ORIGINAL COMMUNICATION

Morphology of the Humeral Insertion of the Supraspinatus and Infraspinatus Tendons: Application to Rotator Cuff Repair

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In shoulder surgery, a precise understanding of anatomical relationships is required for accurate reconstruction. Reports in recent literature have challenged the traditional definitions of the humeral footprints of the supraspinatus and infraspinatus tendons. This study aims to precisely delineate these footprints. The rotator cuffs of 54 shoulders from 27 Australian Caucasoid donor cadavers were examined. The tendinous portions were dissected down to their region/footprint of attachment upon the humerus. Measurements of those footprints, upon the greater and lesser tuberosities, were made. Those measurements were statistically analyzed for any association with age, sex, height, or side. Twenty-seven cadavers had an average age at death of 74.9 ($\pm$12.8), 56% were male, average height was 168 ($\pm$8.6) cm. Due to premorbid fracture, or degeneration, 11 shoulders were excluded. The footprint of the supraspinatus was triangular, with a medial, anteroposterior length of 20.4 ± 4.2 mm. Its lateral anteroposterior length was 6.3 ± 1.6 mm and its maximal mediolateral width was 6.6 ± 2.7 mm. Its calculated area was 122.0 ± 66.6 mm^2. The footprint of the infraspinatus was trapezoidal, with a medial anteroposterior length 22.6 ± 3.0 mm. Its lateral anteroposterior length was 25.4 ± 3.3mm and its maximal mediolateral width was 12.0 ± 2.7 mm. Its calculated area was 294.9 ± 74.1 mm^2. There was no statistical correlation between size of the footprint and age, sex, side, or height. The humeral footprints of the supraspinatus and infraspinatus tendons upon the greater tuberosity were distinct. The lateral border of the infraspinatus' humeral attachment extended much farther anteriorly upon the highest facet of the greater tuberosity than in traditional descriptions. Clin. Anat. 00:000–000, 2015.

Key words: shoulder; cadaver; rotator cuff; dissection

INTRODUCTION

Symptomatic rotator cuff tears are common, functionally debilitating, age-related injuries. In Australia, they account for up to 14/1,000 General Practice presentations per year (Hopman et al., 2013). Although they may occur at any age, these tears are predominant among the elderly population. Precise anatomical knowledge of the supraspinatus and infraspinatus muscles' humeral footprints is

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essential for advancement of rotator cuff repair, with the development of techniques such as double row repair coming on the basis of sound anatomical knowledge (Lo and Burkhart, 2003 ; Millett et al., 2004). The literature is equivocal about the exact morphology of the insertion of the supraspinatus and infraspinatus muscles (Dugas et al., 2002; Curtis et al., 2006; Mochizuki et al., 2008; Nimura et al., 2012).

Textbooks (Romanes, 1986; Standring et al., 2008) have traditionally described the insertion of the supraspinatus tendon into the highest facet and the infraspinatus into the middle facet of the greater humeral tuberosity. Studies by Clark and Harryman (1992), Mingawa et al. (1998), and Mochizuki et al. (2008) described the humeral attachment of infraspinatus as having a wider footprint than previously thought. In addition, they described interdigitation of infraspinatus' and supraspinatus' fibers (Clark and Harryman, 1992), with overlapping of those fibers (Mingawa et al., 1998), and an infraspinatus humeral footprint extending from anterosuperior to posteroinferior along most of the length of the inferior aspect of the highest facet of the greater humeral tuberosity (Mochizuki et al., 2008).

The findings of these studies conflict with the textbook descriptions with respect to supraspinatus' and infraspinatus' precise humeral footprints. On this subject, current literature is scant, particularly with respect to cadaver dissection studies. A recent study (Mochizuki et al., 2008) in a Japanese cadaver population showed a previously undescribed extension of the infraspinatus tendon's attachment. That extension of the infraspinatus tendon's insertion reached more anteriorly onto the highest facet of the greater tuberosity. These discrepancies have arisen with the advent of new imaging technologies allowing greater visualization of structures in vivo, and attempts to correlate findings with clinical results, leading to targeted dissections. Such dissection has not previously been performed in an Australian Caucasoid population. We considered that examination of the humeral footprints of these two muscles would contribute to the surgically relevant anatomy of the shoulder, to the understanding of rotator cuff structure, to interpretation of imaging and understanding of pathogenesis of rotator cuff tears, and thus to improved techniques in surgical repair.

This study aimed to delineate the precise humeral attachment regions for supraspinatus and infraspinatus muscles.

MATERIALS AND METHODS

Fifty-four shoulders from 27 Australian Caucasoid donor cadavers were dissected; male (55.6%—15/27); mean age at death (74.9 ± 12.8 years), age range 49–96 years (Table 1). Virus-negative donor cadavers were embalmed using Genelyn™ solution and dissected after a 12-month holding period. Height was measured from the base of the heel to the vertex of the skull with the cadaver in a supine, neutral position. Informed consent for participation in scientific research was obtained during the standard patient consent process for body donation.

TABLE 1. Demographics of Cadaver Population

Number	54
Unmeasurable	11 (20%)
Measured	43 (80%)
Age (years)	75 ± 13
Male	30 (56%)
Height (cm)	168 ± 9

In 10 cadavers, following removal of the superficial tissue and deltoid muscle, the lateral half of the clavicle and the proximal third of the humerus were divided. The shoulder joint, scapula, and proximal humerus were removed en bloc for examination.

In 17 cadavers, the deltoid muscle was incised horizontally, below the level of the humeral surgical neck. The deltoid muscle was released from its attachments to the scapular spine, the acromion, and the clavicle. The lateral half of the clavicle was divided and its attached muscles freed from it. The shoulder joint capsule was kept intact. This method permitted additional use of the cadavers for other teaching purposes by minimizing immediate regional structural damage.

In all shoulders, the acromion was resected and regional connective tissue removed from around the shoulder joint. At that stage, eleven shoulders were excluded due to the presence of pre-mortem anatomical disruption due to degeneration, or destruction of their shoulder structures and/or tendon tears, or fractured humeral heads—changes which would have prevented precise delineation of attachment regions for the rotator cuff tendons.

In the remaining 43 specimens, observations of the myotendinous nature of the supraspinatus and infraspinatus muscles were made. The supraspinatus and infraspinatus muscles were incised lateral to the medial border of the scapula, and related muscles were peeled away, medial to lateral, from the scapula toward their humeral attachments.

The supraspinatus and infraspinatus muscles were then carefully peeled more laterally from the underlying joint capsule, toward their humeral attachment areas upon the greater tuberosity. The attachment regions for the supraspinatus and infraspinatus tendons upon the humerus were defined by following their tendinous components into the bone. Measurements of the size of the base of the tendons as they attached into the bone were taken. The tendon footprint measurements upon the humerus were made with respect to the lesser humeral tuberosity and the highest (and middle facets) of the greater humeral tuberosity. Using a micrometer, one author measured the maximal width (medial to lateral) and length (anterior to posterior) of the footprints, measurements were taken in triplicate and averaged to the nearest 0.01 of a mm. The footprint area was then estimated for comparative purposes using the formula:

$$\frac{(\text{medial length}+\text{lateral length})\times\text{maximal width}}{2}$$

Using Graphpad Prism 6 (La Jolla, CA) statistical analysis software, an analysis was performed to assess any association between cadaver age at death, height, and tendon footprint size. A paired Student's *t* test was used for statistical analysis comparing means with a significance level of $P \leq 0.05$. Correlations were expressed using Pearson's correlation coefficients. Unless otherwise stated, means are expressed as value $\pm$ standard deviation.

Ethical approval was received from the University Human Research Ethics Committee.

RESULTS

Infraspinatus Muscle, Its Tendon, and Humeral Attachment Footprint

The larger of the two muscles examined, infraspinatus arose from, and occupied, its eponymous fossa on the scapula, with the exception of a "bare area" (spinoglenoid notch) which lay between the labrum, laterally, the inferior aspect of the root of the scapular spine, superiorly, and the rise of infraspinatus' most lateral muscle fibers, medially.

From the infraspinous fossa, beneath the scapular spine, infraspinatus' fibers ascended superolaterally, to enter their tendon, which, as it crossed the aforementioned bare area of the scapula, flattened into a broad tendon which ascended to its attachment upon the posterosuperior aspect of the greater tuberosity.

Within infraspinatus, its tendon formed as a central round tendon from which descended a flat inferior extension. In the region of the inferior aspect of the scapular spine, the deepest infraspinatus fibers inserted into the central round part of the tendon. The more superficial fibers, in that region, which partially obscured the central round part of the tendon, inserted into its most superficial aspect.

From the extensive posterior surface of the scapula, the deepest infraspinatus fibers ascended superolaterally to join the "flat inferior extension" portion of the tendon. More medial and superficial fibers of the posterior scapular region inserted into the muscle's central round tendon.

As the infraspinatus tendon approached, and traversed, the region of the scapular "bare area," it flattened into a broad tendon which ascended to its greater tuberosity attachment. The tendinous appearance of infraspinatus became more prominent its footprint upon the greater tuberosity was approached.

With respect to the region of scapula from which muscle fibers arose, their representation in the infraspinatus tendon, and their humeral footprint in the tendon, it was found that the most inferior of infraspinatus' fibers inserted into the tendon in a manner which gave them representation upon the tendon's humeral footprint upon the posterolateral and lateral region, of the middle facet of the greater tuberosity, and upon the posterolateral region of the highest facet of the greater tuberosity. The most superior of infraspinatus' fibers joined their portion of the tendon whose attachment was to the anterosuperior aspect of the highest facet of the greater tuberosity.

The infraspinous fossa attachment of the infraspinatus muscle was clearly distinct from the scapula's lateral border attachment of the teres minor muscle. Between these muscle's scapular footprints, there lay a sheet of fascia which arose from the inferior surface of infrapinatus fascia. It crossed to the periosteum of the lateral border of the scapula and continued laterally as a partition between those two muscles. This facial layer varied in thickness from an almost negligible fascial film, to a distinct membrane as thick as the overlying infraspinatus fascia. The distinct fascial sheet was present in 78% (42/54) of shoulders. In the 22% (12/54) of shoulders in which this fascial sheet was an almost negligible film, the structural arrangement of the muscles permitted identification of the fibers belonging to infraspinatus, and those belonging to teres minor. The parentage of each of these muscle's fibers was determined by first identifying each muscle's distinct tendon attachment upon the humerus and then moving medially toward the scapula to identify from where, upon the scapula, the muscle fibers arose.

With respect to the supraspinatus and infraspinatus tendons, at initial examination, their tendons appeared fused. After careful dissection, following the body of the infraspinatus muscle, the tendons of the two muscles became distinct. Posterior to the humerus, infraspinatus' tendon was gently curved as it ascended to its greater tuberosity attachment. By following the infraspinatus tendon to its humeral attachment, the trapezoidal-shaped humeral footprint was then clearly defined (Fig. 1). Medially, that trapezoidal humeral footprint extended from the inferior aspect of the middle facet of the greater humeral tuberosity. It ascended to reach the medial aspect of the posterosuperior border of the highest facet of the greater tuberosity. From that medial point, the footprint's anterior border extended laterally to reach the posterolateral margin of the highest facet's lateral aspect upon the greater tuberosity. The lateral border of this trapezoidal footprint then descended from this point, on the lateral aspect of the highest facet of the greater tuberosity. The lateral border descended, taking an inferomedial path, which reached beyond the level of the middle facet of the greater tuberosity.

In this study, the measured average dimensions of the trapezoidal footprint for the infraspinatus tendon's attachment upon the greater tuberosity were: Medial border anteroposterior length, 22.9 ± 3.0 mm. Lateral border anteroposterior length, 25.6 ± 3.4 mm. The footprint's maximal mediolateral width was 12.2 ± 2.8 mm. Its calculated area was 294.9 ± 74.1 mm^2 (Table 2, Fig. 2).

Supraspinatus Muscle and Its Humeral Attachment Footprint

The supraspinatus muscle arose from the medial third of its eponymous fossa, travelling laterally to reach the highest facet of the greater humeral tuberosity. Its deepest fibers were attached to the root the scapular spine, they ran laterally from that region toward the muscle's tendon. The most superficial fibers of the muscle, which were attached to the superior surface of the scapular spine, took an

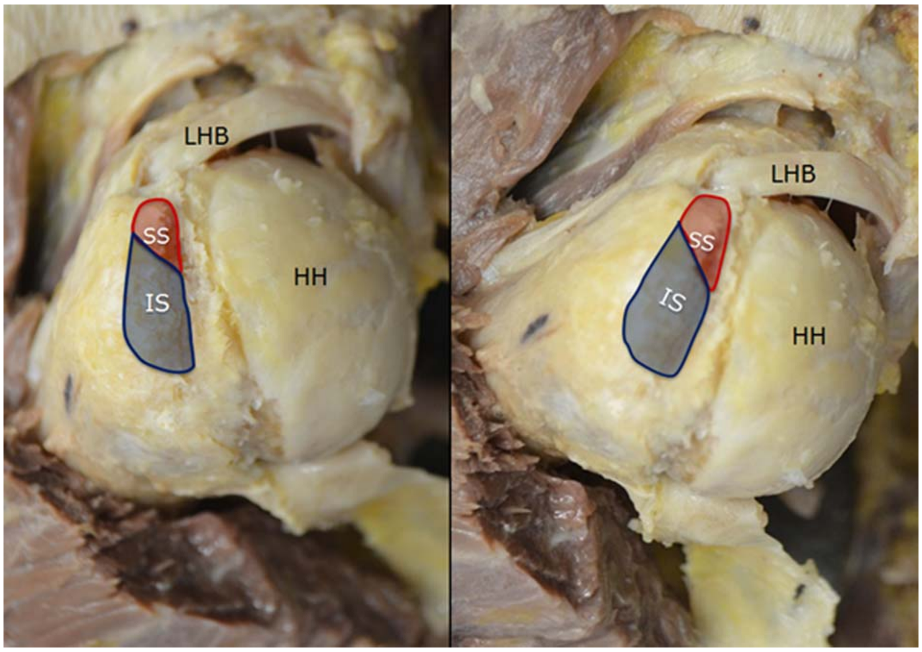

Fig. 1. The supraspinatus (SS) has a triangular footprint and the infraspinatus (IS) has a trapezoidal footprint upon the greater tuberosity of the humeral head (LHB: long head of biceps tendon, HH: humeral head). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

anterolateral path to insert into the flat portion of the supraspinatus tendon. The anterior margin of the tendon had a slightly thickened round cord shape, formed from the fibers arising from the laterally running fibers arising from the laterosuperior aspect of the supraspinous fossa, before passing subacromially to the highest facet of greater tuberosity

The humeral footprint of the supraspinatus was triangular, extending from the most anterior border of the footprint of attachment of the infraspinatus (the triangle's base) (Fig. 1), then forward, to reach the anterior edge of the highest facet of the greater tuberosity (the triangle's apex). In 30% (15/54), the anterior extent of the attachment footprint reached the lesser tuberosity via the transverse humeral ligament.

In this study, the triangular humeral footprint upon the greater tuberosit, of the supraspinatus had a medial anteroposterior length of 20.9 ± 3.9 mm. Its lateral border had an anteroposterior length of 6.4 ± 1.5 mm. The maximum mediolateral width was 6.7 ± 2.6 mm. Its calculated area was 122 ± 66.6 mm^2 (Table 2, Fig. 2).

Data Analysis

No statistically significant correlation was found between the footprint area and age (IS $r^2 = 0.086$, SS $r^2 = 0.101$), height (IS $r^2 = 0.070$, SS $r^2 = 0.153$), gender (IS $P = 0.808$, SS $P = 0.239$), or side (IS $P = 0.137$, SS $P = 0.456$).

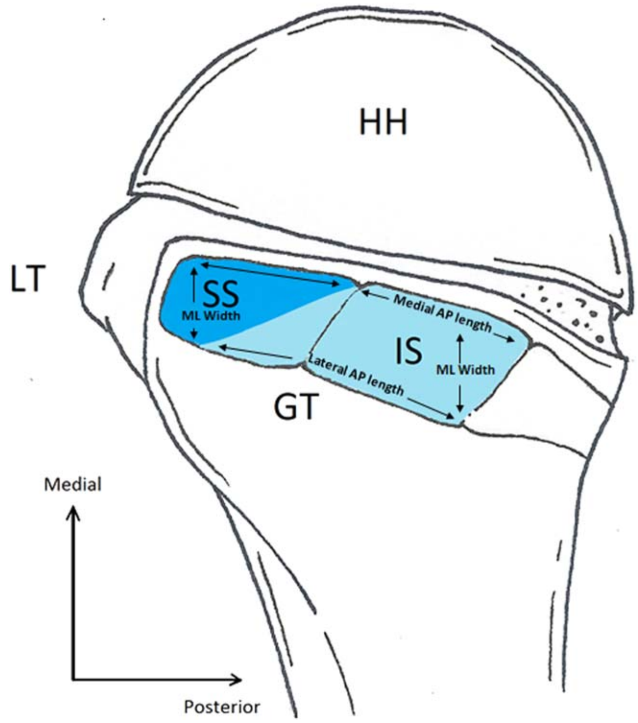

Fig. 2. Schematic of the supraspinatus and infaspinatus insertion upon the greater tuberosity of the humerus, overlying the highest and middle facet. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 2. Footprint Size Upon Greater Tuberosity (mm (SD))

	Total	Male	Female	*P*
Infraspinatus				
Width	12.18 (2.8)	12.35 (2.6)	12.00 (3.0)	0.657
Medial length	22.86 (3.0)	22.73 (3.0)	23.01 (3.1)	0.772
Lateral length	25.64 (3.4)	25.50 (3.6)	25.80 (3.2)	0.779
Area (mm^2(SD))	294.86 (74.1)	291.87 (81.3)	297.47 (69.0)	0.808
Supraspinatus				
Width	6.68 (2.6)	6.70 (2.1)	6.64 (3.0)	0.236
Medial length	20.88 (3.9)	22.58 (4.3)	19.21 (2.38)	0.180
Lateral length	6.37 (1.5)	6.36 (1.5)	6.39 (1.4)	0.845
Area	121.99 (66.6)	109.45 (59.8)	133.39(66.19)	0.239

DISCUSSION

Accurate anatomical knowledge of the structure of the rotator cuff is critical in the successful restoration of torn tendons to their correct positions of humeral attachment. Humeral stability has been shown to be dependent upon the coordinated actions of the rotator cuff mechanism (Soslowsky et al., 1997a,b). Although evidence is limited regarding anatomical precision of restoration and functional outcome, it makes sense that anatomical restoration would result in a more balanced repair and better return to biomechanical function.

Assessment of tears and tendon involvement is based on pre-operative MRI and ultrasound and intraoperative visualization of the tuberosities and the humeral articular surface (Mochizuki et al., 2008), knowledge of precise delineations of the rotator cuff insertions will aid in assessment of determining which tendon has torn. Given the ease at identifying humeral bony landmarks on CT (Parlier-Cuau et al., 1998) relative to soft tissue, more information regarding the exact insertions will potentially aid diagnostic investigation. In reference to partial tears, knowledge of the size of the footprint and distance from the articular surface is important to allow assessment of degree of tear when viewed arthroscopically or radiologically (Dugas et al., 2000). In particular, in patients in whom tears are longstanding or neglected, the original anatomy may be even more difficult to distinguish, and awareness of intended target for repair would aid the surgeon.

Previous biomechanical studies examining musculotendinous anatomy and loading of the rotator cuff highlight the opposing functions of both anterior and posterior myotendinous unit function (Roh et al., 2000), stating that for true physiological loading, the supraspinatus muscle needs to have both its anterior and posterior musculotendionus portions placed in tension (Roh et al., 2000). Balanced contraction of the whole rotator cuff unit is also important for the stabilization of the humeral head within the glenohumeral joint during movement (Soslowsky et al., 1997a, 1997b; Halder et al., 2000) with forces of the infraspinatus, in combination with the subscapularis and teres minor, balancing the deltoid and supraspinatus superior pull (Boon et al., 2004; Billuart et al., 2006 ;). Anatomical restoration would be ideal to restore and rebalance these forces evenly and maintain as stable a joint as possible.

The orientation of the rotator cuff insertion has been shown to be associated with likelihood of rotator cuff deterioration, in particular the middle facet (Le Corroller et al., 2009). The orientation of this facet was observed to be significantly less dorsally orientated in the sagittal plane in patients with rotator cuff tears than those without, possibly indicating reduced inferior translatory forces of the infraspinatus and facilitating rotator cuff dysfunction (Le Corroller et al., 2009). By reducing the effectiveness of the infraspinatus counterbalance for supraspinatus and deltoid (Boon et al., 2004; Billuart et al., 2006), superior translation of the humeral head is less controlled and impingement of the subacromial structures is not prevented. Thus, an improved understanding of the insertional anatomy may aid in creating more balanced reconstructions.

Commonly consulted surgical textbooks (Romanes, 1986; Standring et al., 2008) describe the supraspinatus tendon inserting into the highest facet of the greater tuberosity, and the infraspinatus tendon inserting into the middle facet of the greater tuberosity. In the aforementioned manner, many authors (Mingawa et al., 1998; Curtis et al., 2006; Dugas et al., 2006) describe the supraspinatus and infraspinatus tendon insertions in their reports. In contrast, Mochizuki et al. (2008) challenged these descriptions. In a Japanese cadaver population, they reported that the infraspinatus' insertion extended much more anteriorly along the inferolateral aspect of the highest facet of the greater tuberosity than previously thought. In our cadaver population, we also found an anteromedial localization of the supraspinatus attachment upon the highest facet of the greater tuberosity, and we found the infraspinatus occupying the middle facet, with an extension of the lateral border of the infraspinatus footprint onto the highest facet. Although, in our study, this extension was less marked than the observations of Mochizuki et al. (2008) (25.6 mm vs.32.7 mm). Tactile and visual examinations of undamaged human skeleton humeri similarly reflect this description.

Our results build upon the work of previous authors. Clark and Harryman (1992) examined the entire rotator cuff insertion and demonstrated the "blending of fibers"; however, they did not measure insertion points (footprints). Mingawa et al., (1998) in their Japanese cadaver study, were the first to measure the dimensions of the tendons, in terms of their

TABLE 3. Summary of Other Study Findings (mm)

	Lumsdaine	Mochizuki	Curtis	Dugas	Ruotolo	Nimura
Infraspinatus						
Width	12.2	6.9	19	13.4		9.7
Medial length	22.9		29			
Lateral length	25.6	32.7				
Supraspinatus						
Width	6.7	7.6	16	12.7	12.1	7.6
Medial length	20.9	32	26			
Lateral length	6.4	1.3				

length and overlap in order to guide surgical repair. Curtis et al., (2006) demonstrated measurable unique insertions of each rotator cuff tendon (its humeral footprint), and they referenced these footprints to landmarks in the shoulder—improving the accuracy of arthroscopic and open shoulder surgery.

Curtis et al. (2006) measured the maximal medial-lateral width of the insertion (footprint) of the supraspinatus as 16 mm, and that for the infraspinatus as 19 mm. They found the average maximal length for the supraspinatus was 23 mm, and for infraspinatus, 29 mm. Dugas et al. (2002) reported the supraspinatus maximal width as 12.7 mm, and the infraspinatus maximal width as 13.4 mm. Ruotulo et al. (2004) reported supraspinatus' width as 12.1 mm. Nimura et al. (2012) measured the supraspinatus maximal width as 7.6 mm, and the infraspinatus maximal width as 9.7 mm (Table 3).

Mochizuki et al. (2008) measured the supraspinatus maximal width as 6.9 mm and that for infraspinatus as 10.2 mm. These results are comparable with our results, with the exception of the measurements reported by Curtis et al. (2006). Those differences are most likely due to differences in dissection technique. Nimura et al. (2012) found similar discrepancies and commented that the difference in degree to which the capsule was dissected from each tendon would account for the reported variations.

Mochizuki et al. (2008) measured the medial and the lateral anteroposterior lengths of the supraspinatus and infraspinatus humeral footprints. They found, for infraspinatus, a mean lateral anteroposterior length of 32.7 mm. For supraspinatus, a mean lateral anteroposterior length of 1.3 mm. In contrast, we found the mean lateral anteroposterior length for infraspinatus was 25.6 mm, and for supraspinatus, the mean lateral anteroposterior length was 6.4 mm. We found that the infraspinatus footprint extended onto the superior (or highest) facet of the greater tuberosity, however, to our observations, the footprint did not extend onto the superior (or highest) facet of the greater tuberosity to the extent described by Mochizuki et al. (2006). This may be due to racial differences or due to variations in dissection technique.

One of the weaknesses of our cadaver study is the number of cadavers we examined; however, our sample size was comparable to that of other studies. Our study included some demographic data relating to age, sex, and height, although due to the de-identified nature of our body donor program, we were unable to ascertain handedness, work history, or weight. We found no statistically significant correlation between these data points and size of the tendon attachment footprints. Again, this negative finding is limited by the small sample size. In view of the limitation of not knowing handedness, we also analyzed according to side, on the assumption that most people are right handed, but found no significant differences between the groups. Our cadaver sample's age range, 49–96 years, mean age at death (74.9 ± 12.8), (Table 1), was quite high, which is to be expected in a sample drawn from a body-donor program, and clinically is the age that patients with rotator cuff tears often present. Whether a younger population of cadavers would demonstrate different characteristics would be a relationship which future studies might examine.

Future studies examining associations between rotator cuff tears and size of the footprint and orientation of the footprint would be useful. Comparisons between racial groups or stratification by size of humeral head and percentage size of the insertional footprints would also aid in our understanding of the role the footprints play in rotator cuff pathology. Lastly, an observational study examining pre- and post-operative positioning of rotator cuff repairs relative to humeral tuberosities, and medium to long-term functional outcomes would add insight into the significance of anatomical restoration and anatomical variants as factors influencing rotator cuff pathology.

In conclusion, we defined the tendinous attachments (footprints) of the supraspinatus and infraspinatus muscles upon the greater tuberosity of the . Our findings demonstrated a footprint for the infraspinatus which extended along its lateral anteroposterior border to a point more anterior than that documented in text content in textbooks, or in previous papers. The findings from our cadaver population showed some variation in comparison with recent Japanese cadaver studies. Our population demonstrated less anterior extension of the lateral edge of the infraspinatus upon the highest facet of the greater tuberosity. Finally, we found no statistically significant correlation between age, sex, and height and the insertion (footprint) size within our cadaver population.

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