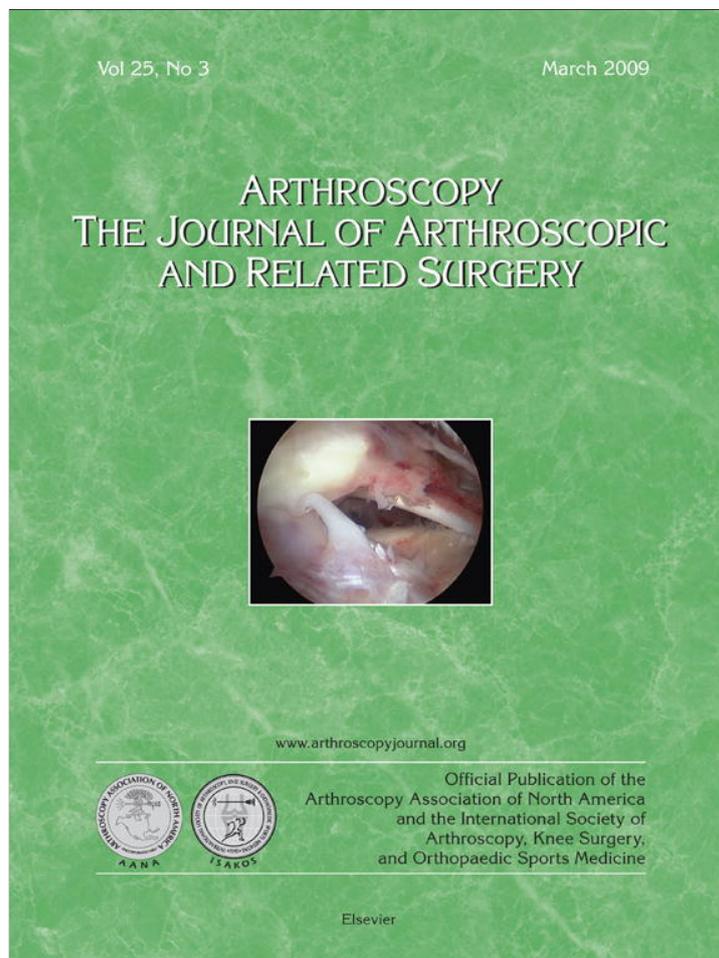


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## Current Concepts

## Current Perspectives on Rotator Cuff Anatomy

Michael J. DeFranco, M.D., and Brian J. Cole, M.D.

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**Abstract:** Understanding the anatomy of the rotator cuff and the surrounding structures that influence its function is essential to treating rotator cuff disease. During the past decade, advances in basic science and surgical technology have improved our knowledge of this anatomy. This review article presents the current concepts on rotator cuff anatomy and how they should be used in the surgical management of rotator cuff tears. **Key Words:** Rotator cuff—Anatomy—Coracoacromial arch—Acromioplasty—Bursectomy—Vascularity.

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**A**lthough many factors influence the treatment of rotator cuff tears, understanding the anatomy and how it relates to function is the most important one. Indeed, fundamental to rotator cuff surgery is knowledge of the normal anatomic relations. Both the osseous and soft-tissue structures have a significant impact on rotator cuff function. Recent research has expanded our knowledge specifically with regard to the rotator cuff as well as the coracoacromial (CA) arch, bursae, and neurovascular structures. On the basis of these data, there are several controversial issues that continue to be debated. Some of these issues include the influence of the morphology of the acromion, CA ligament, and coracoid process on the development of rotator cuff tears; the role of the subacromial bursa as a source of pain or as an essential contributor to a fibrovascular response that may help rotator cuff repairs heal; the relation between greater tuberosity osteopenia and rotator cuff disease; the anatomic definition of the rotator cuff footprint; and the anatomic location of the neurovascular structures surrounding

the rotator cuff. The purpose of this article is to review the current literature on rotator cuff anatomy and how it influences decision making in the surgical care of patients with rotator cuff tears.

## CORACOACROMIAL ARCH

The CA arch is defined as a confluence of the acromion, the CA ligament, and the coracoid process. The morphology of the acromion is relevant to the surgical management of rotator cuff disease for several reasons. First, abnormalities in the development of the acromion may lead to the formation of an os acromiale (Fig 1). Approximately 8% of patients have an os acromiale. In 33% of patients this development abnormality occurs bilaterally.<sup>1</sup> Recent studies suggest an association between os acromiale and rotator cuff tears, but this relation is not well defined.<sup>2-4</sup> In fact, on the basis of the data in the literature, it is unlikely that the os acromiale has a pathologic effect on the rotator cuff.<sup>5</sup> The presence of an os acromiale also does not influence the number of tendons involved in the rotator cuff tear.<sup>5</sup> These findings are important considerations in the preoperative planning for rotator cuff repairs. Boehm et al.<sup>5</sup> retrospectively reviewed the surgical management of 33 patients who received treatment for a rotator cuff tear and an os acromiale. They concluded that at the time of rotator cuff repair, resection is an appropriate treatment for a small, symptomatic os acromiale. A large, symptom-

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*From Midwest Orthopaedics, Rush University Medical Center, Chicago, Illinois, U.S.A.*

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*Address correspondence and reprint requests to Brian J. Cole, M.D., 1725 W Harrison Ave, Suite 1063, Chicago, IL 60612, U.S.A. E-mail: bcole@rushortho.com*

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FIGURE 1. Axillary radiograph. The arrow indicates os acromiale. (Reprinted with permission.<sup>99</sup>)

atic os acromiale can be fused to the acromion. However, fusion of the os acromiale after rotator cuff repair does not result in a better clinical outcome compared with acromioplasty or unsuccessful fusion.<sup>5</sup> Furthermore, acromioplasty as a treatment for os acromiale should be used with caution because it may destabilize the acromion.<sup>6</sup> Practically speaking, in most cases the os acromiale is asymptomatic and can be neglected. However, if symptomatic, the surgeon must determine whether the pain is coming from the os acromiale or acromioclavicular (AC) joint. A prudent clinical evaluation differentiates a symptomatic os acromiale from a painful AC joint. Evaluating magnetic resonance imaging (MRI) studies for AC joint edema and using selective preoperative local anesthetic injections help make this distinction. Recognizing a destabilized os acromiale after an AC joint resection or acromioplasty is also important. Treatment of this iatrogenic instability involves resection (small os acromiale) or rigid fixation (large os acromiale).

Second, the morphology of the acromion and its relation to impingement as a cause of rotator cuff disease is controversial. As a result, the debate continues over whether rotator cuff tears are caused by degenerative changes in cuff tendons or by extrinsic mechanical compression caused by a hooked acromion. Neer<sup>7</sup> developed the concept that rotator cuff tears result from subacromial impingement. Subsequently, the technique and justification for acromioplasty during rotator cuff repairs developed from this ideology.<sup>7</sup> Bigliani et al.<sup>8</sup> further defined subacromial impingement by classifying acromial morphology into

3 primary types: flat (type I), curved (type II), and hooked (type III). The hooked acromion (type III) is most often associated with impingement and rotator cuff tears.<sup>9</sup>

Several recent studies support the relation between subacromial impingement and the development of rotator cuff tears.<sup>10-12</sup> In a cadaveric study Flatow et al.<sup>10</sup> showed a marked increase in contact between the rotator cuff and type III acromions. They suggest that these results support the use of anterior acromioplasty when indicated in older patients with primary impingement. On the basis of a review of their patients treated for impingement syndrome, Wang et al.<sup>11</sup> suggest acromial morphology has a predictive value in determining the success of conservative measures and the need for surgery. In the study 88.9% of patients (24/27) with type I acromions and 73.1% (19/26) with type II acromions responded to conservative management. However, 58% (7/12) of the patients with type III acromions required surgical intervention. Overall, the success of conservative management decreased with increasing acromial type, whereas the need for surgery increased with acromial type ( $P = .008$ ). Gill et al.<sup>12</sup> defined the independent association between acromial morphology and rotator cuff disease using univariate analysis. They showed that acromial morphology is significantly ( $P < .01$ ) associated with rotator cuff pathology. In fact, 50% of patients with rotator cuff tendinitis had a type I acromion, and 50% of patients with a full-thickness rotator cuff tear had a type III acromion. In the same study, multivariate logistic regression analysis identified acromial morphology as an independent multivariate predictor of rotator cuff pathology. Overall, the study showed an association between acromial morphology and rotator cuff pathology.

In general, another source of impingement is enthesophytes that are located at the CA ligament insertion on the acromion. In a cadaveric study by Natsis et al.,<sup>13</sup> enthesophytes were significantly ( $P < .05$ ) more common in type III acromions. The authors concluded that the combination of enthesophytes and acromial morphology is particularly associated with subacromial impingement and rotator cuff tears. Other types of acromions recently described include a type IV (convex) acromion<sup>14</sup> and a keeled acromion (Fig 2).<sup>15</sup> There are no data to strongly support an association between type IV acromions and rotator cuff pathology.<sup>14</sup> The keeled acromion, on the other hand, refers to a central, longitudinal, downward-sloping spur on the undersurface of the acromion, which may contribute to the development of rotator cuff tears. Tucker and



FIGURE 2. Anteroposterior radiograph with outline of keeled acromion. (Reprinted with permission.<sup>15</sup>)

Snyder<sup>15</sup> retrospectively reported on 20 patients with this type of acromion. Of these patients, 100% (20/20) had significant bursal-sided tears and 60% (12/20) had full-thickness rotator cuff tears associated with a keeled acromion. Although additional studies need to confirm and further define these findings, the authors recommend early surgery for a keeled acromion to minimize the risk of rotator cuff tear progression.

In an MRI study of rotator cuff disease, Baechler and Kim<sup>16</sup> reported that the percentage of the humeral head not covered superiorly by the anterolateral acromion may be a factor in the pathogenesis of full-thickness rotator cuff tears. Greater “uncoverage” may allow hinging of the humeral head on the anterolateral edge of the acromion during early shoulder abduction, causing impingement of the supraspinatus tendon between these 2 structures.<sup>16</sup> Conversely, on the basis of a radiographic study of patients with rotator cuff disease, Nyffeler et al.<sup>17</sup> reported a statistically significant ( $P < .001$ ) association between a large lateral extension of the acromion and full-thickness degenerative rotator cuff tears. In another radiographic study Torrens et al.<sup>18</sup> studied acromial coverage of the humeral head as a factor in the development of rotator cuff tears. They suggest that patients with rotator cuff tears have statistically significantly ( $P < .001$ ) more coverage of the humeral head by the acromion compared with the control group without tears. Overall, additional studies need to clarify the degree of acromial coverage that contributes to the development of rotator cuff tears.

Even though research studies support the association between type III acromions and rotator cuff tears, there is an equivalent amount of evidence

disputing it. Zuckerman et al.<sup>19</sup> were unable to identify the 3 acromial types in a cadaveric study. They concluded that the acromial classification described by Bigliani et al.<sup>8</sup> does not accurately describe anatomic findings, and the relation to rotator cuff tears remains unclear and requires further study. Chang et al.<sup>20</sup> used MRI to perform 3-dimensional analysis of the acromion. They concluded that osseous impingement by the acromion is not a primary cause of shoulder impingement syndrome or rotator cuff tears. In another MRI study Hirano et al.<sup>21</sup> determined that with type III acromions, rotator cuff tears were significantly larger than in types I and II. The study suggests that acromion morphology influences rotator cuff tear size. Interestingly, comparison of age-matched patients with and without rotator cuff tears showed that the occurrence rate of type III acromial shape in the rotator cuff tear group was not significantly higher. These results suggest that a type III acromion does not always correlate with the development of rotator cuff tears. Schipinger et al.<sup>22</sup> reported that no type III acromions were identified in their study. Their findings suggest that hooked acromions (type III) are not present in the normal population and are likely to be an acquired abnormality. Several recent clinical studies also suggest that avoiding acromioplasty at the time of rotator cuff repair does not change the clinical or anatomic outcome.<sup>23-27</sup>

Given the results of these studies, the association between acromial morphology and rotator cuff tears may not be as strong as described in the literature.

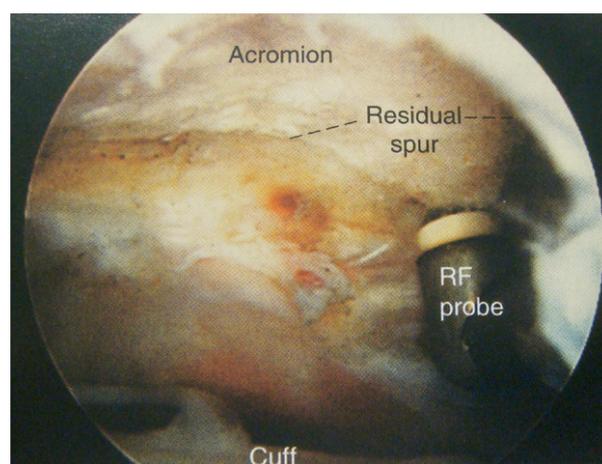


FIGURE 3. Inadequate acromioplasty in a right shoulder. A residual anterolateral spur is shown in the photograph. The radiofrequency (RF) probe has been inserted through the lateral portal.

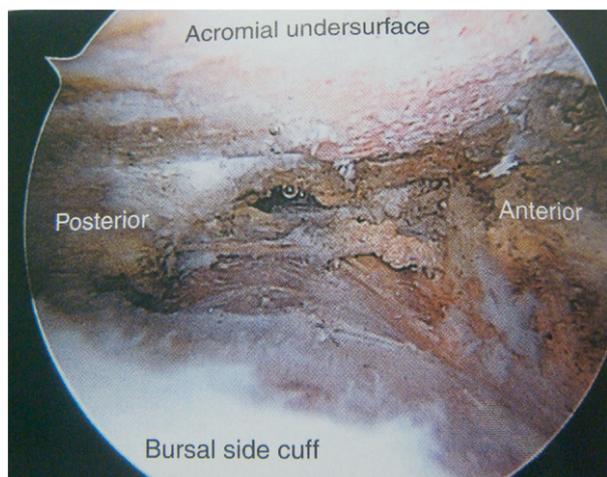


FIGURE 4. An adequate acromioplasty with an even line of resection as viewed from the lateral portal.

Nevertheless, acromioplasty continues to be used by most shoulder surgeons, except in cases where the CA arch provides superior stability to prevent escape of the humeral head, as in massive rotator cuff tears. During acromioplasty, preservation of the normal anteroposterior dimension of the acromion is essential. Large acquired osteophytes found within the CA ligament should be removed without destroying the acromial architecture. According to Flatow et al.,<sup>28</sup> smoothing the anterior third of the acromial undersurface removes all focused contact on the supraspinatus insertion (Figs 3 and 4). Totally flattening the acromion is unnecessary to relieve impingement. Excessive release of the deltoid origin should also be avoided during acromioplasty. According to a study by Green et al.,<sup>29</sup> 4 mm of acromial bone resection results in release of  $56\% \pm 11\%$  of the deltoid origin. Increasing the amount of resection to 5.5 mm leads to release of  $77\% \pm 15\%$  of the deltoid origin. They conclude that the amount of deltoid released correlates statistically with both the thickness of the acromion and acromial angle ( $P < .0001$  and  $P = .04$ , respectively). These factors should be considered during preoperative planning to decrease the risk of inadvertent deltoid detachment. Overall, although a casual relation between impingement syndrome, rotator cuff pathology, and acromial morphology is strongly suggested by published scientific data, the exact sequence of cause and effect between these entities is not well defined in the orthopaedic literature.

## CA LIGAMENT

The CA ligament originates along the distal two thirds of the lateral aspect of the coracoid process as a broad ligament. It passes posteriorly to insert onto the anteromedial and anteroinferior surfaces of the acromion.<sup>30,31</sup> A recent cadaveric study showed variation in the morphology of the CA ligament. The most common configuration of the CA ligament is 2 distinct ligamentous bands: anterolateral and posteromedial.<sup>32</sup> Spur formation occurs preferentially in the anterolateral band. As a result, the anterolateral band is commonly involved in impingement syndrome. If the posteromedial bundle is mistaken to be the entire ligament, then the surgeon may fail to visualize the anterolateral corner of the acromion and perform an incomplete subacromial decompression.

Despite the conclusions by Fealy et al.<sup>32</sup> regarding the role of the CA ligament in impingement syndrome, Pieper et al.<sup>33</sup> found no significant relation between the morphology of the CA ligament and the incidence of rotator cuff degenerative changes or spur formation. Similarly, Kesmezarar et al.<sup>34</sup> reported on 5 anatomic variations of the CA ligament. On the basis of the results of this study, the Y-shaped ligament is the most common type. There was no statistical significance ( $P < .05$ ) between rotator cuff degeneration and the type of geometric measurement of the ligament.<sup>34</sup> However, the CA ligaments with more than 1 bundle showed a significant ( $P < .05$ ) association with rotator cuff degeneration. These CA ligaments were unique in having a longer lateral border and larger coracoid insertion than other ligaments.

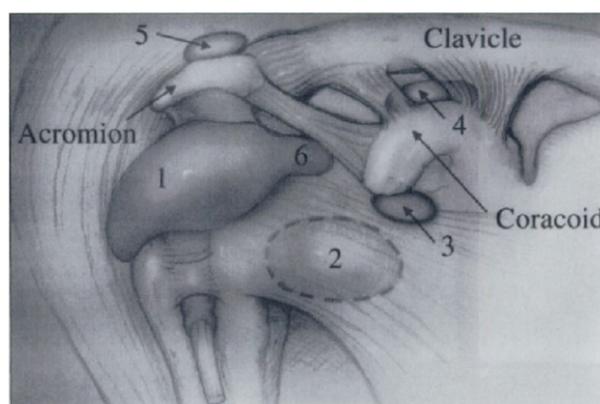


FIGURE 5. Subacromial anatomy. (1, subacromial-subdeltoid bursa; 2, subscapularis recess; 3, subcoracoid bursa; 4, coracoclavicular bursa; 5, supra-acromial bursa; 6, medial extension of subacromial-subdeltoid bursa.) (Reprinted with permission from the *American Journal of Roentgenology*.<sup>98</sup>)

Fremerey et al.<sup>35</sup> also used a cadaveric study to define anatomic and biomechanical properties of the CA ligament in shoulders with either intact rotator cuffs or rotator cuff disease. Specimens from cadavers with rotator cuff disease had a shorter medial and lateral band of the CA ligament than specimens taken from shoulders with intact rotator cuffs. The cross-sectional area of the lateral band was enlarged in older specimens with rotator cuff degeneration. These enlarged lateral bands had a decreased failure stress in shoulders with rotator cuff degeneration, but this was found only in the older cadaveric groups. On the basis of these findings, the authors suggest that substantial alterations in morphologic and biomechanical properties occur in the CA ligament during aging. However, more studies are needed to determine whether variation in the CA ligament morphology causes impingement or is a function of it.

### CORACOID PROCESS

Many anatomic studies define the morphology of the coracoid process.<sup>36-40</sup> In a recent study Bhatia et al.<sup>41</sup> used quantitative and statistical analysis of linear and angular dimensions to define the individual pillars of the coracoid process. The pillar anatomy of the coracoid and its effect on subcoracoid space are essential to understanding the concept of coracoid impingement. According to Bhatia et al., impingement of the rotator cuff occurs between the posterolateral coracoid and humeral head. Clinically, this condition manifests itself as anterior shoulder pain with forward flexion, internal rotation, and horizontal adduction of the humerus.<sup>42</sup> Subcoracoid pain is the result of impingement of the subscapularis tendon between the lesser tuberosity and coracoid process.<sup>42-46</sup> Changes associated with this impingement include supraspinatus tendon injury, subscapularis tendon injury, changes to the rotator interval, and thickening of the CA ligament.

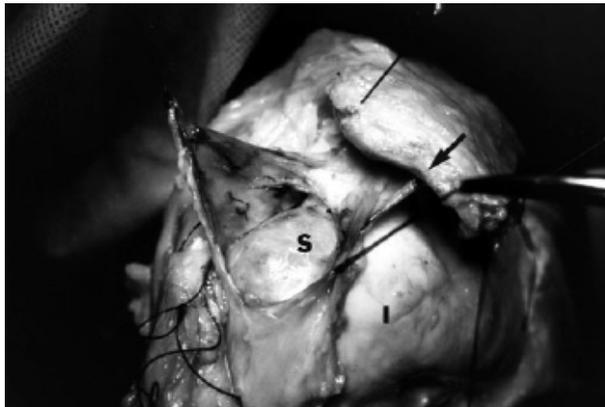
Theoretically, an increase in axial angulation of either pillar, a decrease in interpillar angulation, or a decrease in the length of either pillar may predispose an individual to coracoid impingement and place the supraspinatus or subscapularis at risk for tearing.<sup>41</sup> In a cadaveric study, Ferreira Neto et al.<sup>47</sup> showed that women have a smaller distance between the apex of the coracoid process and the lesser tuberosity of the humerus with the arm in internal rotation. This finding suggests that impingement may be more likely between these 2 bony structures in female patients.<sup>47</sup>

Previous studies have also suggested that mechanical bony irritation caused in part by pathologic coracoid morphology is an important etiologic factor in the development of coracoid impingement.<sup>48</sup>

Schulz et al.<sup>49</sup> correlated coracoid tip position with rotator cuff tears. In their radiographic study they used a true anteroposterior view of the shoulder to classify the coracoid into 1 of 2 types. Type I coracoids (in which the tip of the coracoid process projects onto the inferior half of the glenoid surface) are associated with supraspinatus tears ( $P = .0002$ ). Type II coracoids (in which the tip of the coracoid process projects onto the superior half of the glenoid surface) are associated with subscapularis tears ( $P < .0001$ ). Overall, the authors suggest that identification of the coracoid type in shoulders suspected of having rotator cuff pathology shows an 86% sensitivity and a 71% specificity for supraspinatus tears (type I coracoid). In subscapularis tears (type II coracoids) the sensitivity and specificity are 71% and 86%, respectively.

Richards et al.<sup>50</sup> used a retrospective cohort to show a significant relation between a narrowed coracohumeral distance and subscapularis pathology. In this study the coracohumeral distance was measured on axial magnetic resonance images. The mean coracohumeral distance in the group with no subscapularis pathology was  $10 \pm 1.3$  mm. In the group with subscapularis tears, the distance was  $5 \pm 1.7$  mm, which was a statistically significant difference ( $P < .0001$ ). This information is helpful as an adjunct in the clinical evaluation of anterior shoulder pain and in the preoperative planning in patients undergoing rotator cuff repair who may also need a coracoplasty.

When coracoid impingement is refractory to nonoperative management for at least 6 months, the patient may be a candidate for coracoplasty. In a prospective study by Kragh et al.,<sup>51</sup> coracoplasty resulted in statistically significant relief of pain ( $P < .0001$ ) and improved function ( $P < .006$ ) in patients with primary coracoid impingement in whom nonoperative management failed. Coracoplasty may be indicated in patients with rotator cuff repairs when it is obvious that abrasion from the coracoid has contributed to tearing of the tendon. Subcoracoid impingement can also be a problem during the postoperative period. Suenaya et al.<sup>52</sup> studied postoperative subcoracoid impingement syndrome in 11 of 216 patients who underwent an acromioplasty and rotator cuff repair. In these 11 patients, the authors identified subcoracoid impingement as the cause of ongoing pain and unsatisfactory clinical outcome. If a patient has a rotator cuff tear, symptomatic coracoid impingement, and a



**FIGURE 6.** Lateral aspect of subacromial space. The subacromial bursa has been opened. The posterior bursa attaches midway between the anterior and posterior corners of the acromion. The bursal cavity is situated over the supraspinatus tendon (S) but only extends over a limited portion of the infraspinatus tendon (I). When reduced anatomically, the anterolateral corner of the acromion (top needle) is centered within the subacromial bursa. The arrow indicates the acromial corner. (Reprinted with permission.<sup>60</sup>)

narrow coracohumeral space, then all of these problems should be managed during the same surgery by performing a rotator cuff repair, anterior acromioplasty, and coracoplasty.<sup>52</sup> Even though these studies suggest a relation between subcoracoid stenosis and the development of rotator cuff tendon tears,<sup>50,53,54</sup> recent studies are not in agreement with this hypothesis.<sup>55,56</sup>

Tan et al.<sup>55</sup> used MRI of the coracoid and subcoracoid space to study the association between these structures and rotator cuff tears. They reported no significant differences in coracoid morphology between patients with normal findings and patients with varying degrees of rotator cuff disease involving the supraspinatus tendon. On the basis of their results, they were unable to define the role of coracoid anatomy in the development of pathology of the subscapularis tendon and long head of the biceps.

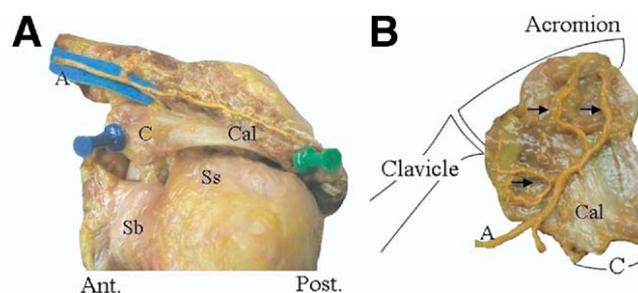
In a cadaveric study Radas and Pieper<sup>56</sup> evaluated coracoid impingement of the subscapularis. The distance between the lesser tuberosity and the coracoid was measured at different degrees of humeral rotation. The lesser tuberosity approaches and, in some cases, touches the coracoid process at early stages of internal rotation. In most cases contact between the 2 bones occurs at 50° to 60° of internal rotation.<sup>56</sup> With regard to the measurements, no significant differences (*P* value not reported) were found between the shoulders with and without rupture of the subscapularis tendon. On the basis of the findings of this study, coracoid

impingement does not seem to be caused by anatomic variations of the coracoid. Instead, it results from a functional problem, such as anterior instability of the shoulder joint, which leads to a functional narrowing of the coracohumeral distance.<sup>56</sup>

## BURSAE

There are 3 bursae relevant to the development of shoulder pain and rotator cuff disease: subacromial, subdeltoid, and subcoracoid (Fig 5). The subacromial bursa occupies a space above the rotator cuff and under the acromion. It is a synovium-lined cavity that acts as a gliding surface in 2 locations: (1) between the rotator cuff tendons and the CA arch and (2) between the deltoid muscle and the cuff tendon. The subdeltoid bursa is an independent structure located on the deep surface of the deltoid muscle.<sup>57</sup> In some cases, this bursa is referred to as the subdeltoid extension of the subacromial bursa. The subacromial and subdeltoid bursae act together and extend as far medially as the coracoid process. The subcoracoid bursa is located inferior to the coracoid process between the subscapularis tendon and the conjoined tendon of the coracobrachialis muscle and short head of the biceps muscle. There may be a connection between the subcoracoid and subacromial bursae.<sup>58</sup> Voloshin et al.<sup>59</sup> reported that high levels of inflammatory cytokines and enzymes produce a catabolic environment in the bursae of patients with rotator cuff tears. This emphasizes the importance of bursectomy to reduce pain and inflammation associated with rotator cuff disease.

Understanding the boundaries of the bursae is essential to performing an adequate bursectomy. Beals et al.<sup>60</sup> defined the subacromial bursal margins and relation to the axillary nerve in a cadaveric study (Fig 6).



**FIGURE 7.** Left shoulder. (A) Acromial artery (A), which travels medial to lateral as it passes over the CA ligament (Cal). (C, coracoid insertion [anterior pin]; Ss, supraspinatus tendon; Sb, subscapularis tendon; Ant, anterior; Post, posterior.) (B) The acromial artery (A) passes from medial/inferior to lateral/superior and then divides into CA arterioles (arrows). (C, coracoid insertion; Cal, CA ligament.) (Reprinted with permission.<sup>71</sup>)

In general, the margins of the bursa are 2 cm or more from the anterolateral corner of the undersurface of the acromion. More specifically, the mean distance from the anterolateral corner of the acromion to the posterior bursal cavity is  $2.8 \pm 0.6$  cm (55% of the anteroposterior acromial length). The mean distance from the midpoint of the acromion to the subdeltoid bursal reflection of the subacromial bursa is  $4.0 \pm 1.0$  cm. The distance between the AC joint and the medial extent of the subacromial bursa is variable. Some bursae do not cross medial to the plane of the AC joint. However, others cross at a maximum of 2.3 mm medial to the AC joint. The distance from the medial AC joint to the medial extent of the bursa is  $0.7 \pm 0.7$  mm. Only the anterior half of the distance between the anterolateral and posterolateral corners of the acromion is contained within the subacromial bursa cavity. The anterolateral corner, therefore, is central to the boundary reflections of the subacromial bursa. For this reason, the anterolateral corner is a useful landmark for placement of an arthroscopic portal into the bursa.

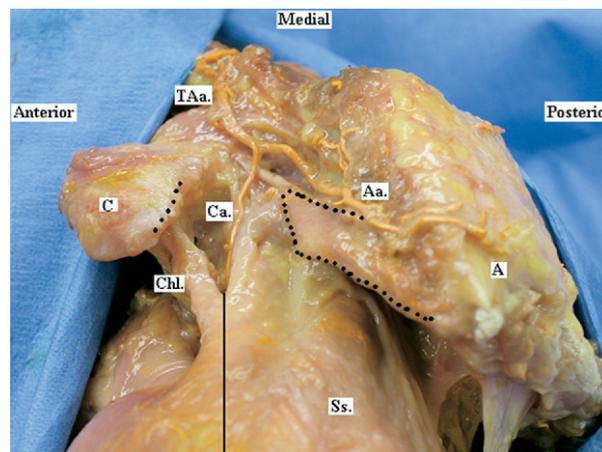
In the same study by Beals et al.,<sup>60</sup> the mean distance from all points of the acromion to the axillary nerve was 5 cm. The mean minimum distance from the subdeltoid bursal reflection to the axillary nerve was  $0.8 \pm 0.5$  cm, with a range of 0.0 to 1.4 cm. In the unelevated extremity the inferior bursal reflection was always cephalad to the axillary nerve. Given these data, surgeons should exercise caution at the inferior boundary of the subdeltoid bursal reflection because of the proximity of the axillary nerve.<sup>60</sup>

Duranthon and Gagey<sup>57</sup> performed a cadaveric study to define the anatomy and function of the subdeltoid bursa. An increase in thickness of the subdeltoid bursa can contribute to subacromial impingement. They identified 2 attachments for the subdeltoid bursa. The first is proximal and superficial along the entire free border of the CA ligament and along the deep surface of the deltoid. There are no insertions anteriorly, posteriorly, or directly to the acromion. The distal attachment is to the greater tuberosity of the humerus, lateral to the origin of the supraspinatus and infraspinatus. The distal pouch passes just beyond the distal deltoid attachment to the humerus. The distal end of the pouch is located at a mean of 10 mm (range, 5 to 12 mm) proximal to the axillary nerve. The study also found anatomic continuity between the CA ligament and the subdeltoid bursa, which can mask the outer edge of the CA ligament. Recognition of these anatomic findings is helpful in performing a thorough subacromial decompression.

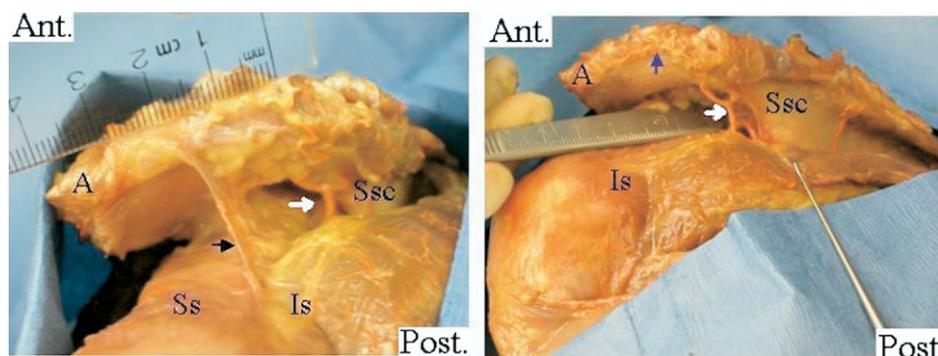
In an MRI study White et al.<sup>61</sup> analyzed the subacromial-subdeltoid fluid in relation to rotator cuff tears. The normal subacromial-subdeltoid bursa fluid is rarely thicker than 2 mm and tends to be located posteriorly. An abnormal amount of fluid is suggestive of a rotator cuff tear. More specifically, there should be a high index of suspicion for a rotator cuff tear when the subacromial-subdeltoid thickness exceeds 3 mm, when bursal fluid is present medial to the AC joint, and when fluid is seen in the part of the bursa anterior to the humerus.<sup>61</sup>

Subacromial disease encompasses a spectrum of disease ranging from bursitis to adhesion formation. Rotator cuff tears are often associated with subacromial bursitis, and this bursitis leads to the formation of adhesions, which contributes to impingement.<sup>62-65</sup> Machida et al.<sup>66</sup> studied 18 patients with shoulder pain. They found that adhesions of the subacromial bursa increase impingement between the acromion and the insertion of the rotator cuff. The adhesions need to be released completely during surgery of the rotator cuff as part of the subacromial decompression. When an adequate release is performed, the mean subacromial pressure and mean subacromial contact area decrease significantly.<sup>66</sup>

Funk et al.<sup>67</sup> studied patients who were diagnosed with a subacromial plica during arthroscopic subacromial decompression. The odds of impingement were



**FIGURE 8.** Lateral view of shoulder with deltoid removed. Dotted lines represent insertion points for the CA ligament, which has been removed. The anterior capsular artery (Ca) passes through the triangle formed by the base of the coracoid (C), anterior border of the supraspinatus (Ss), and coracohumeral ligament (Chl). The anterior capsular artery is at risk for getting cut when an anterior interval slide (solid line) is completed by the surgeon to mobilize the retracted tendon. (TAA, thoracoacromial artery; Aa, acromial artery; A, acromion.) (Reprinted with permission.<sup>71</sup>)



**FIGURE 9.** (A) Left shoulder with deltoid removed. The black arrow indicates the posterior wall of the bursal sac. The white arrow represents the posteromedial acromial artery (branch of suprascapular artery). (A, anterior border of acromion; Ss, supraspinatus; Is, infraspinatus; Ssc, spine of scapula; Ant, anterior; Post, posterior.) (B) The posterior wall of the bursal sac has been removed to show the spine of the scapula (Ssc). The white arrow represents the posteromedial acromial artery that terminates in the lateral border of the acromion. The blue arrow indicates its course at the inferolateral border of the acromion. (Ant, anterior; Post, posterior.) (Reprinted with permission.<sup>71</sup>)

3.41 times higher in shoulders with a plica compared with shoulders without a plica. Overall, the prevalence of subacromial plica is 6% in shoulders presenting with subacromial impingement. The impingement changes caused by the plica are not degenerative. They are mechanical abrasions due to rubbing between the rotator cuff and the undersurface of the acromion and the CA ligament. In younger patients the diagnosis of plica as a reason for impingement should be considered only after secondary impingement due to instability has been ruled out.<sup>67</sup>

Overall, the bursae are essential to normal rotator cuff function. Knowing the boundaries of the bursae guides the ability to perform an adequate decompression and to avoid injury to neurovascular structures. Inflammation within the bursae can lead to pain and shoulder dysfunction. Bursectomy and plica removal as part of a thorough subacromial decompression are required to help alleviate pain and to make an accurate assessment of other structures, such as the acromion, CA ligament, and rotator cuff. This opinion, however, is not without controversy. There are investigators who recommend bursal preservation at the time of rotator cuff repair because of the theoretic contribution of blood supply to healing at the tendo-osseous junction.<sup>65,68-70</sup> For example, on the basis of biopsy specimens from 115 patients with complete rotator cuff tears, Uhthoff and Sarkar<sup>65</sup> suggest that extensive subacromial debridement including bursectomy should be avoided. According to them, the main source of fibrovascular response after a rotator cuff tear is the wall of the subacromial bursa. Therefore, if this tissue is preserved during rotator cuff repair, it could hypothetically contribute to tendon reconstitution and remodeling.<sup>65</sup>

### SUBACROMIAL VASCULATURE

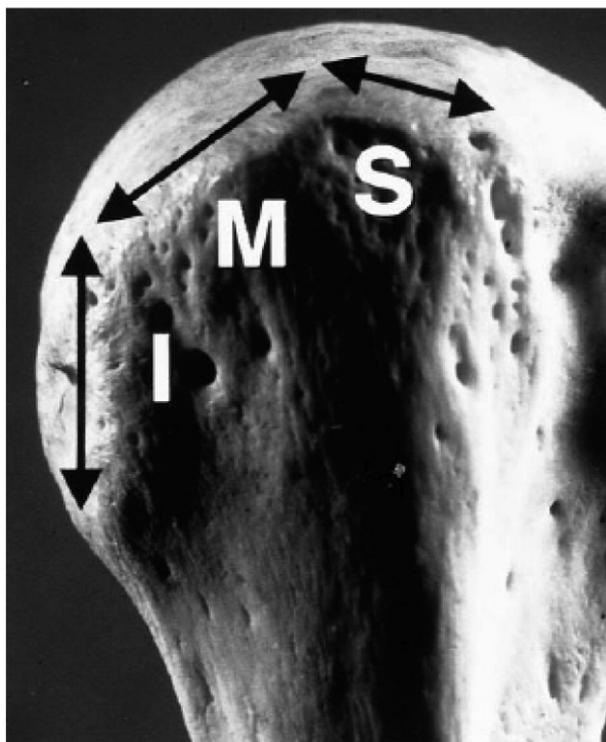
Understanding the vascular anatomy of the subacromial space is important to control bleeding and to maintain visualization during arthroscopy. Yepes et al.<sup>71</sup> defined the arterial supply to the acromion and subacromial space (Figs 7-9). The pattern of blood supply is constant in 60% of shoulders (Table 1). During acromioplasty, bleeding often occurs from vessels originating from the acromial branch of the thoracoacromial artery. These vessels are easily injured during acromioplasty and bursectomy when one is working near the anterior aspect of the AC joint. Another vessel commonly at risk is the suprascapular artery. It runs over the neck of the glenoid close to the spinoglenoid notch and anastomoses with the ascending posterior scapular circumflex artery.<sup>72</sup> Surgeons should remember that surgical instruments directed parallel to the glenoid neck may

**TABLE 1.** *Vascular Anatomy of Acromion*

	Primary Blood Supply
Anterior wall	Acromial branch of thoracoacromial artery
Posterior wall	Posteromedial branch of suprascapular artery
Medial wall	Anterior and posterior arteries of AC joint*
Lateral wall	Posteromedial branch of suprascapular artery and lateral divisions of acromial artery
Superior wall	
Anterior	Arterioles from CA ligament Posterior AC artery† and posteromedial acromial branch of suprascapular artery
Medial	
Lateral	Intramuscular arterioles of deltoid muscle

\*Branches of the acromial artery supply the anterior AC joint.

†A branch of the suprascapular artery supplies the posterior AC joint.



**FIGURE 10.** Proximal humerus, showing 3 facets of greater tuberosity (superior [S], middle [M], and inferior [I]). (Reprinted with permission.<sup>80</sup>)

injure these arteries if they are advanced beyond 20 mm from the glenoid rim.<sup>72</sup>

### GREATER TUBEROSITY

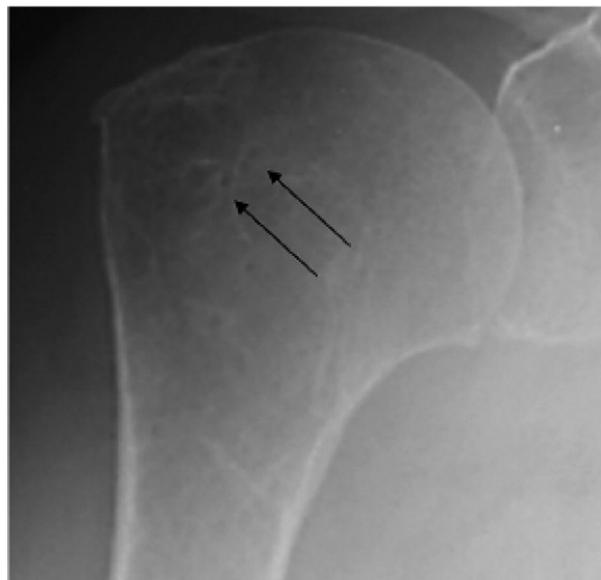
The greater tuberosity has 3 facets (superior, middle, and inferior) where rotator cuff tendons (supraspinatus, infraspinatus, and teres minor) insert (Fig 10). Bone mineral density in this area is an important factor in the surgical treatment of rotator cuff tears. Osteopenia at the greater tuberosity can complicate surgical repair and healing of the rotator cuff tendons (Fig 11). In a retrospective review of 27 patients by Cadet et al.,<sup>73</sup> there were significantly greater osteopenic changes in the greater tuberosity in patients with chronic retracted rotator cuff tears. According to Wolff's law,<sup>74</sup> bone remodels in response to mechanical stress and this process helps determine bone mass density. After a rotator cuff tear, the forces normally transmitted to the greater tuberosity through the rotator cuff tendons are no longer present. As a result, osteopenia develops and can decrease the pullout strength of anchors and sutures used for rotator cuff

repair.<sup>73,75,76</sup> Jiang et al.<sup>77</sup> suggested that the degree of bone loss was dependent on the nature of the rotator cuff tear. In other words, full-thickness tears result in more bone loss than partial-thickness tears.<sup>77,78</sup> Previous studies have defined intraoperative strategies for improving fixation in osteopenic bone.<sup>75</sup> Overall, proximal humerus bone mineral density should be evaluated preoperatively as a factor relevant to the clinical outcome of patients undergoing rotator cuff repair.

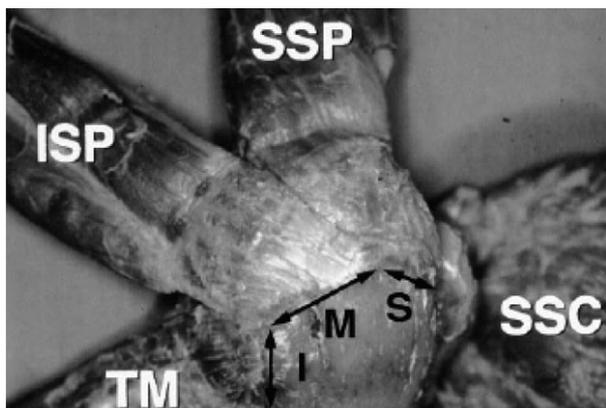
### ROTATOR CUFF FOOTPRINT

Understanding the insertional anatomy of the rotator cuff tendons is important not only in diagnosing the extent of rotator cuff tears but also in repairing them correctly. Table 2 outlines the recent studies that define the dimensions of the rotator cuff insertions onto the proximal humerus. This area is known as the rotator cuff footprint.<sup>79,84</sup> It is the basis for anatomic repair of the rotator cuff (Figs 12-14).

Using cadaveric shoulders, Minagawa et al.<sup>80</sup> described the insertional anatomy (width only) of the supraspinatus and infraspinatus tendons in reference to the greater tuberosity. According to their measurements, the supraspinatus tendon attaches to the superior facet and the superior half of the middle facet of the greater tuberosity. The infraspinatus attaches to



**FIGURE 11.** Anteroposterior radiograph of a tight shoulder showing osteopenia of humeral head (arrows) in a patient with rotator cuff tear. (Reprinted with permission.<sup>73</sup>)



**FIGURE 12.** Insertion points of rotator cuff tendons. The supraspinatus (SSP) inserts onto the superior facet of the greater tuberosity and the superior half of the middle facet. The infraspinatus tendon (ISP) is attached to the entire length of the middle facet covering the posterior half of the supraspinatus. (TM, teres minor; SSC, subscapularis; S, superior; M, middle; I, inferior.) (Reprinted with permission.<sup>80</sup>)

the entire middle facet and covers part of the supraspinatus tendon. More specifically, Dugas et al.<sup>79</sup> defined the mean anteroposterior distance across the rotator cuff insertion onto the greater tuberosity as 37.8 mm. The mean minimum medial-to-lateral distance across the rotator cuff insertion onto the greater tuberosity is 14.7 mm. The mean area of insertion of the supraspinatus, infraspinatus, and teres minor onto the greater tuberosity is 6.2 cm<sup>2</sup>. In conclusion, they suggest that recreating this normal anatomic area at the time of surgery increases the likelihood of normal healing and subsequent normal function.<sup>79</sup>

Volk and Vangsness<sup>85</sup> used cadaveric shoulders to define the insertional anatomy of the supraspinatus. The primary measurement was the length of the anterior and posterior tendinous and muscular portions from the lateral insertion. The anterior lateral portion of the supraspinatus had more tendon, which in one

third of the specimens was associated with separate muscle fibers. Posteriorly, the tendinous portion of the lateral supraspinatus muscle did not extend as far medially from its insertion at the greater tuberosity. The authors suggest that the consistent anterior tendinous portion of the supraspinatus (5.4 cm in length) may provide a firm area for rotator cuff repair or rotator interval closure.

In a cadaveric study, Roh et al.<sup>86</sup> reported that the anterior muscle belly of the supraspinatus is larger than the posterior one. The larger anterior portion of the supraspinatus is primarily responsible for arm abduction and humeral head depression. Therefore, a rotator cuff tear in this area results in a loss of functional tendon length as well as an inability to transmit contractile loads to the humerus to perform these functions. In addition, they propose that the larger anterior muscle pulls through a smaller cross-sectional area of tendon. As a result, the anterior portion of the tendon experiences more stress. Therefore, during rotator cuff surgery, this area should be incorporated into the repair because it transmits most of the contractile load and will allow for the best functional outcome.<sup>86</sup>

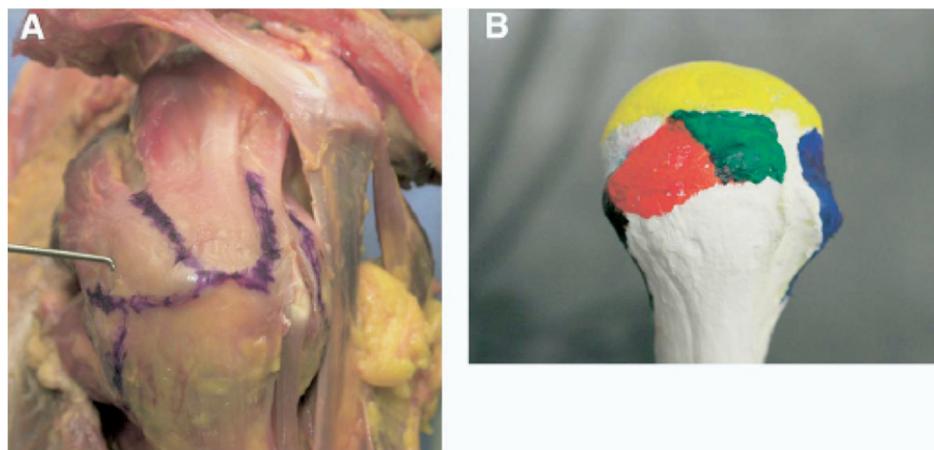
Boon et al.<sup>83</sup> performed a cadaveric study to look at the extension of the supraspinatus tendon into the subscapularis. The subscapularis extends over the bicipital groove interdigitating with the supraspinatus over the greater tuberosity of the humerus. The direction of the subscapularis over the lesser tuberosity and the direction of the tendon of the supraspinatus toward the bicipital groove facilitate their biomechanical function of stabilizing the shoulder joint. The area of interdigitation between the subscapularis and the supraspinatus may become disrupted as part of a rotator cuff tear. In such cases the tendons should be realigned and sutured to provide additional strength to the rotator cuff repair.<sup>83</sup>

**TABLE 2.** Dimensions of Rotator Cuff

Author	Rotator Cuff Dimensions (mm) (Mean Length × Width)			
	Subscapularis	Supraspinatus	Infraspinatus	Teres Minor
Minagawa et al. <sup>80</sup>	NA	NA × 22.5 ± 3.1	NA × 14.1 ± 3.9	NA
Volk and Vangsness <sup>85</sup>	NA	27.9 × NA	NA	NA
Roh et al. <sup>86</sup>	NA	NA × 21.2	NA	NA
Dugas et al. <sup>79</sup>	24 × 18	16 × 12	16 × 13	20 × 11
Ruotolo et al. <sup>82</sup>	NA	NA × 25	NA	NA
Curtis et al. <sup>84</sup>	40 × 20	23 × 16	29 × 19	29 × 21

Abbreviation: NA, not available.

**FIGURE 13.** (A) A right shoulder, showing myotendinous units with intervals marked before dissection. (B) Anatomic model showing footprint of supraspinatus tendon (green), infraspinatus tendon (red), and subscapularis tendon (blue) anterior to biceps groove. The humeral head is indicated in yellow. (Reprinted with permission.<sup>84</sup>)



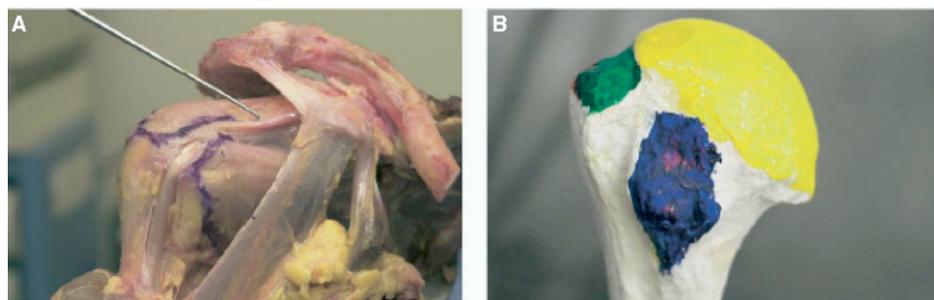
Curtis et al.<sup>84</sup> defined the dimensions of each rotator cuff tendon. With regard to the supraspinatus, the most lateral attachment continues over the lip of the greater tuberosity. The anterior border of the infraspinatus insertion overlaps the posterior border of the supraspinatus. Because the tendons do overlap near their insertion into the humerus, this can make defining the interval difficult and somewhat arbitrary. The supraspinatus fibers insert closer to the articular surface, whereas the infraspinatus fibers intertwine and cross over to insert more laterally and anteriorly onto the tuberosity. The infraspinatus footprint extends inferiorly on the greater tuberosity, essentially framing the upper half of the bare area.

#### ARTICULAR SURFACE MARGIN

Articular-sided partial-thickness rotator cuff tears develop at the attachment of the tendon just lateral to the articular margin. Ellman<sup>87</sup> described a classification system for partial-thickness tears based on the thickness of the rotator cuff tendon. On the basis of data in the literature, the thickness of the rotator cuff varies from 10 to 14 mm.<sup>79,82,84,87</sup> A normal margin

(1.5 mm) of exposed bone exists between the articular cartilage and the supraspinatus insertion. Measuring the exposed bone in an anteroposterior plane and mediolateral plane determines the surface area of tendon lost from the supraspinatus footprint.

Several studies have defined the forces associated with supraspinatus and infraspinatus function.<sup>88-90</sup> These forces are concentrated at the lateral insertion point on the greater tuberosity and move laterally with progressive abduction of the arm. More specifically, finite-element analysis shows that the area of maximum stress is on the articular side of the supraspinatus tendon and shifts closer to its insertion at 60° of abduction.<sup>89</sup> The frequent finding of rotator cuff tears in this area may be explained by its high concentration of stress with arm elevation.<sup>89</sup> Indeed, Sano et al.<sup>91</sup> negatively correlated the width of the articular margin with ultimate tensile strength of the supraspinatus. The width of this sulcus, therefore, is a useful clinical indication of the integrity and tensile strength of the supraspinatus tendon.<sup>91</sup> The addition of a medial row to rotator cuff repair may help to strengthen fixation and to distribute force by increasing surface area and allowing the tendon to heal under less stress. The mid-



**FIGURE 14.** (A) A right shoulder showing anterior view of subscapularis tendon before dissection of footprint. (B) Anatomic model showing footprint of subscapularis tendon (blue). Yellow indicates the humeral head and green indicates the footprint of the supraspinatus tendon insertion. (Reprinted with permission.<sup>84</sup>)

point of tendon insertion can be moved up to 10 mm medially with no resultant negative biomechanical consequences.<sup>92</sup> Overall, the greater extent to which a given repair covers the healing zone (footprint), the greater the chance for tendon-bone healing.

The relation between the insertion of the rotator cuff and the articular surface varies in the literature. According to Dugas et al.,<sup>79</sup> the distance from the articular margin to the most medial rotator cuff fibers was less than 1 mm along the anterior-most 2.1 cm of the rotator cuff insertion onto the greater tuberosity. Curtis et al.<sup>84</sup> reported that the subscapularis inserts onto the lesser tuberosity adjacent to the biceps groove at the edge of the articular surface. It tapers from 0 mm superiorly to 18 mm at its inferior border. The supraspinatus inserts at the articular surface along its entire insertion from the bicipital groove to the top of the bare area. The insertion appears at a mean of 0.9 mm (range, 0 to 4 mm) from the edge of the articular surface. In most cases the supraspinatus inserts directly onto the articular surface through the entire length of the tendon. The infraspinatus wraps the posterior border of the supraspinatus superiorly at the articular surface. It tapers from the articular margin 0 mm superiorly to 16 mm inferiorly. The gap between the articular surface and inferior insertion forms the "bare area."<sup>84</sup>

Ruotolo et al.<sup>82</sup> defined the mean distance from the articular cartilage to the supraspinatus footprint (tendinous attachment) as 1.7 mm (1.9 mm at the rotator interval, 1.5 mm at the midtendon, and 1.8 mm at the posterior edge). They define all tears with more than 7 mm of exposed bone lateral to the articular cartilage edge as significant (approximately 50% of the tendon substance) and suggest that they be repaired.

### LANDMARKS

Reliable landmarks are helpful in evaluating normal anatomy as well as defining the characteristics (tendon, location, dimensions) of rotator cuff tears. One useful landmark is the anterior margin of the greater tuberosity. Measuring from the most anterior aspect of the greater tuberosity, the initial  $12.6 \pm 1.1$  mm of rotator cuff is supraspinatus. The next  $9.8 \pm 3.2$  mm consists of supraspinatus and infraspinatus tendon.<sup>80,82</sup> The most posterior portion ( $12.9 \pm 3.2$  mm) consists only of the infraspinatus tendon. More specifically, the superior facet of the greater tuberosity is a useful landmark because only the supraspinatus tendon attaches to it. However, in cases of degenerative joint disease, the superior facet may not be readily

identifiable. Therefore the distance between the anterior margin of the greater tuberosity and the anterior margin of the infraspinatus tendon ( $12.6 \pm 1.1$  mm) can be used to determine whether the infraspinatus is involved in the tear.<sup>80,82</sup> Likewise, the supraspinatus and infraspinatus overlap at the superior aspect of the middle facet. When a full-thickness tear occurs in this area or more than 12.6 mm from the anterior margin of the greater tuberosity, it means that the tear involves both the supraspinatus and infraspinatus tendons.<sup>80,82</sup>

Curtis et al.<sup>84</sup> used 3 easily identifiable landmarks to assess the rotator cuff. The landmarks are the biceps groove, the articular surface, and the bare area. The bare area is created as the infraspinatus and teres minor taper laterally away from the articular margin. More specifically, there is a 5- to 10-mm area where the infraspinatus fibers overlap the supraspinatus fibers and insert more laterally and anteriorly onto the greater tuberosity. This area of overlap is just anterior to the tip of the bare area, which is an arthroscopic landmark for the interval between the supraspinatus and infraspinatus. The infraspinatus extends inferiorly on the greater tuberosity, framing the upper half of the bare area. Minagawa et al.<sup>80</sup> also described the sulcus between these 2 tendons as a useful landmark. They described its location as slightly posterior ( $4.3 \pm 2.4$  mm) to the posterior margin of the supraspinatus tendon.

### SUPRASCAPULAR AND AXILLARY NERVES

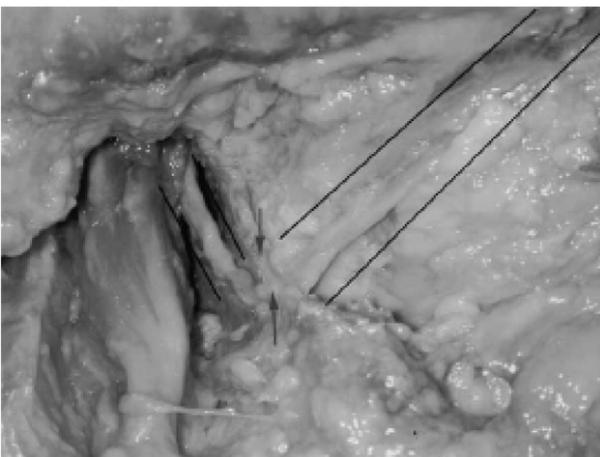
Damage to the suprascapular nerve during lateral mobilization (>3 cm) for repair of a rotator cuff tendon places the suprascapular nerve at risk for injury. It may also explain the inability to regain strength in the supraspinatus and infraspinatus muscles postoperatively.<sup>93</sup> A recent study suggests that medial retraction of a torn rotator cuff may also injure the suprascapular nerve (Figs 15 and 16).<sup>94</sup> Retraction of a large or massive rotator cuff tear may change the course of the suprascapular nerve through the suprascapular notch. This change may lead to increased tension and cause a traction injury to the suprascapular nerve. In a cadaveric study Albritton et al.<sup>94</sup> showed that medial retraction of a rotator cuff tear (supraspinatus and infraspinatus) decreases the angle between the main trunk of the suprascapular nerve and its first motor branch. The nerve tension that develops may contribute to the development of atrophy in the muscle bellies of the supraspinatus and infraspinatus. This atrophy is most likely due to the combination of nerve



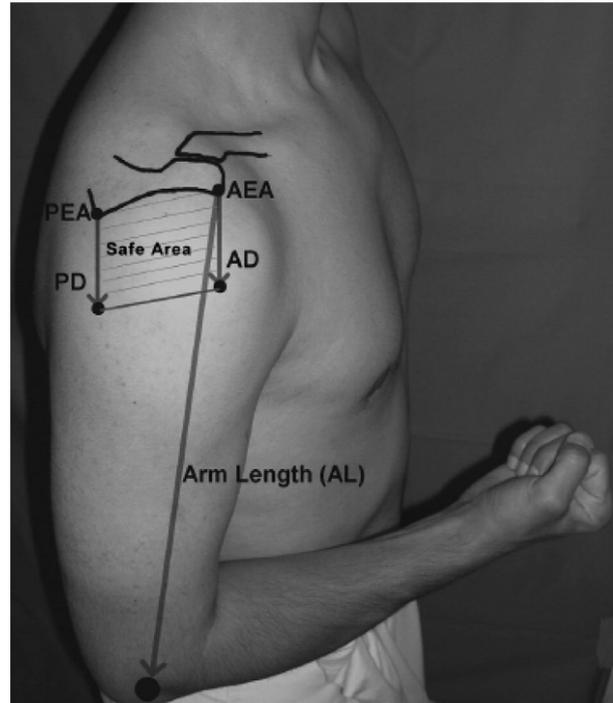
**FIGURE 15.** Suprascapular nerve. The black lines outline the suprascapular nerve (right side) and its first motor branch (left side). The arrows point to the transverse scapular ligament spanning the scapular notch. (Reprinted with permission.<sup>94</sup>)

injury and motor inactivity resulting from the rotator cuff tear.<sup>94</sup>

Deltoid-splitting approaches are widely used for open and mini-open rotator cuff repairs. Several authors have described the location of the axillary nerve in relation to the lateral acromion. Indeed, the mean distance from the insertion of the deltoid on the acromion varies (34 mm, 70 mm, and 60 mm).<sup>95-97</sup> Cetik et al.<sup>97</sup> recently described a quadrangular safe area for surgery. From a line connecting the anterolateral and



**FIGURE 16.** Suprascapular nerve and its first motor branch after medial retraction of supraspinatus tendon. The black lines outline the suprascapular nerve (right side) and its first motor branch (left side). The arrows point to the transverse scapular ligament. Note the decreased angle that occurs as a result of the retraction of the supraspinatus tendon. (Reprinted with permission.<sup>94</sup>)

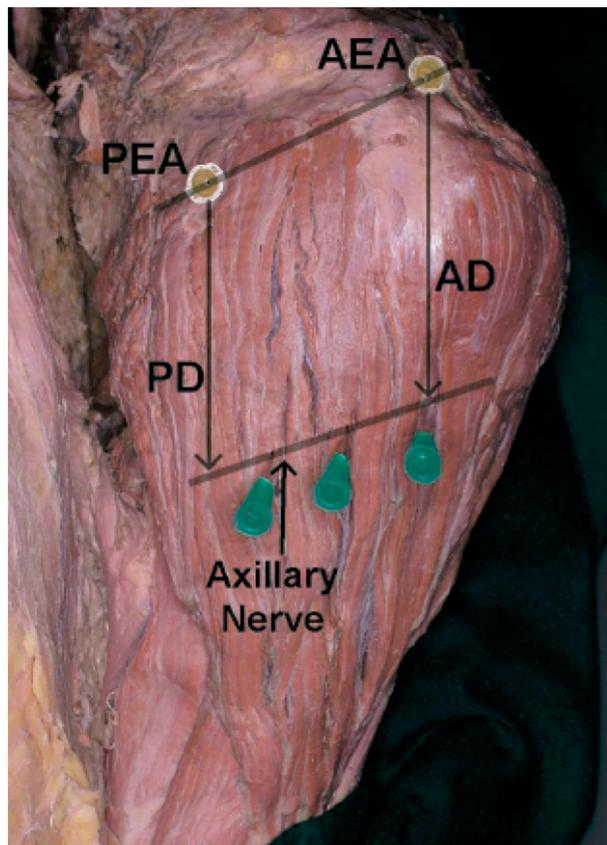


**FIGURE 17.** Superficial anatomy for safe area of axillary nerve. The safe area is a quadrangular shape in which the length of the lateral edges is dependent on the length of the arm (AL). (AD, anterior distance; PD, posterior distance; AEA, anterior edge of acromion; PEA, posterior edge of acromion.) (Reprinted with permission from The Journal of Bone and Joint Surgery, Inc.<sup>97</sup>)

posterolateral edges of the acromion, the distance distally to the axillary nerve anteriorly and posteriorly is 6.1 cm and 4.9 cm, respectively. The length of the lateral edges of the quadrangle are dependent on the patient's arm length ( $P < .001$ ) (Figs 17 and 18). The authors also conclude that the axillary nerve does not lie at a constant distance from the acromion at every point along its course.

## CONCLUSIONS

The muscles of the rotator cuff and their corresponding tendons function as a unit. Studies looking at muscular atrophy and fatty infiltration confirm that these processes are 2 different expressions of rotator cuff disease but are very relevant to its function. Equally important to rotator cuff function are anatomic repair of torn tendons and treatment of associated conditions, such as subacromial or coracoid impingement. Awareness of neurovascular structures is also paramount to avoid iatrogenic injury. Controversial issues continue to surround the treatment of rota-



**FIGURE 18.** Safe area of axillary nerve. The quadrangular shape outlines the safe area. The green pins show the course of the axillary nerve. (AD, anterior distance; PD, posterior distance; AEA, anterior edge of acromion; PEA, posterior edge of acromion.) (Reprinted with permission from The Journal of Bone and Joint Surgery, Inc.<sup>97</sup>)

tor cuff disease. Nevertheless, understanding the anatomy of the rotator cuff and the structures surrounding it is essential to delivering competent care. The primary clinical relevance of the data reviewed in this article is to provide surgeons with a current perspective on this subject to guide the care of their patients. Understanding the current research is also essential to developing surgical principles to treat rotator cuff disease. Application of this knowledge to clinical practice and to future research will result in appropriate care for patients with rotator cuff tears.

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