# Quantitative Assessment of the Rotator Cuff and Superior Capsule Insertion Site Morphology

by

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Michael Patrick Smolinski, M.S.

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The goal of the project was to quantify measurements of the insertion of the rotator cuff muscles and superior capsule in three-dimensions.

Cadaveric specimens were dissected down to the level of the rotator cuff/capsular complex. Each of the four rotator cuff muscles (subscapularis, supraspinatus, infraspinatus, and teres minor) were removed individually from the humerus and marked, followed by the superior capsule on the humerus and scapula. A laser scanning system was to make three-dimensional models of each of the specimen. The perimeter of each insertion was also digitized with a probe and incorporated into the models. The surface area and centroid of each insertion were calculated and measurements along the surface of the longest dimension and perpendicular dimension through the centroid as well the distance from the centroid to the apex of the bicipital groove were made.

The infraspinatus had the largest insertion area at 277.7 $mm^2$, followed by the subscapularis (262.8 $mm^2$), the teres minor (251.0 $mm^2$), and the supraspinatus had the smaller insertion area (133.7 $mm^2$).

The subscapularis, infraspinatus, and teres minor have larger insertions areas on the humerus when compared to the supraspinatus.

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## Preface

First, I would like to thank my advisors for their guidance and support: Dr. Chris Schmidt, Dr. Mark C. Miller, and Dr. Jeen-Shang Lin, and my advisor Dr. Qing-Ming Wang. I could not have asked for better mentors during my time as a graduate student. I would also like to thank the graduate students and lab managers I worked with in the lab: Sean Delserro, Tyler Madonna, Chris Spicer, Ryan Blake, Anthony Davidson, and Jamie Greenwell. I would like to thank orthopaedic Fellows Georgios Panagopoulos and Luis Carrazana-Suarez for their help. Finally, I would like to thank all my friends and family for their support and encouragement.

# 1.0 Introduction

## 1.1 Motivation

This study measured the insertions of the rotator cuff and superior capsule on the humerus and scapula. The structure of the rotator cuff has been well studied through gross anatomic dissection and histologically, specifically by Clark and Harryman, who have described the rotator cuff as a composite structure of the capsule, ligaments, and tendons that surround the shoulder joint.[1] More commonly, this structure is described from anterior to posterior as four muscles: subscapularis, supraspinatus, infraspinatus, and teres minor. Clinically, degenerative rotator cuff tears generally occur at the insertion of rotator cuff, 13 to 17 mm posterior to the biceps tendon, more specifically at the insertions of the supraspinatus and infraspinatus on the greater tuberosity.[4]

## 1.2 Goals

The goal of this project was to use advanced measurement techniques to quantitatively describe the insertions of the four tendons of the rotator cuff and superior capsule in three dimensions. The results could give surgeons a better understanding of the function and injury mechanisms of these soft tissues and guide new repair techniques that can be used to improve surgical outcomes.

# 2.0 Background

## 2.1 Anatomic Definitions

The standard anatomical position is used to describe the anatomic features and directions of the human body (Fig. 1). The position is standing with arms hanging down at the side of the body with the palms and head facing forward.

**Figure 1: Human in the standard anatomical position [registerednursern.com]**

Based on this position, the terms anterior and posterior are used to describe the positions towards the front and back of the body, respectively. Superior and inferior are used to describe the positions with respect to the head of the body. Superior referring to closer to the head while inferior refers to closer to the feet (or away from the head). Medial and lateral are used to describe positions in relation to the vertical midline of the body. Medial is closer to the midline and lateral is farther away from the midline. Distal and proximal are used to describe location along the extremities. Proximal is closer to the trunk while distal is farther away from the trunk. For example, the shoulder is proximal to the elbow and the wrist is distal to the elbow. Rotation toward the midline and away from the midline are referred to as internal and external rotation, respectively.

## 2.2 Shoulder Anatomy

The focus of this research project is the shoulder, more specifically the rotator cuff and superior capsule. The shoulder joint is a ball and socket joint consisting of two bones: humerus and scapula. The scapula is medial to the humerus and contains the glenoid (socket) in which the head, or proximal end, of the humerus (ball) articulates. The distal end of the humerus extends to the elbow. Therefore, the shoulder can produce a wide range of movement including abduction/adduction, flexion/extension and internal/external rotation. The anatomy of the shoulder joint is shown in Figure 2.

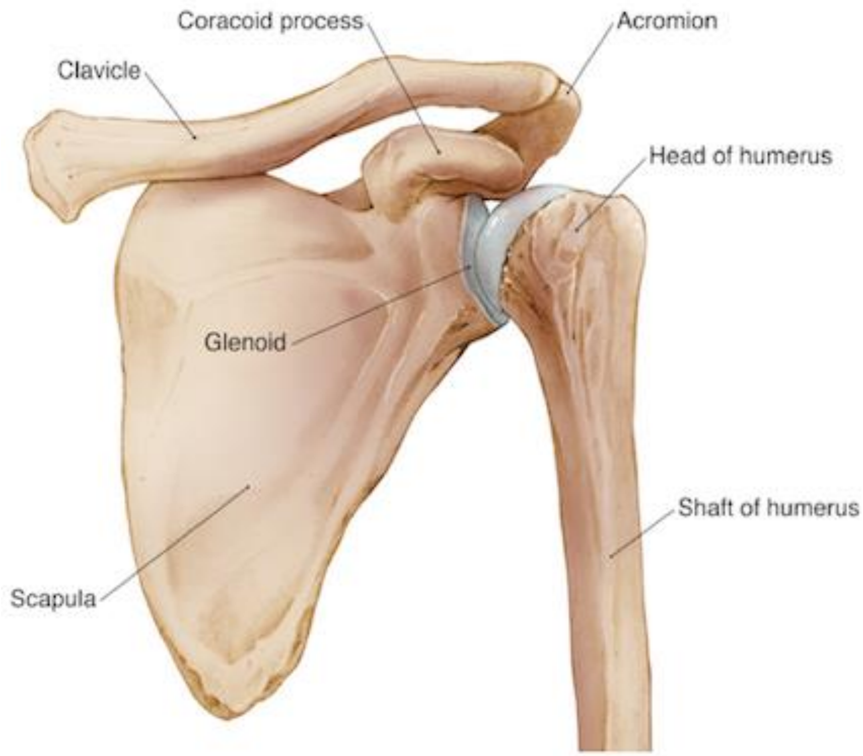


**Figure 2: Shoulder Skeletal Anatomy [anatomy.lexmedicus.com.au]**

Abduction is the lifting of the upper limb at its side, such that angle between the upper limb and the torso increases. Adduction decreases the angle between the upper limb and the torso. Flexion is defined as raising the upper limb towards the front of the body, while extension is moving the upper limb towards the back of the body. Internal and external rotation describe the rotation of the upper limb about its long axis. Rotation of the upper limb towards the midline, so that the thumb is pointing medially describes internal rotation. External rotation is the rotation of the upper limb away from the midline, so that the thumb is pointing laterally. Each movement is shown in Figure 3.

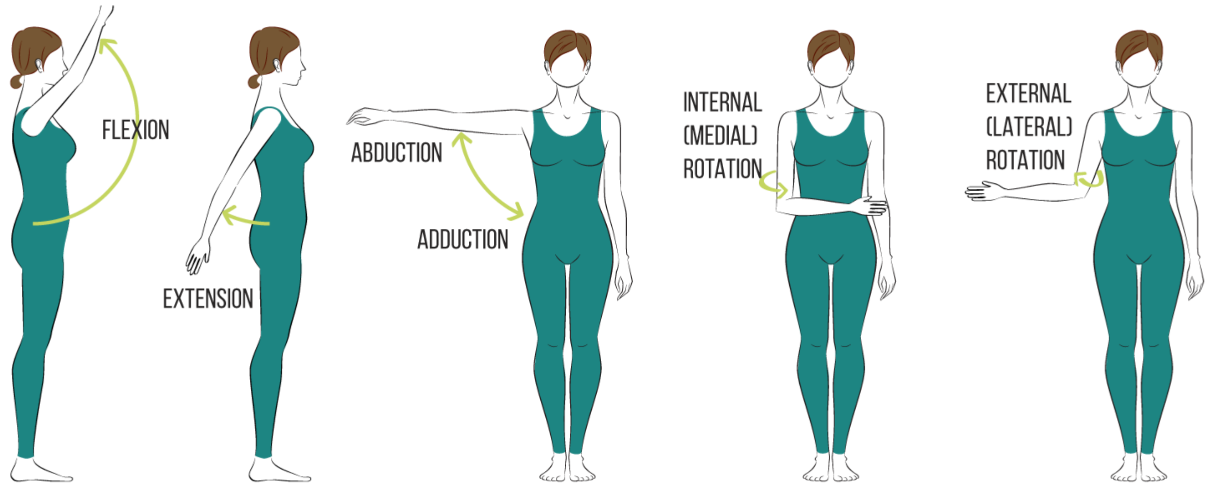


**Figure 3: The six movements of the shoulder joint ([www.sequencewiz.org](www.sequencewiz.org))**

Many muscles are involved in the motion of the shoulder, shown in Figure 4 and Figure 5. These muscles are necessary for abduction/adduction, flexion/extension and internal/external rotation as well as joint stability. The main muscles involved in abduction are the middle deltoid and supraspinatus. Flexion is produced by the pectoralis major and anterior deltoid, while extension is achieved by the posterior deltoid, latissimus dorsi and teres major. Internal rotation is produced by the subscapularis, pectoralis major, latissimus dorsi, teres major and anterior deltoid. External rotation is produced by infraspinatus and teres minor. Primary joint stability is maintained through force coupling of the subscapularis, supraspinatus, infraspinatus and teres minor muscles (rotator cuff).

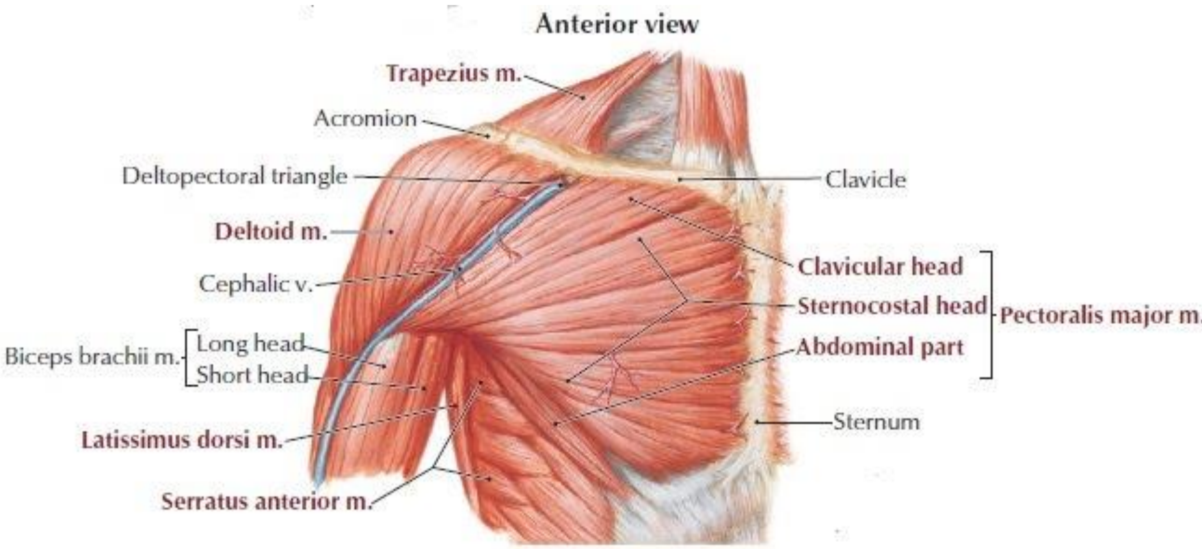


**Figure 4: Anterior Shoulder Muscular Anatomy [sites.google.com]**

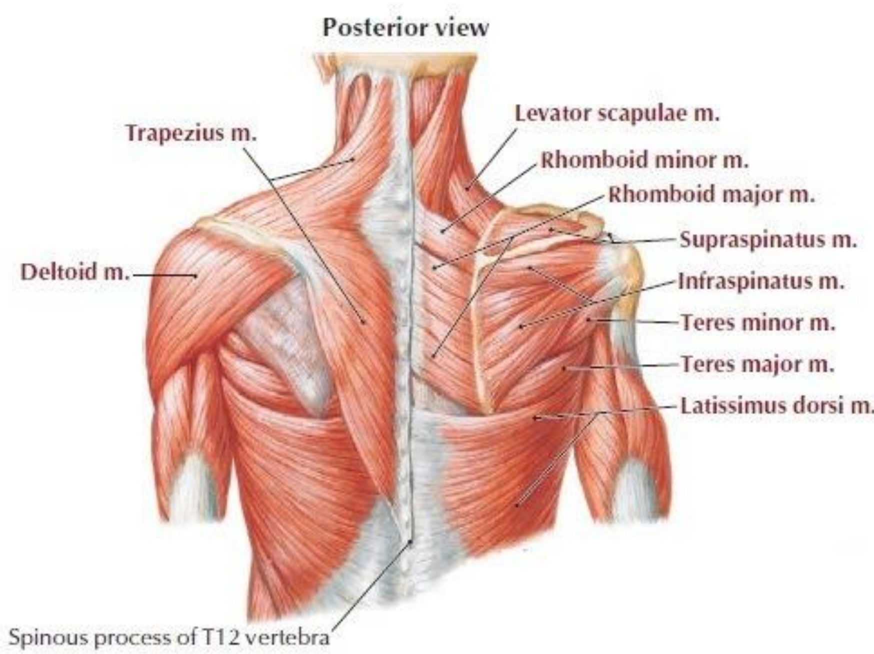


**Figure 5: Posterior Shoulder Muscular Anatomy [sites.google.com]**

### 2.3 Rotator Cuff/Capsule Anatomy

The rotator cuff complex is a group of muscles and tendons that encompass the shoulder joint, maintaining shoulder stability and active shoulder movement. The four muscles of the rotator cuff (from anterior to posterior) include the subscapularis (SubS), supraspinatus (SS), infraspinatus (IS), and teres minor (TM) (Figure 6). Each rotator cuff muscles originates medially on the scapula, travelling laterally to their insertions on the humerus.

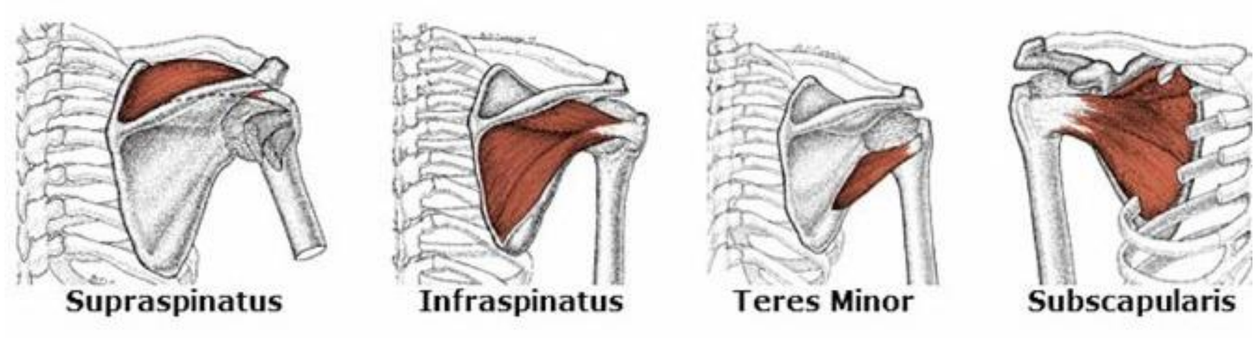


**Figure 6: Rotator Cuff Musculature [bodyharmonics.com]**

The supraspinatus originates at the supraspinous fossa on the scapula, superior to the scapular spine, inserting onto the superior facet of the greater tuberosity of the humerus. The infraspinatus originates on the infraspinous fossa on the dorsal surface of the scapula, inferior to the scapular spine, and inserts onto the posterior aspect of the greater tuberosity of the humerus, and the capsule of the shoulder joint. The teres minor originates on the upper two-thirds of the lateral border of the scapula and inserts laterally into the inferior facet of the greater tubercle of the humerus and directly below the inferior facet of the greater tubercle of the humerus. The subscapularis originates at the subscapular fossa on the anterior surface of the scapula and inserts onto the lesser tuberosity of the humerus.

Beneath the rotator cuff muscles, the capsule forms a thin sheath around the joint attaching laterally around the neck of the humerus and medially around the glenoid and labrum.

## 2.4 Previous Rotator Cuff Insertion Work

The first study to quantify the anatomy of the rotator cuff insertions was Minagawa et al.[5] in 1998. They investigated the relationship of the supraspinatus and infraspinatus and their humeral attachment through dissection of cadaveric specimens. Figure 7 depicts the points that were used to make measurements of each of the tendons. Point a represents the anterior margin of the supraspinatus, point b is the anterior margin of the infraspinatus, point c is the posterior margin of the supraspinatus, point d is the superior margin of the sulcus (bicipital groove), and point e is the posterior margin of the infraspinatus. Measurements between each point were taken.

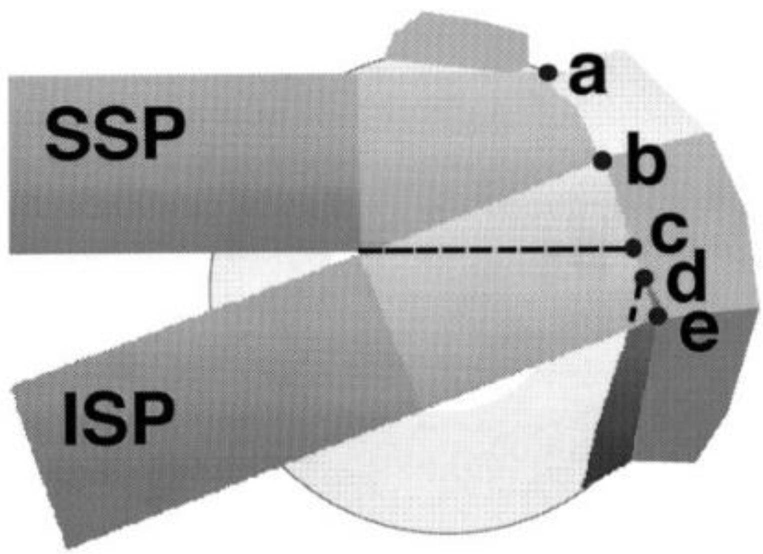


**Figure 7: Schematic of the points used for measurements taken by Minagawa et al.5**

In 2002, Dugas et al.[3] made measurements of the humeral insertions were taken in two groups: the unit of three rotator cuff tendons that insert onto the greater tuberosity (SS, IS, and TM) and each rotator cuff tendon individually (SubS, SS, IS, and TM). For each group, the perimeters were marked in 3-mm intervals, the points digitally measured in three-dimensions (Figure 8), and then projected on a best-fit plane. On the plane, the area and centroid were calculated and measurements of the antero-posterior (AP) and medio-lateral (ML) dimensions passing through the centroid were taken for each group.

**Figure 8: Humerus with the perimeter of the rotator cuff insertions marked.[3]**

Curtis et al[2] dissected cadaveric specimens down to the four rotator cuff tendon insertions (SubS, SS, IS, and TM), marking each boundary on the humerus. Dimensions in the AP and ML directions as well as the distance from the medial border of each insertion to the articular surface in the ML direction were measured using a caliper.

Mochizuki et al[6], also investigated the insertions of the supraspinatus and infraspinatus by dissecting fixed cadaveric shoulders. The AP lengths of the medial and lateral borders and maximum ML length was measured for both tendon insertions as well as the distance from the articular surface (superior capsule) to the posterior edge of the supraspinatus medial border in the ML direction (Figure 9). No method of measurement was described.

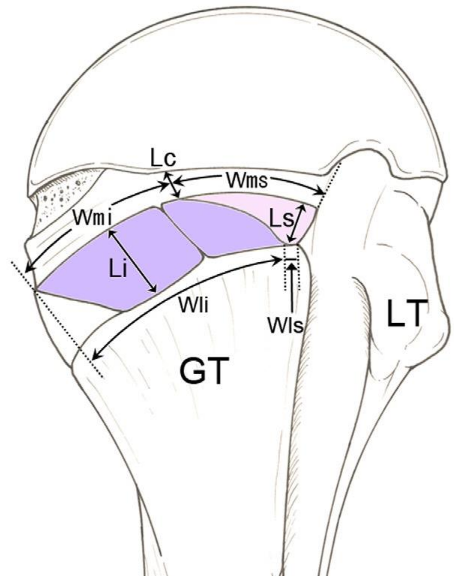


**Figure 9: Illustration of the measurements performed by Mochizuki et al.[6]**

In 2012, Nimura et al[7], using fixed specimens, were the first to measure the articular (superior) capsule in detail, in addition to measurements of the supraspinatus and infraspinatus. The mediolateral dimensions of the capsule and RC insertions were taken at the anterior margin of the greater tuberosity, posterior margin of the supraspinatus, the point of maximum width of the infraspinatus, posterior margin of the infraspinatus, and the point of minimum width of the articular capsule. Along the lateral border of the articular cartilage, the distances from the anterior margin of the greater tuberosity to the point of minimum width of the articular capsule and from the point of minimum width of the articular capsule to the posterior margin of the supraspinatus were measured (Figure 10). No method of measurement was described for this study.

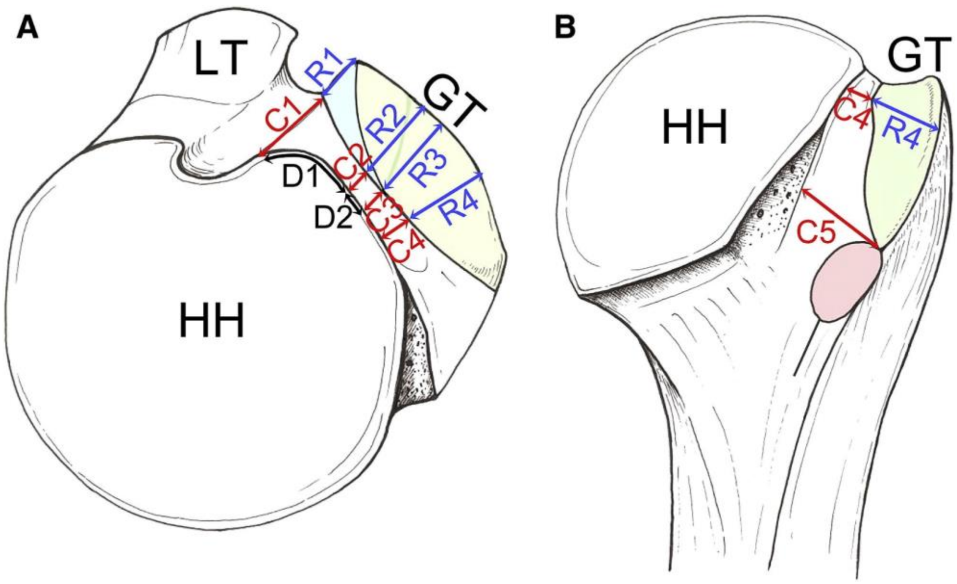


**Figure 10: Illustration of the measurements taken by Nimura et al.[7]**

Most recently, Vosloo et al[10] systematically removed the entire rotator cuff as a single unit and the outlined the perimeter of the humeral insertion in 2-5 mm intervals. Following removal, photographs from three different views (anterior, anterior-superior, and posterior) were taken at a consistent distance from the specimen. Using an AutoCAD program, the photographs were analyzed to measure the footprint area (Figure 11).

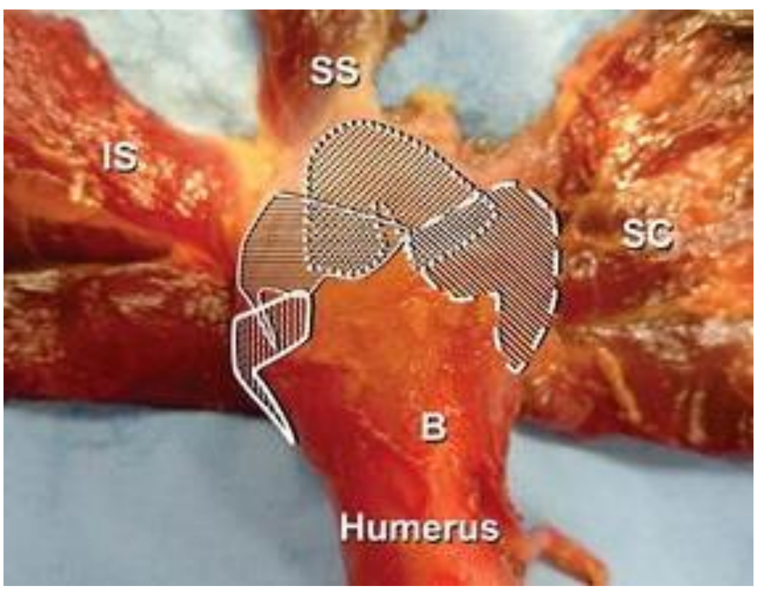


**Figure 11: Dissected specimen with AutoCAD insertions overlayed.[10]**

# 3.0 Methods

## 3.1 Cadaveric Specimen Preparation

The humerus was transected mid shaft, 5 mm distal to the insertion of the deltoid, and the proximal extremity was isolated. Subcutaneous tissue was excised to reveal the deltoid and underlying musculature. The deltoid and soft tissue of the humerus were then removed, and the acromion process was osteotomized at the junction of the scapular spine to allow for clear observation of the rotator cuff. The rotator cuff muscles were released from their scapular origins and elevated off the scapula (Figure 12). The tendons were separated from the capsule individually and transected at their humeral footprint. Following removal, the insertion was carefully marked; SubS – light blue, SS – black, IS – red, TM – green. The remaining soft tissue superior-anterior to the TM and superior-posterior to the SubS muscles was defined as the superior capsule (SC) (Figure 13). The second phase of dissection consisted of the removal and marking of the SC (blue) on the humerus and scapula (Figure 14).

**Figure 12: Posterior view of specimen dissected to the level of the rotator cuff with the infraspinatus and teres minor tendons reflected**

**Figure 13: Superior view of a specimen dissected to the superior capsule with the rotator cuff insertions marked**

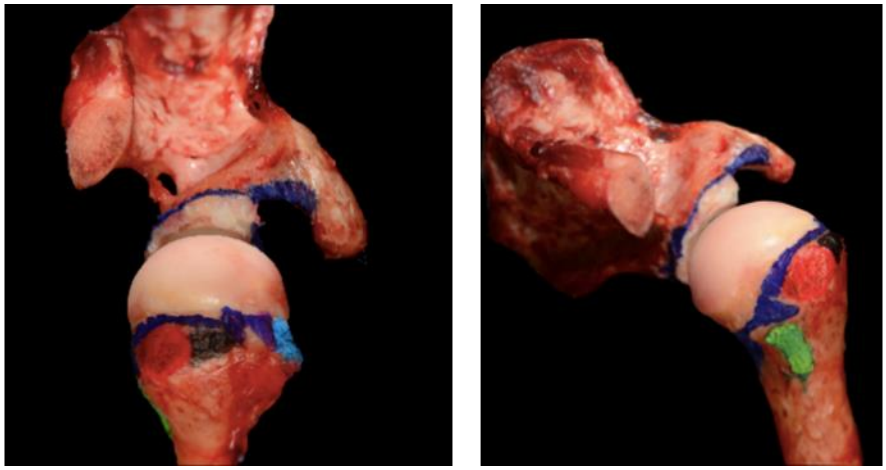

Figure 14: **Dissected specimen with insertion of rotator cuff and superior capsule marked**

### 3.2 Scanning of Geometry

The three-dimensional surface geometry of the humerus and scapula were scanned and probed using a laser-based system with a probe digitizer (Faro, Inc., Lake Mary, FL, USA). The scanner is a portable coordinate measuring machine (CMM) which allows contact and non-contact 3D scanning for measuring surfaces. Using the spherical probe digitizer, points along the insertion site boundaries of the rotator cuff tendons and superior capsule were digitized. The single point repeatability and volume accuracy of the system are 0.043 and 0.036, respectively.[8,9]

### 3.3 Geometric Analysis

The laser scan data was converted into solid models using software (Geomagic Studio, 3D Systems, Rock Hill, SC, USA) and the digitized points were incorporated into the solid models (Fig. 15). The digitized points were connected using splines to create the boundaries representing the attachment sites of the rotator cuff muscles and superior capsule on both the humerus and scapula.

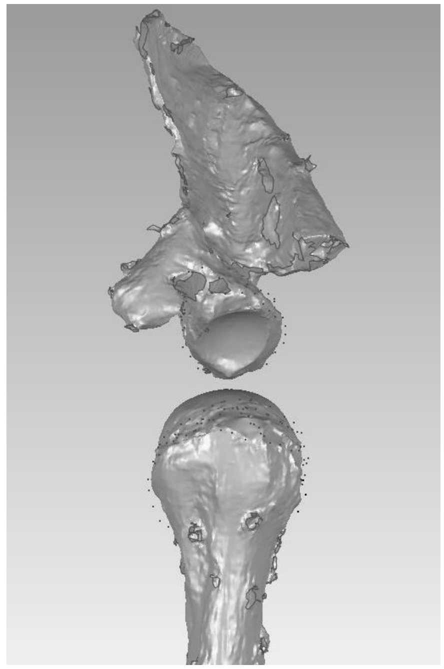

**Figure 15: 3D model with points probed along the insertions of the rotator cuff and superior capsule**

Each insertion was then isolated, the centroid of the surface was calculated, and a best-fit sphere was fitted to the surface (Fig. 16). This allowed a line to be created between the center of the sphere and the centroid that was used to project the centroid onto the surface of the insertion (Fig. 17). Planes about the central axis were then created in the major (largest) dimension and the dimension perpendicular to the major dimension, the minor dimension. The intersection of the major and minor planes with the surface was used to project a curve along the surface and the length of each projected curve was measured (Fig. 18). For each rotator cuff tendon, the shortest distance along the surface from the apex of the bicipital groove (BG) to the centroid was measured (Fig. 19). The surface area of each insertion was also calculated.

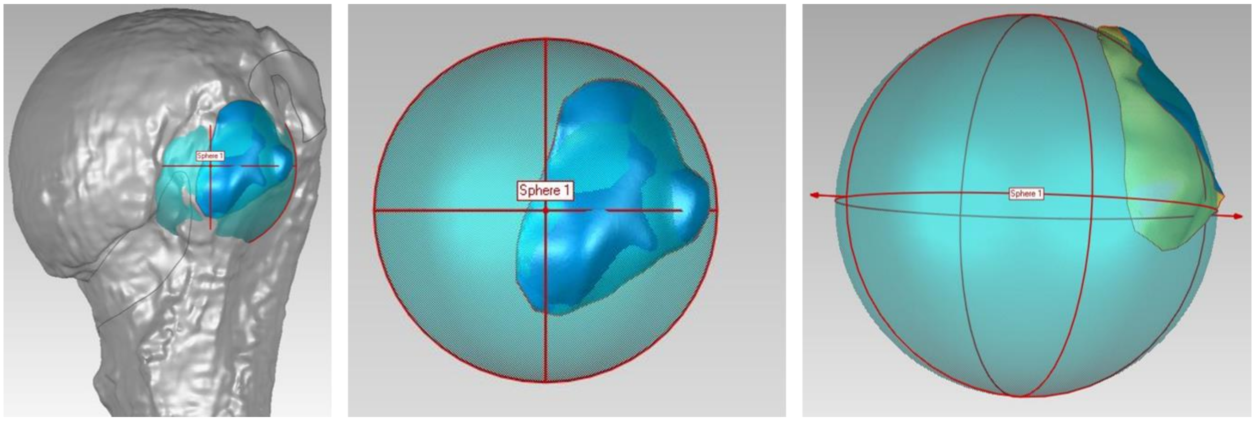


**Figure 16: Best-fit sphere fitted to the insertion of the subscapularis**

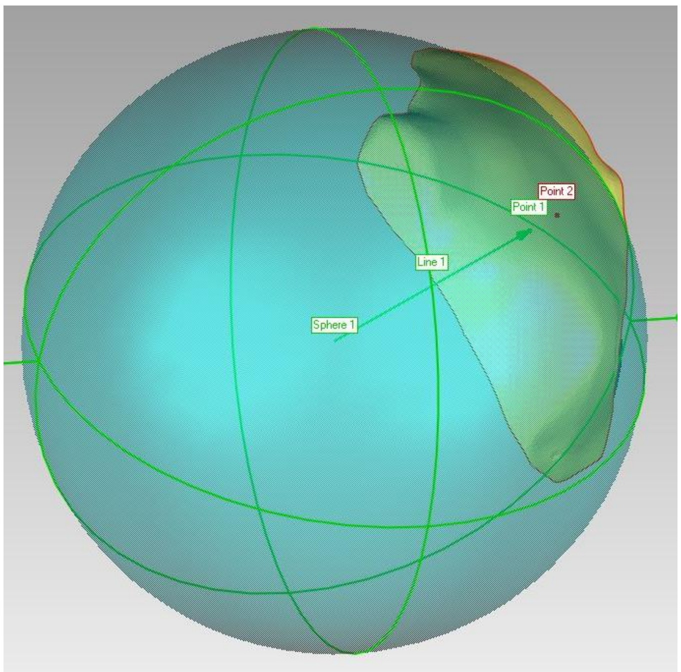


**Figure 17: Projection of centroid onto the surface of the subscapularis**

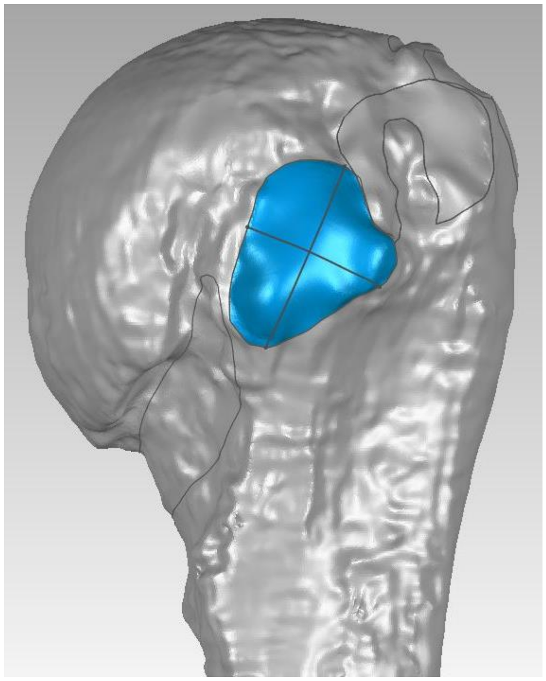

**Figure 18: Major and minor planes projected onto the surface of the subscapularis**

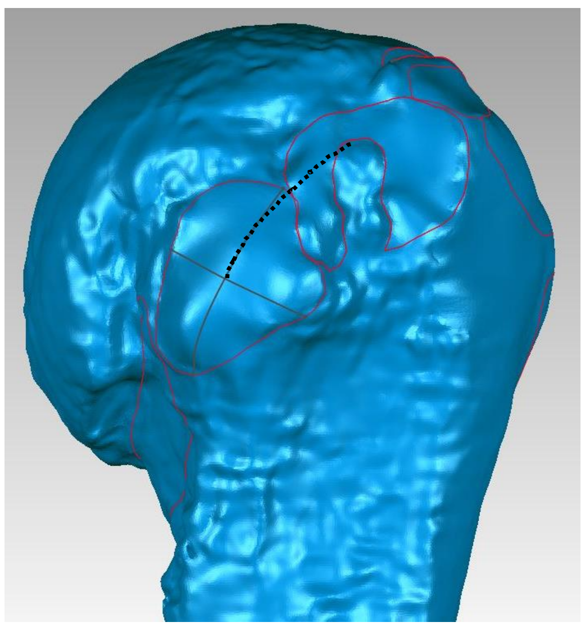

**Figure 19: Distance along the surface from the apex of the bicipital groove to the centroid of the subscapularis**

Because the superior capsule is a continuous structure, the insertion on each model was split into 6 distinct regions: 3 on the humerus and 3 on the scapula. The humeral insertion regions consisted of the coracohumeral ligament (CHL), the mid-capsule beneath the insertion of the SS and IS, and spine region adjacent to the spine of the scapula (Fig. 20). The scapular insertion was composed of the CHL, mid-capsule beneath the SS, and spine region, lateral to the scapular spine (Fig. 21).

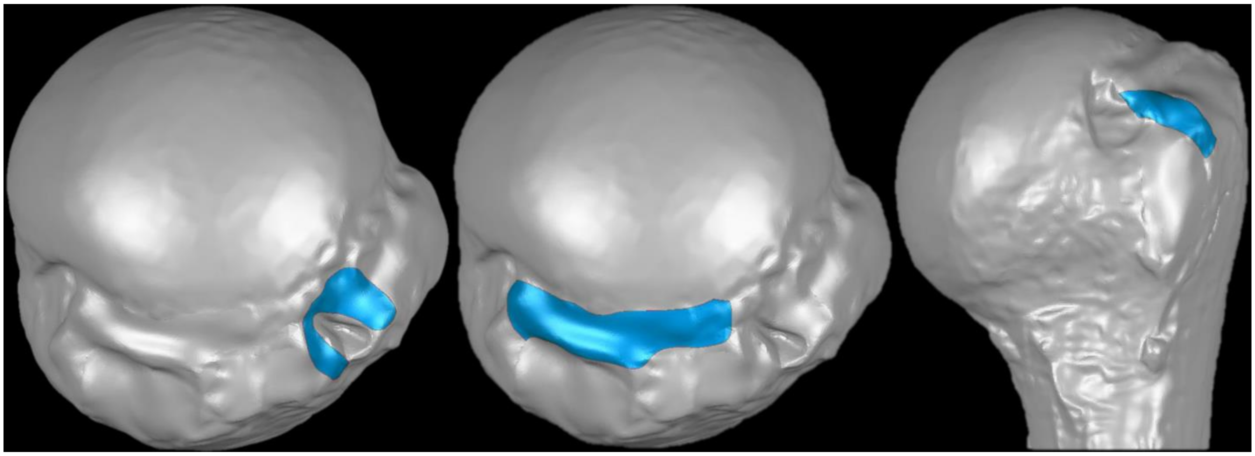

**Figure 20: Humeral superior capsule regions: coracohumeral ligament (left), mid-capsule (middle), and spine (right).**

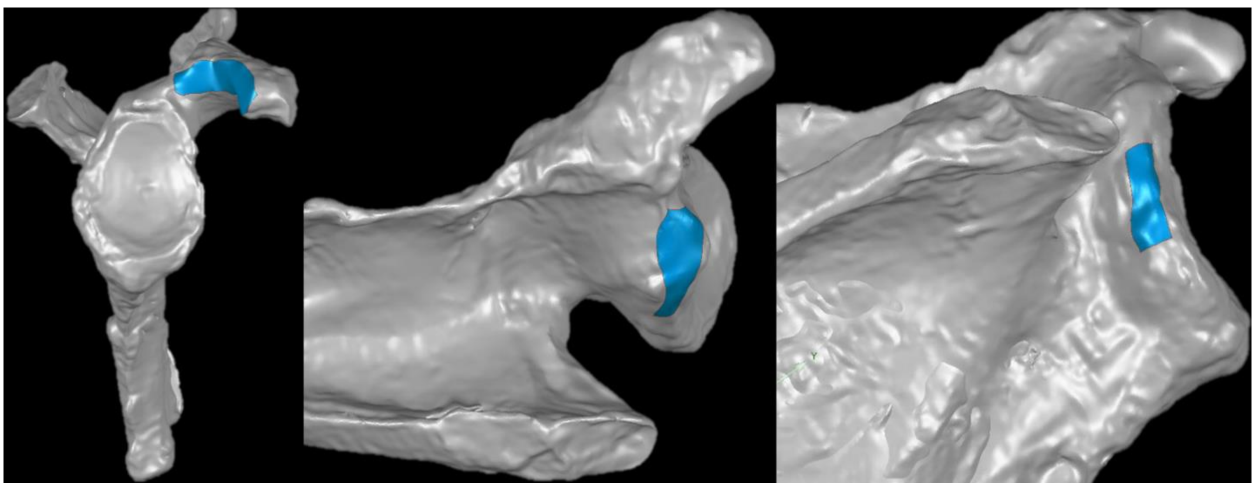

**Figure 21: Scapular superior capsule regions: coracohumeral ligament(left), mid-capsule (middle), and spine (right).**

## 4.0 Results

The previously described methods were applied to nine cadaveric shoulders (4 right, 5 left).

### 4.1 Rotator Cuff Insertion Results

Figure 22 shows the insertions of the rotator cuff and superior capsule on the humerus and scapula. Measurements of the major dimension, minor dimension, insertion area, and distance from the centroid of each insertion to the apex of the bicipital groove for each region of the humeral insertion of the rotator cuff are shown in Figure 23 and Table 1.

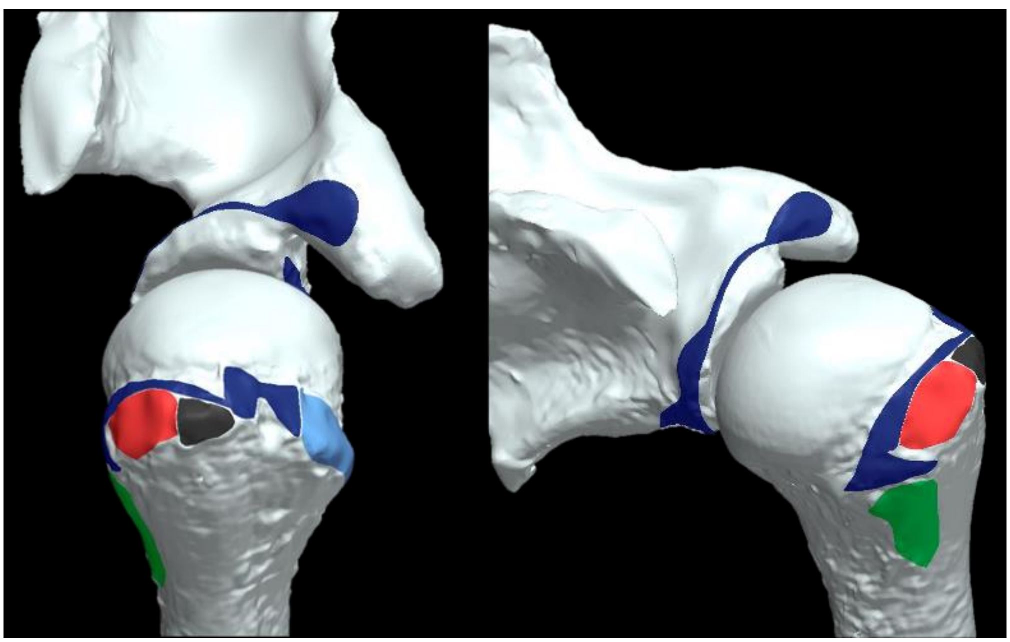

**Figure 22: Three-dimensional model of the rotator cuff and capsular insertions on the humerus and scapula**

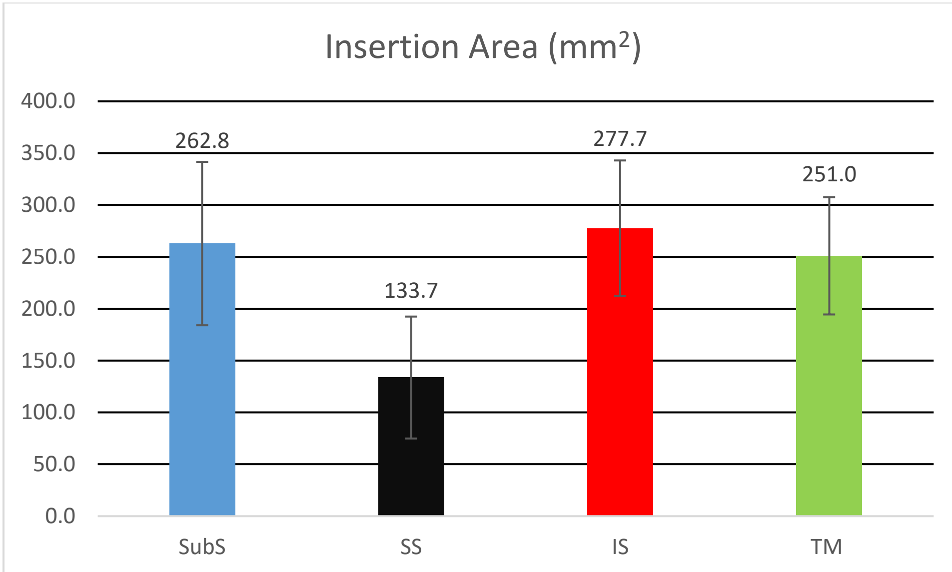


**Figure 23: Rotator cuff humeral insertion areas from anterior to posterior**

**Table 1: Mean measurements and standard deviations of the humeral insertions of the rotator cuff**

| | **Major Dimension (mm)** | **Minor Dimension (mm)** | **Distance to BG (mm)** |
|---|---|---|---|
| Supraspinatus | 16.1 ± 2.3 | 9.1 ± 3.9 | 14.4 ± 2.4 |
| Infraspinatus | 25.0 ± 4.1 | 13.9 ± 4.1 | 31.4 ± 4.0 |
| Teres Minor | 24.2 ± 4.2 | 11.7 ± 3.2 | 54.9 ± 7.7 |
| Subscapularis | 28.4 ± 8.0 | 11.3 ± 4.0 | 25.7 ± 6.5 |

## 4.2 Superior Capsule Insertion Results

Measurements of the length, width, insertion area, and distance from the centroid of each capsular region to the apex of the bicipital groove for the humeral insertion of the superior capsule are shown in Table 2.

**Table 2: Mean measurements and standard deviations of the humeral insertion of the superior capsule by region**

| | Length (mm) | Width (mm) | Area ($mm^2$) | Distance to BG (mm) |
|---|---|---|---|---|
| Spine | 21.3 ± 4.1 | 8.3 ± 3.0 | 141.3 ± 49.3 | 46.8 ± 5.4 |
| Mid-capsule | 32.9 ± 6.3 | 4.4 ± 1.0 | 151.4 ± 44.3 | 27.0 ± 4.7 |
| CHL (Anterior) | 15.1 ± 3.2 | 7.0 ± 3.0 | 184.3 ± 60.8 | - |
| CHL (Posterior) | 14.1 ± 2.7 | 6.0 ± 2.3 | | - |

Measurements of the major dimension, minor dimension, and insertion area of each capsular region for the scapular insertion of the superior capsule are shown in Table 3.

**Table 3: Mean measurements and standard deviation of the scapular insertion of the superior capsule by region**

| | Major Dimension (mm) | Minor Dimension (mm) | Area ($mm^2$) |
|---|---|---|---|
| Spine | 14.5 ± 3.7 | 7.8 ± 4.6 | 99.8 ± 44.7 |
| Mid-capsule | 24.1 ± 4.1 | 8.3 ± 3.6 | 175.8 ± 68.7 |
| CHL | 26.4 ± 6.1 | 12.8 ± 4.1 | 287.1 ± 115.1 |

The major findings of this study were the surface areas and dimensions of the rotator cuff and superior capsule found using advanced measurement techniques. These findings can offer a better understanding of the function and injury mechanisms of these soft tissues as well as guide surgeons in the surgical repair of the rotator cuff and superior capsule. Ten shoulders were included in this study. One shoulder was not included in analysis based on the presence of a massive rotator cuff tear found upon dissection.

Comparing this study to other similar studies, Minagawa et al.[5] used calipers to measure lengths of the insertions of the supraspinatus and infraspinatus tendons. These measurements were performed on 10 cadaver shoulders. The comparison of their results to the current study are shown in Table 4.

**Table 4: Comparison of the mean rotator cuff insertion measurements and standard deviation taken by Minagawa et al. to the current study (*current study measurements may not be oriented in the same directions)**

| | **Length** | |
|---|---|---|
| | **Minagawa** | **Current*** |
| Supraspinatus | 12.6 ± 1.1 | 16.0 ± 2.6 |
| Infraspinatus | 22.8 ± 2.2 | 25.0 ± 4.0 |

The comparison of results show that the current study produced larger measurement of 21% for the supraspinatus and 9% for the infraspinatus. These differences may be attributed to the method of dissection and analysis used in each study. The current study does not differentiate between the layers of the supraspinatus and infraspinatus, whereas Minagawa did. The results of the length of each tendon include the measurement from point b to point c, which they have described as an overlapping region containing the insertion of both the supraspinatus and infraspinatus. The results of the current study do not include any measurements that overlap.

Dugas et al. used a 3D-space digitizer to measure the AP and ML dimensions and area of the 4 insertions of the rotator cuff muscles of 10 cadavers. The results of their study are shown in Table 5.

**Table 5: Comparison of the mean rotator cuff insertion measurements and standard deviation taken by Dugas et al. to the current study (*current study measurements may not be oriented in the anatomic directions)**

| | AP (cm) | | ML (cm) | | Area ($cm^2$) | |
|---|---|---|---|---|---|---|
| | **Dugas** | **Current*** | **Dugas** | **Current*** | **Dugas** | **Current** |
| Subscapularis | 2.43 ± 0.43 | 2.83 ± 0.80 | 1.79 ± 0.73 | 1.13 ± 0.40 | 2.41 ± 0.81 | 2.63 ± 0.79 |
| Supraspinatus | 1.63 ± 0.55 | 1.60 ± 0.26 | 1.27 ± 0.63 | 0.90 ± 0.40 | 1.55 ± 0.66 | 1.34 ± 0.59 |
| Infraspinatus | 1.64 ± 0.31 | 2.50 ± 0.40 | 1.34 ± 0.20 | 1.38 ± 0.16 | 1.76 ± 0.40 | 2.78 ± 0.65 |
| Teres Minor | 2.07 ± 0.54 | 2.52 ± 0.46 | 1.14 ± 0.32 | 1.17 ± 0.33 | 2.22 ± 0.62 | 2.51 ± 0.56 |

For the AP measurements, the differences found between the results of the current study and the results that Dugas et al. reported ranged from 2%, for the supraspinatus, to 34%, for the infraspinatus. For the ML direction, the smallest differences occurred in the infraspinatus and teres minor, where each had a 3% difference. The largest difference between ML measurements in the two studies was found for the subscapularis, at 58%. The area measurements differed from 8% to 37%. Due to the limitation of measurements in two-dimensions, they do not accurately represent the true nature of each insertion.

Curtis et al. used a caliper to measure the insertions of each rotator cuff tendon. Their data included AP and ML measurements of 20 cadaver shoulders. Their results are shown in Table 6.

**Table 6: Comparison of the mean rotator cuff insertion measurements and standard deviation taken by Curtis et al. to the current study (*current study measurements may not be oriented in the anatomic directions)**

| | AP length (mm) | | ML Length (mm) | |
|---|---|---|---|---|
| | **Curtis** | **Current*** | **Curtis** | **Current*** |
| Subscapularis | 40.4 ± 6.5 | 28.3 ± 8.0 | 19.6 ± 3.2 | 11.3 ± 4.0 |
| Supraspinatus | 23.8 ± 4.4 | 16.0 ± 2.6 | 16.6 ± 2.5 | 9.0 ± 3.9 |
| Infraspinatus | 28.6 ± 6.4 | 25.0 ± 4.0 | 18.7 ± 3.7 | 13.8 ± 1.6 |
| Teres Minor | 29.1 ± 6.6 | 25.2 ± 4.6 | 20.6 ± 6.4 | 11.7 ± 3.3 |

In the AP dimension, the SS and SubS both produced the largest differences between this study and the results Curtis et al. reported, at 43% and 49%, respectively. The IS (14%) and TM (15%) both produced smaller differences. For the ML direction, large differences were found between each of the four rotator cuff muscles, where all were greater than 36% (36% - 84%). Similar to Dugas et al., the limitations of this study are attributed to the use of two-dimensional measurements.

Mochizuki et al. used a caliper to measure the insertions of the supraspinatus and infraspinatus. Their data included AP and ML measurements of 26 fixed cadaver shoulders. In addition, the length of the insertion of the articular capsule in the ML direction was measured. Results of this study are shown in Table 7.

**Table 7: Comparison of the mean rotator cuff insertion and articular capsule measurements and standard deviation taken by Mochizuki et al. to the current study (*current study measures may not be oriented in the anatomic directions)**

| Rotator Cuff Insertion | | | | |
|---|---|---|---|---|
| | **AP Length (mm)** | | **ML Length (mm)** | |
| | **Mochizuki** | **Current*** | **Mochizuki** | **Current*** |
| Supraspinatus | 12.6 ± 2.0 | 16.0 ± 2.6 | 6.9 ± 1.4 | 9.0 ± 3.9 |
| Infraspinatus | 32.7 ± 3.4 | 25.0 ± 4.0 | 10.2 ± 1.6 | 13.8 ± 1.6 |
| **Articular Capsule Insertion** | | | | |
| | **ML Length (mm)** | | | |
| | **Mochizuki** | | **Current** | |
| Capsule | 4.5 ± 0.6 | | 4.4 ± 1.0 | |

The AP dimension produced a wider range of differences than the ML dimension. The SS and IS produced differences 21% and 31%, respectively. While in the ML dimension, the differences were found to be 23% and 26%. The measurement of the articular (superior) capsule produced very similar measurements, with a difference of 2%. Much like the three previous studies mentioned, the limitations of this study are attributed to the use of two-dimensional measurements, however Mochizuki et al. was also limited by the use of formalin-fixed specimens which can alter tissue.

In the study conducted by Nimura et al., calipers were used for the measurement of the supraspinatus and infraspinatus insertions and superior capsule insertion on the humerus in 12 formalin-fixed shoulders. Measurements of the width were reported and shown in Table 8.

**Table 8: Comparison of the mean rotator cuff insertion and articular capsule measurements and standard deviation taken by Nimura et al. to the current study (*current study measurements may not directly align with those of Nimura et al.)**

| **Rotator Cuff Insertion** | | |
|---|---|---|
| | **Width (mm)** | |
| | **Nimura** | **Current*** |
| Supraspinatus | 3.5 ± 2.3 | 9.0 ± 3.9 |
| Infraspinatus | 9.1 ± 1.7 | 13.8 ± 1.6 |
| **Superior Capsule Insertion** | | |
| | **Width (mm)** | |
| | **Nimura** | **Current*** |
| Mid-capsule | 4.4 ± 1.2 | 4.4 ± 1.0 |
| Spine | 9.7 ± 1.7 | 8.3 ± 3.0 |

The ML measurements of both rotator cuff muscles reported by Nimura et al. produced difference of 62% for the supraspinatus and 30% for the infraspinatus, when compared to the results of this study. Nimura et al. was also limited by the use of calipers producing two-dimensional measurements as well as formalin-fixed specimens.

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