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THE CLINICAL ANATOMY OF THE INSERTION OF THE ROTATOR CUFF TENDONS

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ABSTRACT

The rotator cuff (RC) insertions according to most anatomical texts are described as being separate. However, clear fusion of the RC tendon fibres exist with prior studies showing an interdigitation forming a common, continuous insertion onto and around the lesser- and greater tubercles (LT & GT) of the humerus. Current surgical repair methods (arthroscopic techniques), rarely mention or consider these connections during repair. Rotator cuff surgery remains a controversial subject, due to various available techniques, surgeon experience and preference and, the contradicting success rates. Therefore, the purpose of this project was to visualise and define the RC footprint and extension insertions with the aim of enhancing and improving knowledge of the basic anatomy in the hope that this will be considered during orthopaedic repair. Twenty shoulders (16 cadaveric & 4 fresh) were used in the study. The fresh shoulders were received from the National Tissue Bank and ethical clearance was obtained (239/2015). Reverse dissection was performed to visualise the RC unit exposing the interdigitated rotator hood (extension insertions), as well as the complete RC unit (tendons + internal capsule) separated from the scapula and humerus. Once the insertions were exposed and documented, the RC muscle footprint (articular surface area) was measured and recorded, using AutoCAD 2016. No statistical significant difference between left and right ($p = 0.424$) was noted, but a significant difference between males and females ($p = 0.000$) was. These findings indicate evidence that the RC tendons and the internal capsule are one complete and inseparable unit. The fact that the RC unit is more complex in its structure and attachment places importance on the biomechanical stresses encountered after repair. Functions of one RC muscle are not necessarily isolated but can be influenced by surrounding muscles as well. These findings also provide clarity for surgeons with the goal of improving and enhancing surgical methods for better post-operative patient outcome.

Key words: Orthopaedic; arthroscopic; re-tear; complex; reverse dissection; capsule

INTRODUCTION

The rotator cuff (RC) is comprised of four muscles (with tendons) including, supraspinatus (SP), infraspinatus (IS), subscapularis (SC) and teres minor (TM). The RC unit serves important functions in the connection between the humerus and the scapula and also as a dynamic stabiliser of the glenohumeral joint. Although the RC muscles are mobile and well-constructed, tears are common, especially amongst elderly people and athletes. These tears can disrupt daily living and even the simplest of activities by causing various degrees of limited movement, pain, swelling, cracking and stiffness of the shoulder.

Current textbooks used in the medical education and several previous studies show

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that the RC muscle tendons insert separately onto the humeral tubercles, which creates a separate footprint shape for each tendon. SC is known to insert onto the lesser tubercle, tapering down onto the humeral neck creating an auricular shape. SP inserts onto the highest impression of the greater tubercle and creates a triangular or trapezoidal shape while IS inserts onto the middle impression of the greater tubercle, creating a trapezoidal shape. Lastly, TM inserts onto the lowest impression of the greater tubercle, tapering down onto the

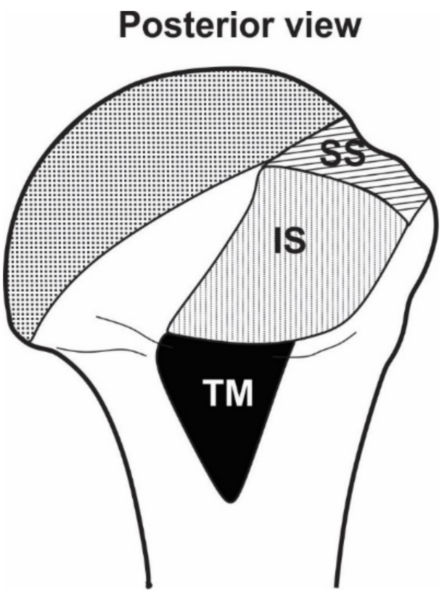

Figure 1: Posterior view of the RC footprint. Supraspinatus (SP), infraspinatus (IS), teres minor (TM)

humeral neck and creates a triangular shape (Curtis *et al*., 2006; Mochizuki *et al*., 2008) (Fig.1). Unfortunately, these studies have shown contradictions in the results with regard to the measurements and analysis, which poses a question on the validity of these statements about the morphology of the footprint of the RC tendons.

A study done by Clark *et al.,* 1992, showed new findings regarding the footprints and interdigitations of these tendons. The study revealed a common insertion on the humeral tubercles of these RC tendons and together with the capsule; it should be regarded as one complete unit with a more singular insertional area on the tubercles. This opposes the outcomes of previous studies done on the separate footprints of the RC tendons, as new studies lean towards the notion that they are not in fact separate but unite and interdigitate to form a singular entity with a common footprint as they insert onto the tubercles.

Numerous studies have emphasised the interdigitation between the tendons of the RC unit. An interdigitation between SC and SP was shown at the point of the bicipital groove (intertubercular groove), creating an extension hood (Fig.2-EH) over the long head of the biceps tendon (Clark *et al*., 1992; Boon *et al.,* 2004). Another interdigitation was observed between IS and SP, being inseparable approximately 15mm proximal to their common insertion onto the bone (Clark *et al.,* 1992; Pouliart and Gagey, 2006). This interdigitation was revealed due to a strained SP tendon causing an increase in strain of the IS tendon, ultimately emphasising the importance of the biomechanical role and link between the muscles of the RC and role in the aetiology of RC tears (Andarawis-Puri *et al*., 2010). These findings also state the anatomical and clinical importance of the internal joint capsule, as it was previously overlooked as being part of the RC unit. The RC tendon fibres interdigitate not only with one another, but fuse together with the internal capsule along

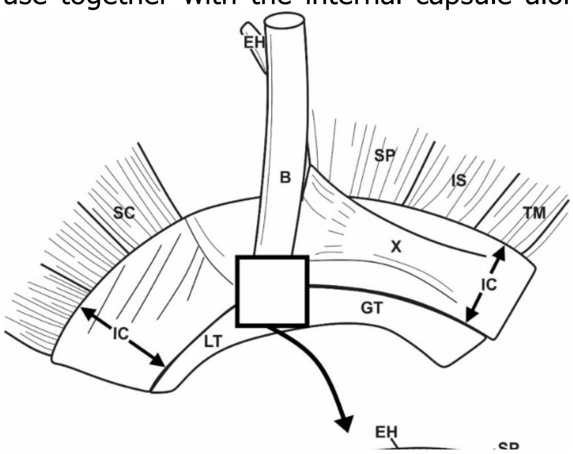

Figure 2: Internal view of the RC. Subscapularis (SC), supraspinatus (SP), infraspinatus (IS), teres minor (TM), internal capsule (IC), lesser tubercle (I-L), greater tubercle (I-G), extension hood (EH), bicipital tendon (B)

its deepest layer (Fig.2-IC) before the common insertion onto the bone (Clark *et al.,* 1992). These findings were mainly investigated for the causes of RC tears and discovered during diagnosis and surgical procedures (Pouliart and Gagey, 2006; Nimura *et al.,* 2012).

One of the most important factors to consider after RC repair is the patient's post-operative results. These not only include pain, stiffness or infection, but also the proper vascularisation of the bone and tendon, restored mobility and a reduced risk of re-tear. The vascularisation of the proximal humerus, especially the humeral head, is often overlooked by orthopaedic surgeons when considering suture-anchor for RC repair and the current literature shows conflicting results with regard to the complete supply of this vital area. Studies have shown a significant decrease in vascular scores after rotator cuff repair using anchor-sutures, with 48% of the patients having post-operative defects and the lowest vascular score at the anchor site. This can cause a multitude of problems during the recovery process after a RC repair, as adequate vascularisation is needed for tissue repair and if not so, may result in re-tear, weakness, pain and other indirect defects due to the unhealed RC tendon and damaged blood flow (Fealy *et al.,* 2006; Gamradt *et al*., 2010). One of the more detrimental outcomes of disturbed vascularity to the proximal humerus is osteonecrosis of the humeral head (Dilisio *et al*., 2013; Goto *et al*., 2015). Authors believe there is a link between this condition and the damage to the branches of the anterior circumflex humeral artery with the obscure placement of the suture-anchors. To date, the literature has reported on nine cases of postoperative humeral head osteonecrosis that have been linked to arthroscopic repair or debridement with the treatment outcome resulting in additional surgical intervention; reverse shoulder arthroplasty (Magee *et al*., 1997; Beauthier *et al*., 2010; Dilisio *et al*., 2013; Goto *et al*., 2013; Parada *et al*., 2015) (Fig.3). Due to the gap in current literature and the contradicting results noted, more evidence-based research into this condition, the blood supply of the proximal humerus and its possible link to arthroscopic repair needs to be conducted.

In addition to the vascular supply, it is vital to consider the bio-mechanical integrity of the shoulder after RC repair. These surgeries are in

Figure 3: Micro CT scan from the anterior view, showing the blood supply within the humeral head

fact performed to restore patient's shoulders to pre-injury function. In numerous studies, the mechanical failure of rotator cuff tendon repairs includes, suture pulling through tendon, a tear in a new location, and suture anchor pulling out of bone (Cummins *et al.,* 2003; Lindley and Jones, 2010). Another study noted that the site of the cuff re-tear was due to an interference of the suture-tendon site and according to ultrasound examination were still attached to the bone but loose (Ahmad *et al*., 2015). The main reason for these failures is due to the incorrect tension applied to the tendons onto the bone, as well as incorrect anchor-to-tendon angle placement. This not only affects the post-operative outcomes on the patient, but also alters the proper function and biomechanical forces endured by the RC tendons, which can lead to the re-tear of the repaired or even non-repaired tendons.

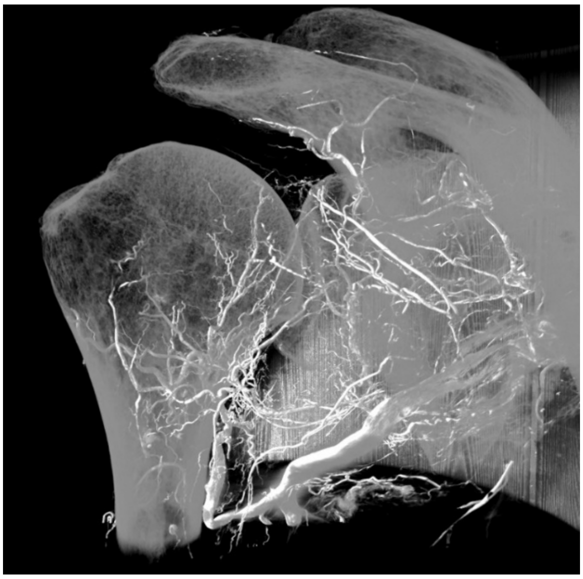

Figure 3: Micro CT scan from the anterior view, showing the blood supply within the humeral head

Various techniques are used to repair these tears, depending on the severity and location of the tear, either surgically or with therapy (non-surgical). Orthopaedic surgeons use a range of surgical techniques to repair RC tears including, arthroscopic, mini-open method and traditional open surgery. During arthroscopic repair, the torn tendon is reattached directly to the bone with the use of suture anchors. The downfalls with the use of these anchors include neurovascular damage, increased re-tear rate of the repaired tendon (up to 94%) and, full range of movement after surgery is often limited (Le *et al.*, 2014).

Arthroscopy using suture anchors is also more costly compared to open surgery and often results in longer recovery periods with increased post-operative pain. Currently, a debate exists whether or not the suture-anchors are successful enough to validate arthroscopic methods, or rather to perform open surgery to include the repair of the tendons extension insertions for better post-operative success. Therefore, the purpose of this project was to study, visualise and define the RC footprint and extension insertions (RC tendon interdigitation) with the aim of enhancing the techniques used in orthopaedic repair of the RC tendons.

This was performed by doing a reverse dissection to expose the continuous insertion complex of the all four RC muscles. In doing so, the morphology of the concept of a singular, interconnected complex of RC tendons, instead of individual tendinous insertions, can anatomically be described.

MATERIALS AND METHODS

Four fresh and 16 cadaveric shoulders were used in the study. The fresh shoulders were obtained from the National Tissue Bank under the auspices of the University of Pretoria with ethical clearance from the Faculty of Health Sciences Student Ethics Committee (239/2015). The cadaveric shoulders were obtained from medical dissection halls in the Department of Anatomy, University of Pretoria. Only adult shoulders, without any known injury, pathology or previous shoulder surgeries were included**.** Sex, weight, height and race were not considered an exclusion factor.

Insertion and fusion (interdigitation) analysis

The reverse dissection was done using a systematic approach to better visualise the structures of the RC unit (Fig.4). Each muscle with its attached tendon was exposed to their insertional level with careful removal of the skin, subcutaneous tissue, fascia and the deltoid muscle. This also exposed the interdigitated rotator hood (extension insertions). The complete RC unit (tendons + internal capsule) was separated from its scapula attachment by firstly removing the muscles from their origins and then cutting as close as possible to the connection with the glenoid labrum. Once separated from the scapula the RC unit was separated from its humeral attachment by cutting through the insertion points on the greater and lesser tubercles. This allowed the unit to be removed as a whole.

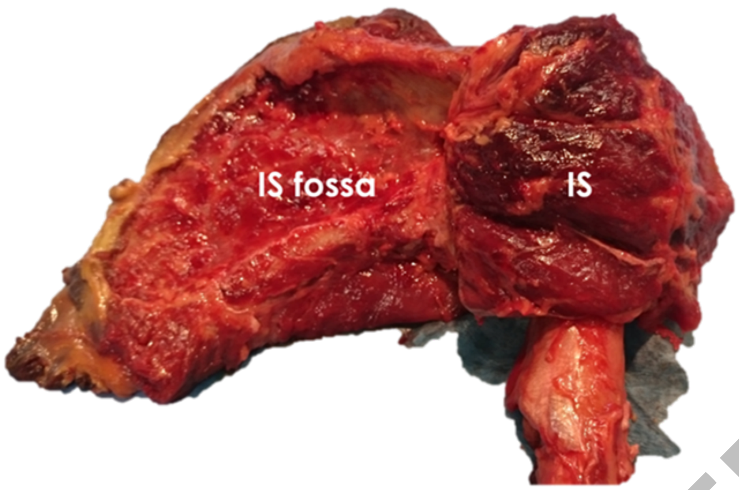

Figure 4: Reverse dissection of infraspinatus muscle

The footprint analysis

Sixteen cadaveric shoulders were used for the footprint analysis. The shoulders were also exposed by careful removal of the skin, subcutaneous tissue, fascia and the deltoid muscle. The muscles and their tendinous implants into the humerus were clearly defined by removing overlying bursa. The labrum was cut as close as possible to the scapula, and the muscular portions of the RC unit were cut and removed from their origin on the scapula; leaving the unit attached to the humerus. A systematic approach was followed by removing the unit, while tracing the implants/ footprints on the humerus with an oil based pen to obtain an outline of the footprint (Fig.5). Photos were taken at a consistent distance from the specimen and the area was then measured by 5mm interval points, using AutoCAD 2016 program.

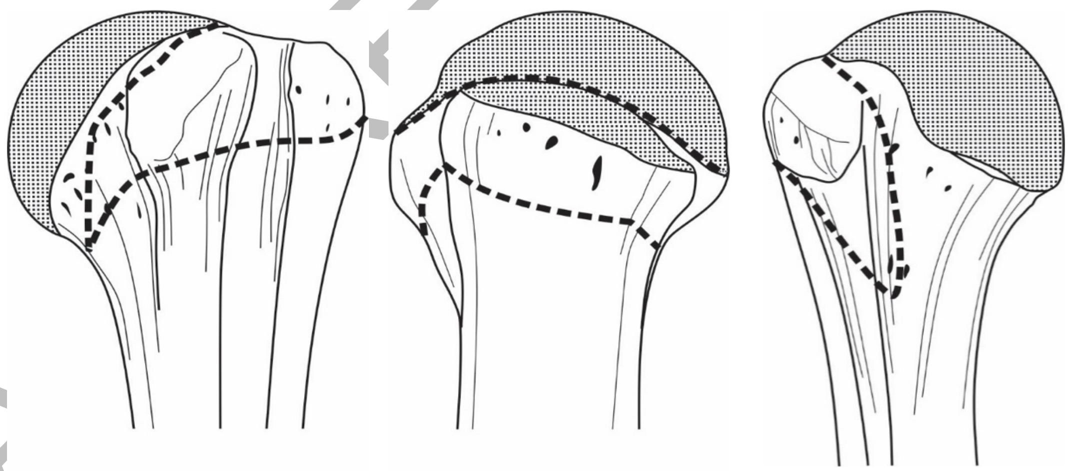

Figure 5: Footprint of the RC from anterior-lateral- posterior view

RESULTS

Insertion and fusion (interdigitation)

The removal of the overlying bursa and the proximal part of the underlying capsule revealed a clear fusion (interdigitation) of the tendons into one another (Fig.6).

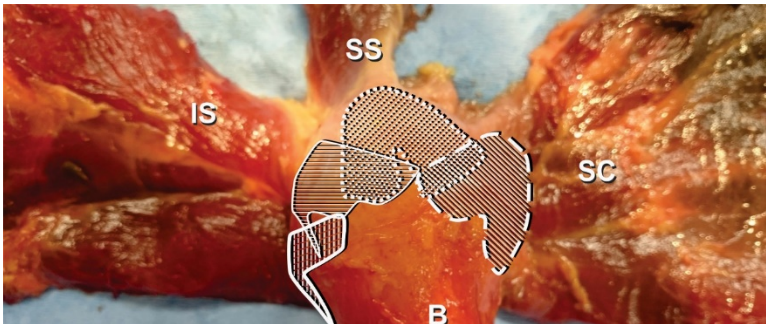

Figure 6: External view of the complete RC unit still attached to humerus. Showing interdigitations between the RC tendons. Long head of biceps (B).

Even though the muscular portions of SP and IS appear separate, their distal tendinous portions, close to the insertion point, proximally 5mm to 1cm, merge and are unable to separate. TM and IS also merge at a small part of their tendinous insertion points and TM's more inferior fibres continue downwards toward the level of the surgical neck of the humerus. There is also a clear interdigitation found between the SC and SP at the bicipital groove surrounding the long head of biceps where they collectively create a roof (hood) and floor, over and underneath the biceps tendon. Subscapularis' more inferior part of the tendon continues distally as far as the surgical neck of the humerus.

After the removal the complete unit, it was observed that the tendons of the RC fused not only into one another, but also into the deep layer of the internal capsule, giving evidence that the RC complex is in fact a complete unit and not separate in structure (Fig.7).

The footprint analysis

The systematic approach was used to trace the implants/ footprints on the humerus. Each shoulder was photographed in 3 different views, anterior view, anterior-superior view and posterior view to show the whole footprint area (Fig.5). Each area was traced using the pen mark, with 2-5mm intervals for accuracy. These areas were then measured using AutoCAD 2016 program (Fig.5). The results were separated into left and right shoulder areas, as well as female and male. Statistical analysis was done on the results using Excel 2010 and SPSS program. The paired t-test was used with a 95% confidence interval and showed no significant difference between the right and left shoulders in the whole population of males and females combined ($p = 0.424$). This concluded that the there is little to no difference in the area size between left and right. Another t-test was done to compare male and female shoulder areas and revealed a significant difference between sexes, with a p-value of 0.000. The results between males and females showed that there is a statistically significant difference between sexes, possibly due to males being more muscular, with a more robust body types and muscular insertions.

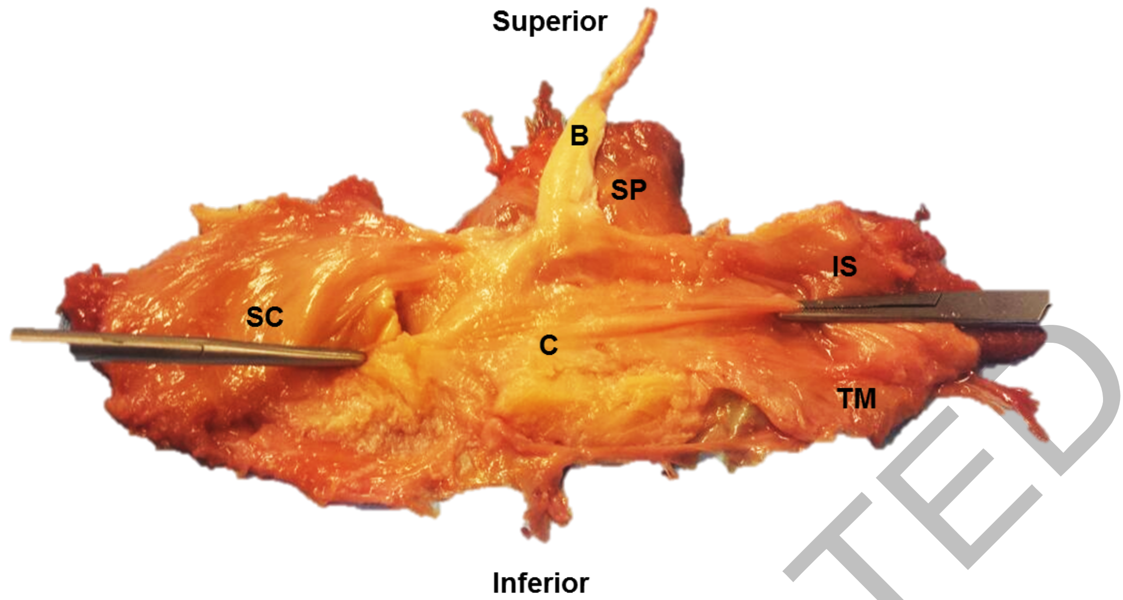

Figure 7: Internal view of the complete RC unit. Subscapularis (SC), supraspinatus (SP), infraspinatus (IS), teres minor (TM), internal capsule (C), long head of biceps (B)

Descriptive statistics were also done for male and female separately, showing the mean, maximum, minimum and standard deviation. The average mean area for males was 243.2 mm² and for females 175.6 mm².

DISCUSSION

The RC insertions according to most anatomical texts are described as being clearly distinct and separate from one another (Williams *et al.*, 1989; Mochizuki *et al.*, 2008) [Fig.8]. However, as demonstrated in previous studies, and corroborated by this study a clear fusion of the RC tendon fibres exist. These findings concur with previous studies that showed this interdigitation that forms a common and continuous insertion onto and around the tubercles of the humerus (Boon *et al.*, 2004; Nimura *et al.*, 2012). Repair methods, especially those utilised with arthroscopic techniques, rarely mention or consider these connections when tendons are repaired and suture anchors are implanted.

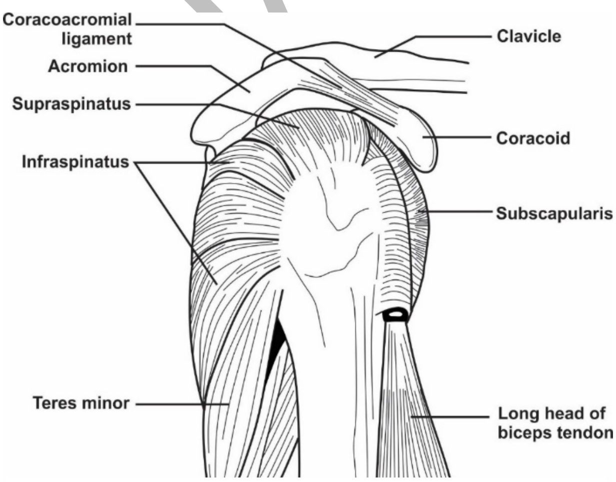

Figure 8: Showing separate insertions of the RC

The desired mechanical repair of RC tendons include a number of principles, namely; the repair should maintain good contact between the tendon and bone; load should be evenly distributed over as many sutures as possible; reinforcement of the bone to tendon should include side to side, tendon-tendon sutures as the tear pattern requires and; a congruent upper surface of the repair cuff-tuberosity construct should be maintained to allow smooth articulation with the under surface of the coracoacromial arch (Park and Cadet, 2005; Bicknell & Harwood, 2005). Biologically, the desired properties include the exclusion of the synovial fluid from the healing site and maximal exposure of the tendon to exposed trabeculae and marrow cells (bone is the source of healing not the tendon) (Koike & Trudel, 2005). In none of the above properties and principles is it mentioned that the extension cuff/hood anatomy and fascial layers, or the role of the internal capsule should be identified and repaired in order to maintain the full biomechanical properties of the shoulder post-operatively. Especially with a torn supraspinatus tendon, as was seen in this study and corroborated with several previously published works, a critical, interconnecting meshwork of fibers exists between supraspinatus and subscapularis (Clark & Harryman, 1992; Boon *et al*, 2004). Additionally, the deeper layers of SP and IP fuse to the internal joint capsule of the glenohumeral joint, which respectively forms a large part of the insertion onto the greater tubercle of the humerus. This reinforcement is not given the importance it warrants during current surgical repair techniques as often just the singular torn tendon is reattached to the bone with the exclusion of it extension insertions to the surrounding RC muscles (Gerber *et al,* 1999).

The second factor that plays an important role in determining the correct placement of the tendon onto bone is the footprint of the rotator cuff. Previous studies have consistently shown separate insertion sites of these tendons onto the tubercles, yet the actual measurements and results are contradictory (Curtis *et al*., 2006; Mochizuki *et al*., 2008). It is apparent in the studies that the insertional areas for the RC muscles are not considered to be a singular and combined unit, but instead are forcefully separated creating pre-perceived shapes as the footprints, subsequently measuring the medial to lateral and posterior to anterior dimensions of each insertional area. The results of the current study clearly demonstrated that there is no separate insertional area for each of the RC muscles inserting onto the greater tubercle, but instead the whole area serves as the insertion zone for all the muscles and the internal joint capsule, and therefore the complete area had to be measured to determine the true combined footprint. The footprint zone could not be measured using simple medial to lateral or posterior to anterior dimensions, as it is seen as a rough, three dimensional and, inconsistent area on the humerus. Therefore, the total area was outlined and measured using AutoCAD, which allowed the rough, curved surface of the tubercles to be quantified. This has implications in that isolated surgery to repair just one tendon may influence the biomechanical effect of the other interdigitated tendons and, not forgetting the internal joint capsule, sharing the same footprint. The fact that the RC unit is much more complex and interconnected as previously thought and once again demonstrated in this study emphasises the fact that the biomechanical stress of one RC muscle is not isolated to that muscles attachment to bone alone but instead is influenced by the surrounding RC muscles and capsular attachment as well.

In conclusion the knowledge of this anatomy plays an important role in not only the surgical procedures, but also in the biomechanical understanding of the rotator cuff muscles and the shoulder joint. The fact that these muscles are interconnected with each other may also influence the previous definitions and actual functional responsibility of each of these muscles; for example, the fusion of SP into IS may result in IS having a larger contribution to abduction of the should instead of only being classified as a lateral rotator. These findings not only give a better understanding of the anatomy of the rotator cuff unit and how it functions, but also a better understanding for surgeons with the goal of improving and enhancing surgical methods for better post-operative patient outcome.

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