8 | 8.3 | **7.5** |

**Table 1:** Medial and lateral tibial plateau slope angles of the 8 cadaveric specimens.

Out of these tests, no statistical correlational was found. One of the correlational graphs, of the Slope Differential by Contact Area 0° ALCD, showed that the correlation r was -0.609, and the p was 0.11. Power Analysis determined that 18 specimens were needed to generate a more accurate result.

**DISCUSSION:** As stated in the Power Analysis, 10 more specimens are needed to further this study. It is concluded that the 2D tibial slopes both in medial and later sides did not correlate with contact pressure data in intact, ALCD, or LET states.

Some limitations of this study included a scan of a bone that was deformed and choppy, even when smoothed. The cadaver had visible cracks; therefore, it was not included in the study. In addition, some bones had prominent tunnels from the LET procedures that made it difficult to segment (Fig. 3). To generate an accurate mask, estimates on where to fill the hole were made by considering the surrounding bone.
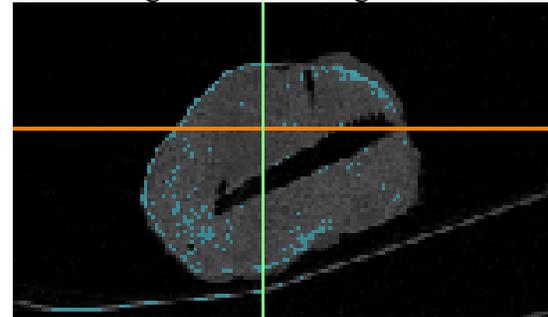


**Figure 3:** Axial view of cadaveric tibia CT scan, with Mimics mask, where a prominent hole can be observed.

The CT scans were taken at an oblique angle. The tibial cadaveric images were not scanned straight, and the orthogonal line had to be made to match with the skewed angle of the bone.

With the models and measurements that were made, statistical shape modeling on cadaveric knees can be further investigated. In addition, other bony morphology differences can be considered to provide an explanation on ACL or ALC injury that can be explained by making femoral measurement comparisons as well.

**REFERENCES:** [1] Kessler et al. KSSTA. 2008 [2] Neri. ACLSG. [3] Novaretti et al. 2019 [4] Hashemi et al. JBJS. 2008 [5] Pfeiffer et al. JBJS. 2018 [6] Hashemi et al. AJSM. 2009

# Plane of Elevation Affects Maximum External Rotation in Subjects With Isolated Supraspinatus Tears

Michael Kassabian[1], Luke Mattar[1], Camille Johnson[2], Tom Gale[2], James Irrgang[3], William Anderst[2], Volker Musahl[2,1], Richard Debski[1,2]

1. Department of Bioengineering, University of Pittsburgh, Pittsburgh, PA, United States.
2. Department of Physical Therapy, University of Pittsburgh, Pittsburgh, PA, United States.
3. Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA, United States.

**INTRODUCTION**: Rotator cuff tears affect more than 20% of the population and have increasing prevalence with age[1,2]. Non-operative treatment is often initially prescribed to patients with rotator cuff tears and focuses on strengthening the rotator cuff and scapular muscles[3]. High treatment failure rates have been reported for non-operative treatment and can result in pain and disability emphasizing the need to improve upon current treatment methods[4]. It is known that in healthy subjects, external rotation of the glenohumeral joint is accompanied by scapular external rotation[5]. This coordinated glenohumeral motion maintains the humeral head in the center of the glenoid[6]. Rotator cuff tears can alter shoulder kinematics resulting in decreased functionality. The objectives of this study were to determine the relationship between glenohumeral kinematics and maximum glenohumeral external rotation (ER) pre- and post-exercise therapy in subjects with an isolated supraspinatus tear during glenohumeral internal and external rotation at 90 degrees of humerothoracic abduction.

**METHODS**: Twenty subjects (mean age 58.6±7.2 years, mean BMI 26.9±4.8) with a symptomatic rotator cuff tear isolated to the supraspinatus tendon were recruited for the study after providing IRB-approved written informed consent. All subjects participated in a 12-week structured exercise therapy program. Glenohumeral kinematics were collected using a dynamic stereoradiography (DSX) system pre- and post-exercise therapy. Subjects were seated with the affected side glenohumeral joint at the focal point of the DSX system. Subjects' arms were positioned on a stand at 90 degrees of humerothoracic abduction and 90 degrees of elbow flexion and were asked to perform an external rotation task. The DSX provided frame-by-frame images of the subjects' scapula and humerus throughout the external rotation task. Outcome parameters included glenohumeral external rotation, elevation, and plane of elevation. Changes in glenohumeral kinematics were calculated as post-exercise values minus pre-exercise therapy values. Shapiro-Wilk was used to test for normality and a paired T-test or Wilcoxon Signed Rank Test was used to compare rotators before and after exercise therapy. A Spearman correlation was conducted to determine the relationship between glenohumeral elevation and glenohumeral external rotation as well as glenohumeral plane of elevation and glenohumeral external rotation. Significance was set at $p<0.05$.

**RESULTS**: There was a significant increase in the maximum glenohumeral external rotation post exercise therapy of 4.3±8.0 degrees (Table 1). There was, however, no change in plane of elevation or glenohumeral elevation angles at maximum external rotation. Of the twenty subjects tested, 65% gained external rotation post-exercise therapy and 35% lost external rotation. Those subjects that increased, gained 9.1±4.7 degrees of glenohumeral external rotation and those that decreased lost an average of 5.5±2.9 degrees. No significant correlation between change in glenohumeral elevation and change in maximum glenohumeral external

rotation (figure 1. R=0.43, $R^2$=0.18, p=0.053), but there was a moderate positive correlation between change in glenohumeral plane of elevation and change in maximum glenohumeral external rotation (figure 2. R=0.58, $R^2$=0.34, p<0.01). An increase in glenohumeral plane of elevation during the external rotation task correlated to an increase in maximum glenohumeral external rotation.

**DISCUSSION**: The results suggest that increased glenohumeral plane of elevation may result in increased maximum external rotation. Increased glenohumeral plane of elevation may be due to either an increase in humerothoracic horizontal adduction, or scapulothoracic external rotation. Subjects' arms were held in place so this increase in glenohumeral plane of elevation is likely caused by scapular external rotation.

Those subjects that increased glenohumeral plane of elevation increased their maximum glenohumeral external rotation by 9.1 degrees suggesting that increased plane of elevation is an important factor in external rotation tasks. In operative interventions rotator cuff patients can take up to a year after surgery to fully recover external rotation[7]. The 12-week structured exercise therapy could be considered successful if it is determined that increased maximum external rotation was caused by strengthening lower serratus anterior muscles leading to increased scapular external rotation. Future studies will determine what role scapulothoracic motions plays in this observed glenohumeral motion.

**SIGNIFICANCE**: These findings provide rationale to further examine scapulothoracic and humerothoracic motion for predictors that might distinguish those subjects that would or would not benefit from non-operative interventions. This could provide information that may help create a functional rotator cuff index for subjects with isolated supraspinatus tears to help best determine treatment.

**REFERENCES**: [1] Yamamoto A et al. J Shoulder Elb Surg 2010, [2] Minagawa H et al. J Orthop 2013, [3] Kuhn et al. JSES 2009, [4] Duquin et al. AJSM 2010, [5] McClure et. al. 2001, [6] Sgroi, Cilenti 2018, [7] Harris J. et al. Orthopedics 2013.

**IMAGES AND TABLES**:

|  | Pre | Post | p |
|---|---|---|---|
| **Maximum ER (°)** | 92.6±12.0 | 96.9±12.9 | 0.031 |
| **Elevation at Max ER (°)** | 54.2±10.7 | 55.0±10.1 | 0.581 |
| **Plane of Elevation at Max ER (°)** | -0.4±15.9 | 1.4±14.5 | 0.366 |

**Table 1.** Average rotation angles for pre- and post-exercise therapy and the significant differences.
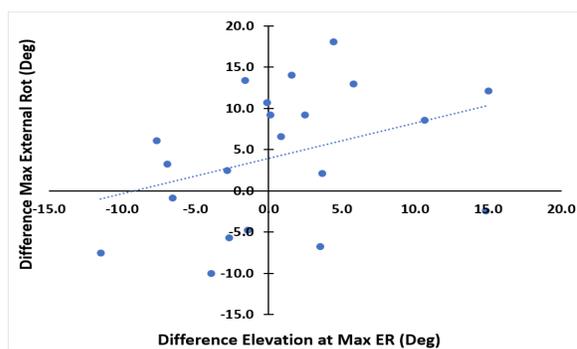


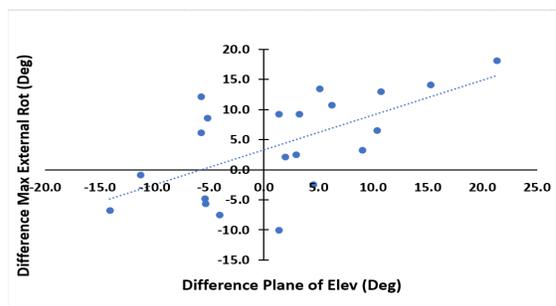**Figure 1.** Change in Elevation Vs. Change in Max External Rotation



**Figure 2.** Change in Plane of Elevation Vs. Change in Max External Rotation

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