DOCTOR OF PHILOSOPHY

Anatomical Variations and Degenerative Features of the Coracoacromial Ligament (CAL) in Shoulders with Rotator Cuff Tears

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ANATOMICAL VARIATIONS AND DEGENERATIVE FEATURES OFTHE CORACOACROMIAL LIGAMENT (CAL) IN SHOULDERS WITH ROTATOR CUFF TEARS

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Abstract

The purpose of this study is to evaluate anatomical variations of the coracoacromial ligament (CAL) in relation to the etiology of subacromial impingement syndrome and rotator cuff tears. A knowledge and understanding of these variations will help to determine how such variations may influence the surrounding tissues and how the biomechanics of the shoulder works, as well as improving accurate diagnosis and subsequent treatment of shoulder impingement syndrome.

The methodological approach involved the dissection of 220 cadaveric shoulders in the Centre for Anatomy and Human Identification (CAHID) with a mean age of 82 years (range 53 to 102 years). The CAL was classified according to its morphology and composed band number. The rotator cuff tendons were inspected for tears that were categorized into partial bursal and complete tears. Furthermore, the study inspected the CAL's parameters and attachment sites: degenerative changes include acromial and coracoid spurs and attrition lesions at the undersurface of the acromion.

Results: the multiple banded ligament was the most commonly observed type and was seen in 101 (46%) specimens. The attachment sites of the ligament varied as the size or number of bands of the ligament increased. An association was found between rotator cuff tears and shoulders which had three or more CAL bands (52%). In addition, shoulders with rotator cuff tears had wider attachments, thicker ligaments and larger subacromial insertions. Shoulders with rotator cuff tears also had a significant incidence and size of acromial spurs. The size of the spurs was correlated with the size of the CAL and attrition lesions on the undersurface of the acromion, and changes in morphology of the acromion. Attrition lesions at the subacromial insertion of the CAL were associated with tears in the rotator cuff tendons, and worsened as the size of the subacromial insertion increased.

In conclusion, anatomical variations of the CAL showed a relationship with rotator cuff tears.

Acknowledgements

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Declaration

I, Abdulrahman Alraddadi, declare that I am the author of this thesis titled “Anatomical Variations and Degenerative Features of the Coracoacromial Ligament (CAL) in Shoulders with Rotator Cuff Tears”. I confirm that the work presented is my own. All cited references have been consulted by me, and I confirm that this work has not been accepted for the award of any other higher degree.

Abdulrahman Alraddadi
16/11/2015

Statement by Supervisors

I, Roger Soames, have read this thesis titled as "Anatomical Variations and Degenerative Features of the Coracoacromial Ligament (CAL) in Shoulders with Rotator Cuff Tears" and certify that the conditions of the relevant ordinance and regulations have fulfilled.

First Supervisor: Roger Soames
16/11/2015

I, Clare Lamb, have read this thesis titled as "Anatomical Variations and Degenerative Features of the Coracoacromial Ligament (CAL) in Shoulders with Rotator Cuff Tears" and certify that the conditions of the relevant ordinance and regulations have fulfilled.

Second Supervisor: Clare Lamb
16/11/2015

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Abbreviations

ACJ: Acromioclavicular ligament

CAL: Coracoacromial Ligament

CALDPC: Coracoacromial ligament-deltoid-periosteal complex

SIS: Shoulder impingement syndrome

Tendinities: Tendon inflammation as a result of microtears in the musculotendinous unit (Bass, 2012).

Tendinosis: Non-inflammatory degeneration of tendinous collagen fibres as a result of chronic overuse (Bass, 2012).

Publications

Published abstracts include:

i. **The coracoacromial falx:** presented at the Winter meeting of the Bristish Association of Clinical Anatomists (BACA) on 20th December 2012 at the Postgraduate Medical Institute, Anglia Ruskin University, Rivermead Campus, Chelmsford, Essex, United Kingdom.
Alraddadi A, Soames R. (2013).The coracoacromial falx. J Clin Anat.

ii. **Morphological variations of coracoacromial ligament:** presented at the Winter Meeting of the British Association of Clinical Anatomists (BACA) on 18th December 2013 at the Stopford Building, University of Manchester, Manchester, United Kingdom: Alashkham A, Alraddadi A, Soames R. (2014) Morphological variation of coracoacromial ligament. J Clin Anat 27:1330-1349.

iii. **Acromial spurs in relation to age and rotator cuff tears:** presented at the Winter Meeting of the British Association of Clinical Anatomists (BACA) on 18th December 2013 at the Stopford Building, University of Manchester, Manchester, United Kingdom.: Alraddadi A, Soames R. (2014). Acromial spurs in relation to age and rotator cuff tears. J Clin Anat 27:1330-1349.

iv. **Variations of the acromial attachment of the coracoacromial ligament:** presented at the Winter Meeting of the British Association of Clinical Anatomists (BACA) on 18th December 2013 at the Stopford Building, University of Manchester, Manchester, United Kingdom: Alraddadi A, Soames R. (2014). Variations of the acromial attachment of the coracoacromial ligament. J Clin Anat 27:1330-1349.

v. **Long head of biceps tears in association with rotator cuff tears and intertubercular sulcus degeneration:** presented at the Winter Meeting of the British Association of Clinical Anatomists (BACA) on 8th January 2015 at the Centre for Comparative and Clinical Anatomy, University of Bristol, Bristol, United Kingdom: Alraddadi A, Alashkham A, Soames R. (2014). Long head of biceps tears in

association with rotator cuff tears and intertubercular sulcus degeneration. J Clin Anat 28:1071-1083.

1 Introduction

Subacromial impingement syndrome is the most common upper limb disorder causing pain and limiting shoulder function (Michener *et al*., 2003). It is caused by friction of the supraspinatus tendon between the humeral head and the coracoacromial arch, i.e. the acromion, coracoid process and coracoacromial ligament. It results in anterolateral shoulder pain that is worsened during overhead activities and in advanced cases may lead to a tear in the rotator cuff tendons and degenerative disease of the shoulder joint (Neer, 1972; 1983). The coracoacromial ligament plays an important role in the development of subacromial impingement syndrome, especially when there is no significant bony abnormality existing in the surrounding structures, such as acromial spurs, acromioclavicular osteophytes or a large coracoid process (Uhthoff *et al*., 1988). Surgically, the coracoacromial ligament is commonly resected during subacromial decompression surgery to relieve the impingement (Neer, 1972). However, this usually results in several shoulder complications (Tibone *et al*., 1985; Ellman and Kay, 1991; Lee *et al*., 2001; Hockman *et al*., 2004; Chen *et al*., 2009; Su *et al*., 2009). The ligament is also used as a graft in acromioclavicular dislocation (Sood *et al*., 2008).

The literature shows that CAL morphology is variable (Edelson & Luchs, 1995; Rockwood & Lyons, 1993; Salter *et al*., 1987; Soslowski *et al*., 1994). However, the influence of these variations on subacromial impingement and rotator cuff tears is not fully understood. Furthermore, there is a lack of explanation in the literature regarding changes in the anatomical attachments of the coracoacromial ligament with respect to these morphological variations.

Knowledge of these changes will provide a better understanding of shoulder biomechanics, as well as the outcomes of surgery.

This thesis consists of five chapters. Chapter one reviews the literature and is divided into ten major sections. Section one considers the anatomy of the shoulder including the articular surfaces, joint capsule, blood and nerve supply, the coracoacromial arch, the subacromial space, the subacromial bursa, deltoid, the rotator cuff muscles (subscapularis, supraspinatus, infraspinatus, teres minor) and biceps brachii. Section two considers shoulder impingement syndrome and includes a brief introduction, epidemiology, classification and etiology of shoulder impingement syndrome, its signs and symptoms, impingement stages, rotator cuff tears, its diagnosis including physical examinations and imaging, as well as its non-operative and operative treatments. Section three considers the anatomy of the coracoacromial ligament including the number of bands, attachments, the coracoacromial falx, the coracoacromial veil, morphology of the coracoacromial ligament, diaphanous membrane, parameters, development of the coracoacromial ligament and finally its blood and nerve supply. In section four, the role of the coracoacromial ligament in shoulders with rotator cuff tears is considered and includes (i) implication of the coracoacromial ligament in subacromial impingement syndrome, (ii) degenerative changes in the coracoacromial ligament and (iii) geometric changes in coracoacromial parameters. Section five discusses: (i) the function of CAL as a dynamic brace ligament, (ii) the superior humeral restraint ligament, (iii) biomechanical properties of the CAL, (iv) subacromial pressure (contact) and (v) CAL reflexes. Section six considers the histology of the CAL including: (i) histological degenerative changes of the CAL related to aging and impingement syndrome, (ii) mechanoreceptors in the CAL and (iii) neural distribution in the CAL. Section seven considers acromial spur formation and degenerative changes in shoulders with rotator cuff tears and consists of: (i) the etiology of acromial spur formation including intrinsic and extrinsic factors, (ii) the incidence of acromial spurs, (iii) observations of acromial spurs in radiographs, (iv) classification of acromial spurs including morphological and geometric classifications, (v) CAL and acromial spurs, (vi) the relation between spurs and acromial morphology inclusing the relation with rotator cuff tears and formation of a hooked acromion, (vii) the role of acromial spurs in shoulders with rotator cuff tears including firstly the incidence of cuff tears in shoulders with acromial spurs and secondly the severity of cuff tears, (viii) the reformation of acromion spurs, and (ix) degeneration of the acromioclavicular joint. Section eight considers release of the CAL during subacromial decompression to relieve the impingement and comprises (i) release of the CAL, (ii) complications of CAL release, (iii) reattachment of the CAL, (iv) regeneration of the CAL after its release and (v) new surgical techniques to release or preserve the CAL. Section nine is a summary of the literature review, while section ten outlines the aim and objectives of the thesis.

Chapter two presents the methods used in the study and is divided into four parts. The first part covers the dissection and preparation of the specimens. The second part covers the first stage of the study which consisted of (i) gross inspection of the morphology of the CAL, attachment of the CAL, rotator cuff tears and acromial spurs, and then (ii) parametric assessment of CAL dimensions. Part three introduces the second stage of the study which investigated (i) the subacromial insertion of the CAL, (ii) subacromial spurs, (iii) the subacromial surface, (iv) coracoid spurs and acromioclavicular joint degenerative changes, and (v) acromial curvature. Finally, part four explains the tools and statistical analyses that were used in the study.

Chapter three presents the results which are considered in two parts. The first part considers the results of the first stage which includes: (i) general description, (ii) CAL morphology, (iii) CAL attachment sites, (iv) formation of an acromial spur in CAL, and (v) rotator cuff tears. The second part presents the observed changes in the coracoacromial arch in relation to rotator cuff tears including (i) acromial spurs, (ii) coracoid spurs, (iii) degeneration of the acromioclavicular joint, and (iv) changes in the subacromial insertion of CAL.

Chapter four is the discussion and is divided into four sections. Section one discusses the anatomical variations of the CAL in relation to rotator cuff tears and acromial spurs and consists firstly of the morphology of the CAL including band number, diaphanous membrane, CAL shapes, development of the CAL, CAL parameters, relation to acromial spurs and rotator cuff tears; and secondly the attachment sites of the CAL which includes the acromial and coracoid attachments, classification of the CAL attachment, relation to rotator cuff tears and a note on the attachment of the CAL. Section two discusses firstly acromial spurs including their incidence, secondly their relation to side, sex and age, thirdly their relation to rotator cuff tears, fourthly the relation between the size of acromial spurs and the CAL, fifthly the classification of acromial spurs, and finally changes in acromion geometry in relation to spur formation. In section three is a discussion of the degenerative changes on the subacromial surface including changes in the undersurface of the acromion, changes in the subacromial insertion of the CAL and the contact geometry at the undersurface of the acromion. Section four discusses other degenerative changes of the coracoacromial arch including coracoid spurs and degeneration of the acromioclavicular joint.

Chapter five brings all of the preceding sections together to present the overall conclusions of the study.

1.1 Anatomy of the Shoulder

The shoulder (glenohumeral) joint is a synovial ball and socket joint that connects the upper limb to the trunk and is described as being the most mobile joint in the body. It permits a wide range of movement: flexion, extension, abduction, adduction, external and internal rotation. The shoulder complex consists of the proximal end of the humerus, scapula and clavicle. The clavicle articulates with the scapula laterally at the acromioclavicular joint and with the sternum medially at the sternoclavicular joint (Drake *et al*., 2010; Mackinnon and Morris, 2005; Whiten, 2006).

1.1.1 Articular Surfaces

The head of the humerus and the glenoid fossa form the articular surfaces of the shoulder joint and are covered with hyaline cartilage. The glenoid fossa has a pear-shaped outline with a shallow concave surface deepened by the glenoid labrum (a fibrocartilaginous rim). Both the glenoid fossa and labrum form the socket of the joint that articulates with the head of the humerus (Figure 1.1), which forms the ball of the joint and has an almost hemispherical smooth articular surface. Comparing the articular surfaces of the humeral head and the glenoid fossa, the glenoid fossa accepts about one third of the humeral head at any time (Drake *et al*., 2010; Mackinnon and Morris, 2005; Whiten, 2006).

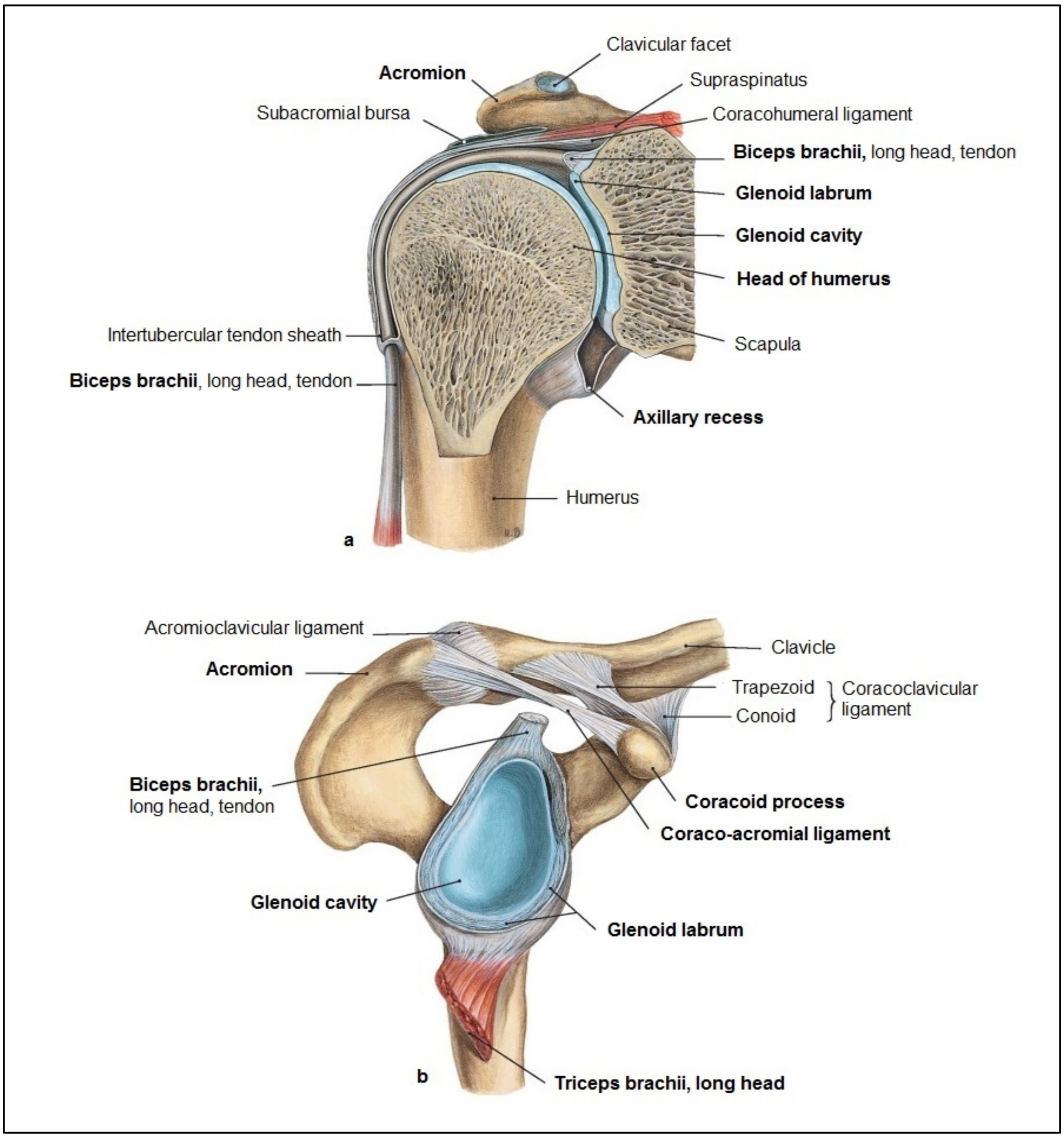


Figure 1.1 Glenohumeral joint, right side: anterior view at the coronal plane (a) and lateral view (b) (Paulsen and Waschke, 2013).

1.1.2 Shoulder Joint Capsule

The shoulder joint capsule is a loose cylindrical sleeve of fibrous membrane extending from the margin of the glenoid fossa outside the labrum to the anatomical neck of the humerus, extending inferiorly to the medial aspect of the shaft of the humerus (Figure 1.2). This makes the capsule loose inferiorly allowing a wide range of movement, especially during shoulder abduction. Internally, the capsule is lined with synovial membrane that secretes synovial fluid to lubricate the joint (Drake *et al*., 2010; Palastanga and Soames, 2012; Moore *et al*., 2010).

The capsule has three openings: anteriorly below the coracoid process where the synovial membrane is continuous with the subscapularis bursa; an opening between the greater and lesser tubercles where the tendon of the long head of biceps and its synovial sheath passes through the capsule to the supraglenoid tubercle; and posteriorly (variable) where the synovial membrane communicates with the infraspinatus bursa (Figure 1.3). Internally, the capsule is thickened and reinforced anteriorly by three glenohumeral ligaments: the superior, middle and inferior. Externally, the capsule is supported by the coracohumeral ligament and tendons of the rotator cuff muscles near its humeral attachment (Johnson *et al*., 2005; Palastanga and Soames, 2012).

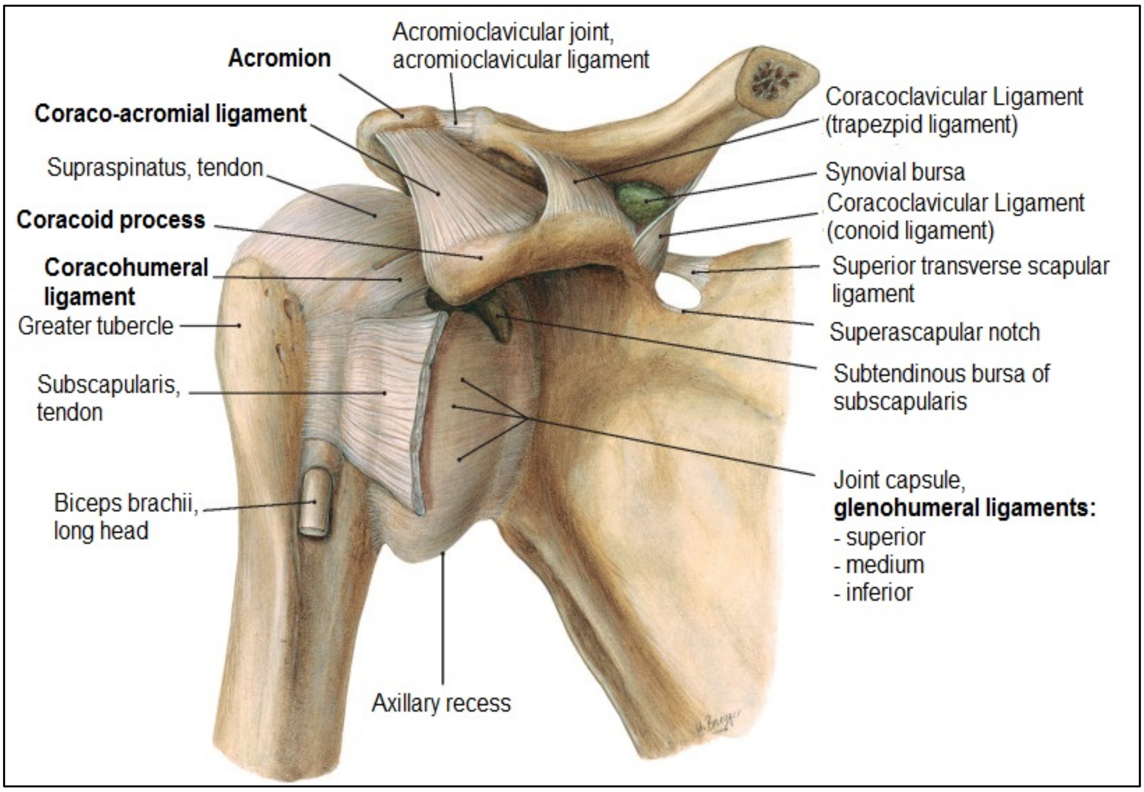


Figure 1.2 Shoulder joint, right side; anterior view showing the shoulder joint capsule (Paulsen and Waschke, 2013).

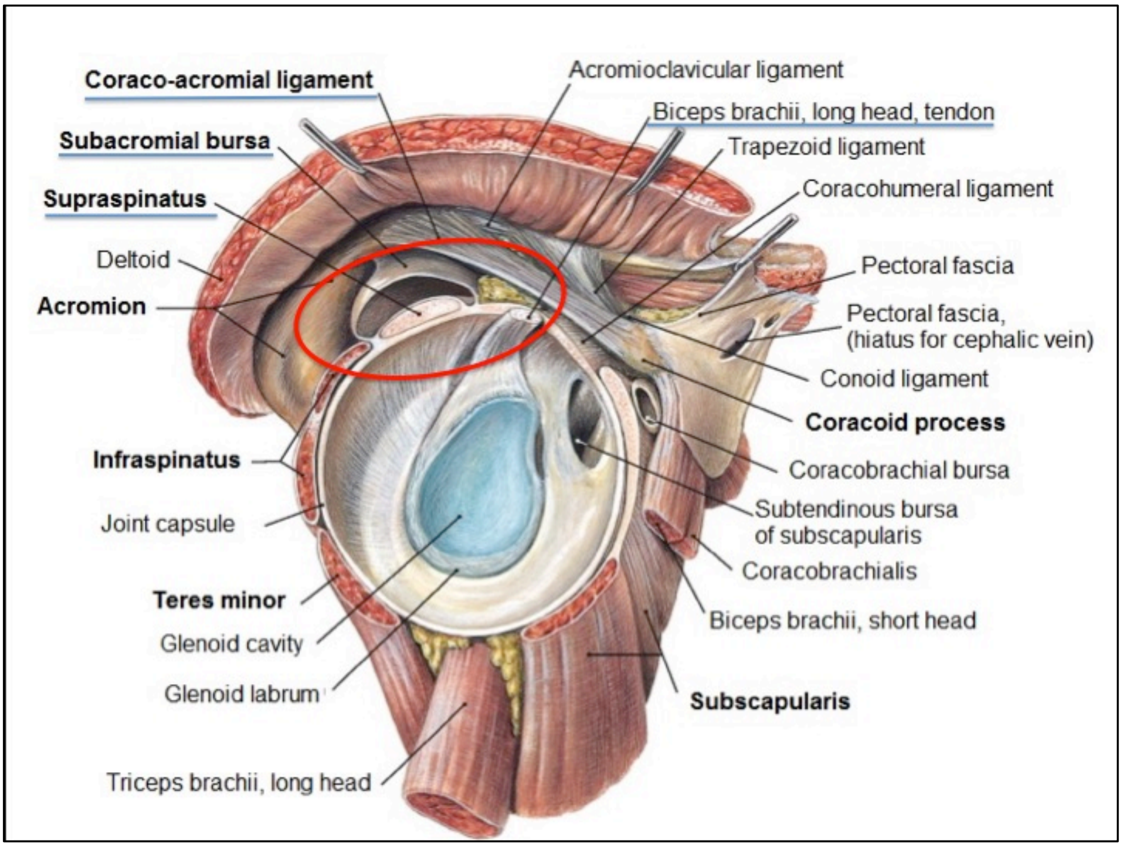


Figure 1.3 Lateral view of the shoulder joint, after the removal of deltoid and the humeral head: red outline shows the subacromial space (Paulsen and Waschke, 2013).

1.1.3 Shoulder Blood and Nerve Supply

The main blood supply of the shoulder joint comes from three sources: the anterior and posterior circumflex humeral arteries and branches of the suprascapular artery (Drake *et al*., 2010; Moore *et al*., 2010). Similarly named veins drain blood from the shoulder into the external jugular and axillary veins. Lymphatic fluid is drained into the axillary lymphatic nodes and then into the subclavian lymph trunk though the apical group of nodes (Palastanga and Soames, 2012). The shoulder is innervated by branches from the posterior cord of the brachial plexus including the upper and lower subscapular and thoracodorsal nerves. The shoulder capsule is innervated by: the suprascapular nerve to the posterior and superior parts; the axillary nerve to the anteroinferior part and the lateral pectoral nerve to the anterosuperior part (Drake *et al*., 2010; Johnson *et al*., 2005; Moore *et al*., 2010).

1.1.4 Subacromial Space

The subacromial space is defined superiorly by the coracoacromial arch and acromioclavicular joint, and inferiorly by the greater tubercle of the humerus and the superior aspect of the humeral head (Figure 1.3) (Drake *et al*., 2010; Johnson *et al*., 2005; Moore *et al*., 2010). The height of the space was 11 ± 1 mm as measured, at 0° of arm elevation and natural rotation, between the midpoint at the anterior edge of the acromion and the direct below point on the proximal humerus (Flatow *et al*., 1994). Structures within the subacromial space include supraspinatus, the subacromial bursa, the tendon of the long head of the biceps brachii and the capsule of the shoulder joint (Johnson *et al*., 2005; Moore *et al*., 2010).

1.1.4.1 Coracoacromial arch

The coracoacromial arch overlies the humeral head and is formed by the acromion, coracoid process and the coracoacromial ligament (CAL). It supports the shoulder joint by preventing superior dislocation of the humeral head (Figure 1.3) (Moore *et al*., 2010).

The acromion projects anterolaterally from the spine of the scapula. It has a short medial border with an anterior oval facet that articulates with the lateral end of the clavicle to form the acromioclavicular joint (Moore *et al*., 2010). The lateral border of the acromion is thick and irregular, the superior surface is subcutaneous, covered by skin and superficial facia, while the inferior surface is smooth. Deltoid attaches to the lateral and anterior margins of the acromion and the horizontal part of trapezius to the medial border, just behind the acromial facet of the acromioclavicular joint (Johnson *et al*., 2005).

The coracoid process is a hook-like structure that projects anterolaterally from the superior border of the scapula (Moore *et al*., 2010). The root of the coracoid process originates from the upper part of the glenoid cavity marked by the supragleonid tubercle. The coracoid process lies below the lateral end of the clavicle and is connected to its inferior surface by the coracoclavicular ligament. The coracoclavicular ligament has two bands: the conoid band originates from the impression on the posterior aspect of the coracoid and the trapezoid band from the horizontal part at the superior aspect of the coracoid. The coracoid process is covered by the anterior part of deltoid that originates from the lateral third of the clavicle. The coracoid tip provides muscle attachment for coracobrachialis (medial side of the tip), the short head of the biceps brachii (lateral side of the tip) and pectoralis minor (medial border and superior surface). Both the coracoacromial and coracohumeral ligaments attach to the dorsolateral border of the coracoid process: the coracohumeral ligament lies inferior to the coracoacromial ligament (Johnson *et al*., 2005).

The coracoacromial ligament (CAL) is a strong, triangular ligament with its apex originating from the tip of the acromion posteriorly (just below the attachment of the middle fibres of deltoid), with the base inserting into the lateral border of the coracoid anteriorly. The CAL is bounded superiorly by deltoid and the acromioclavicular joint, and inferiorly by the subacromial bursa (Johnson *et al*., 2005).

1.1.4.2 Subacromial bursa

A bursa is a synovial-lined membranous sac containing a small amount of lubricating fluid usually underlying skin or tendons subjected to friction against bone (Whiten, 2006). The subacromial (subdeltoid) bursa is found in the subacromial space between the coracoacromial arch superiorly and the supraspinatus tendon inferiorly (Figure 1.3). It does not communicate with the shoulder joint capsule. It helps to prevent irritation of the tendon of supraspinatus against the undersurface of the coracoacromial arch (Moore *et al*., 2010).

1.1.5 Shoulder Muscles

1.1.5.1 Deltoid

Deltoid is a large, thick, triangular muscle covering the shoulder joint on all sides except inferomedially: it gives the shoulder its rounded outline (Figure 1.4). It originates as three parts: the anterior fibres from the anterior border and superior surface of the lateral third of the clavicle, middle fibres from the lateral border and tip of the acromion, and posterior fibres from the lower edge of the crest of the scapular spine. However, these three parts insert as one tendon into the deltoid tubercle of the humerus. Functionally, the three parts of deltoid work together to abduct the arm beyond the first 15˚ produced by supraspinatus. However, the anterior fibres assist in flexion and medial rotation of the arm, while the posterior fibres assist in extension and lateral rotation of the arm. Deltoid is innervated by the axillary nerve and supplied with blood by the posterior circumflex artery (Johnson *et al*., 2005; Moore *et al*., 2010; Palastanga and Soames, 2012).

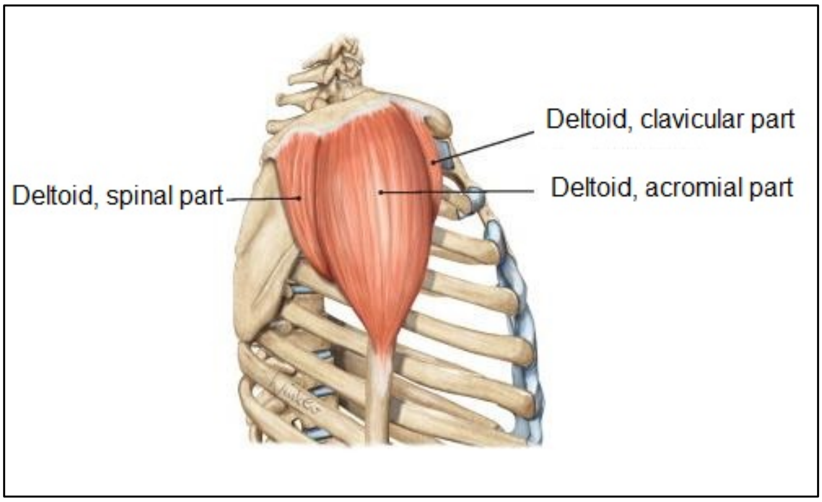


Figure 1.4 Lateral view of the shoulder showing deltoid (Paulsen and Waschke, 2013).

1.1.5.2 Rotator cuff muscles

The rotator cuff muscles are four muscles originating separately from the scapula: they are subscapularis, supraspinatus, infraspinatus and teres minor (Figure 1.5). The rotator cuff muscles insert through fused tendons into the greater and lesser tubercles of the humerus. They work together to act as active stabilizers to brace the head of the humerus firmly against the glenoid fossa during shoulder movements (Mackinnon and Morris, 2005; Palastanga and Soames, 2012) preventing upward displacement of the humeral head. In addition, the rotator cuff muscles surround and support the shoulder joint capsule, except inferiorly, with the tendons blending with the capsular tissue near their humeral attachments. Finally, the area of the shoulder capsule between the anterior border of supraspinatus (superiorly) and the superior border of subscapularis (inferiorly) is reinforced by the lateral part of the coracohumeral ligament. This area is called the rotator interval (Johnson *et al*., 2005; Palastanga and Soames, 2012; Prescher, 2000).

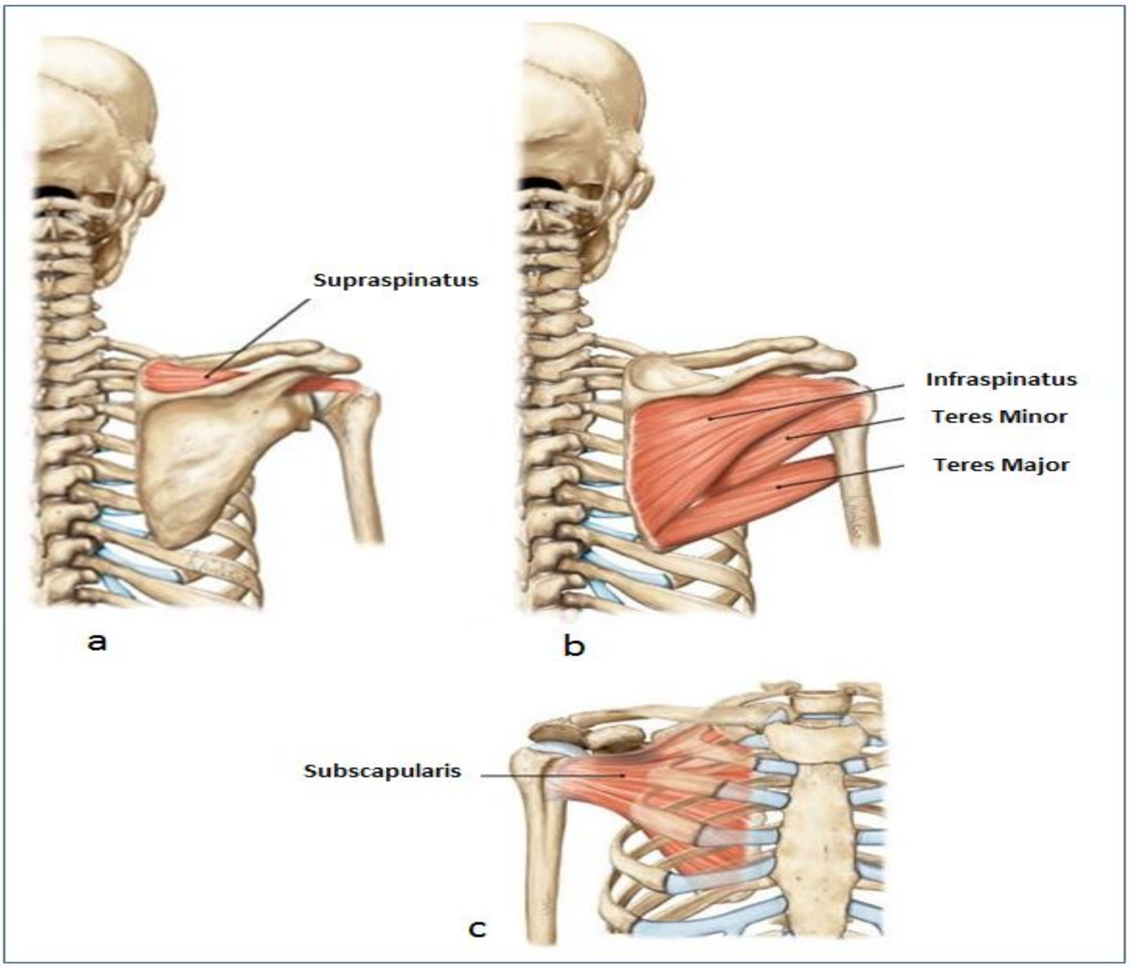


Figure 1.5 Rotator cuff muscles (Paulsen and Waschke, 2013).

1.1.5.2.1 Subscapularis

Subscapularis is a large muscle on the anterior surface of the scapula originating from the subscapular fossa (medial two-thirds) and the tendinous septa attached to the bony ridges of the fossa. It has a narrow, thick tendon inserting into the lesser tubercle of the humerus and is separated from the neck of the scapula by the subscapular bursa. Subscapularis rotates the arm medially and assists in adduction of the arm. It is innervated by the upper and lower subscapular nerves and supplied with blood by small branches from the suprascapular, axillary and subscapular arteries (Johnson *et al.*, 2005; Palastanga and Soames, 2012)

1.1.5.2.2 Supraspinatus

Supraspinatus originates from the supraspinatus fossa (medial two-thirds) above the spine of the scapula and the fascia covering the muscle. It lies beneath trapezius and its tendon passes laterally beneath the coracoacromial arch to insert into the upper facet on the greater tubercle. It is separated from the coracoacromial arch by the subacromial bursa. Supraspinatus initiates the first 15˚ of shoulder abduction. It is innervated by the suprascapular nerve and supplied with blood by the suprascapular and dorsal scapular arteries (Johnson *et al*., 2005; Moore *et al*., 2010; Palastanga and Soames, 2012).

1.1.5.2.3 Infraspinatus

Infraspinatus is a thick triangular muscle on the posterior surface of the scapula originating from the infraspinatus fossa (medial two thirds) below the spine of the scapula, the tendinous septa attached to the bony ridges of the fossa and the infraspinous fascia covering the muscle. The tendon of infraspinatus inserts into the middle facet of the greater tubercle and is separated from the neck of the scapula by the infraspinatus bursa. Infraspinatus rotates the arm laterally. It is innervated by the suprascapular nerve and supplied with blood by the suprascapular and circumflex scapular arteries (Johnson *et al*., 2005; Moore *et al*., 2010; Palastanga and Soames, 2012).

1.1.5.2.4 Teres minor

Teres minor is a narrow, elongated muscle on the posterior surface of the scapula originating from the upper two-thirds of the lateral border of the scapula and the fascia separating it from teres major inferiorly and infraspinatus superiorly. The tendon inserts into the inferior facet on the greater tubercle and the bone immediately below, just above the origin of the lateral head of triceps.

Teres minor rotates the arm laterally and adducts the arm from an abducted position. It is innervated by the axillary nerve and supplied with blood by branches from the circumflex scapular and posterior circumflex humeral arteries (Johnson *et al*., 2005; Moore *et al*., 2010; Palastanga and Soames, 2012).

1.1.5.3 Biceps brachii

Biceps brachii is a long muscle on the anterior aspect of the arm that crosses two joints: shoulder and elbow (Figure 1.6). It has two tendinous heads (long and short) that combine to form a fusiform muscle: it shares the same insertion inferiorly. The long head originates inside the shoulder joint capsule from the supraglenoid tubercle of the scapula and superior margin of the glenoid labrum. The tendon emerges from the joint capsule into the intertubercular groove underneath the transverse humeral ligament. Inside the capsule the tendon is surrounded by a double sheath of synovial membrane and for 2 cm after it exits the capsule. Inferiorly, the tendon of biceps brachii inserts into the radial tubercle and through the bicipital aponeurosis into the deep fascia on the medial/ulnar side of the forearm. The long head of biceps works with the short head to flex and supinate the forearm. However, the long head also has a role in shoulder flexion, as well as shoulder stabilization by preventing superior displacement of the humeral head. Biceps brachii is innervated by the musculocutaneous nerve and supplied with blood by branches from the brachial artery (Johnson *et al*., 2005; Moore *et al*., 2010; Palastanga and Soames, 2012).

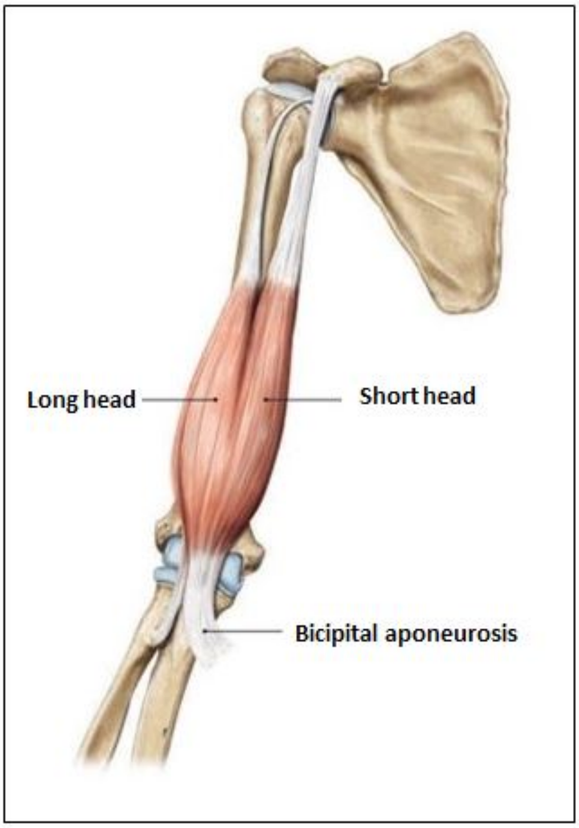


Figure 1.6 Biceps brachii (Paulsen and Waschke, 2013).

1.2 Shoulder Impingement Syndrome

Shoulder impingement syndrome (SIS) is a general term describing anterior or anterolateral superior shoulder pain caused by a pathological reduction in the subacromial space. This reduction leads to attrition between the rotator cuff and the coracoacromial arch (acromion, coracoacromial ligament (CAL) and coracoid), which results in degenerative lesions of the contents of the subacromial space (Lewis *et al.*, 2001; Neer, 1972 and 1983) (Figure 1.7). Shoulder pain intensifies with active movement of the arm into the impingement arc (60° - 120° shoulder abduction) during overhead activities. SIS can present as inflammation or degeneration of the bursa and rotator cuff tendons of the subacromial space. Advanced cases of SIS may lead to a massive tear in the rotator cuff tendons and degenerative joint disease of the shoulder girdle (Neer, 1983). In addition, it has been described with different diagnostic labels: rotator cuff tendinopathy (tendinosis or tendinitis), supraspinatus tendinopathy (tendinosis or tendinitis), subacromial impingement syndrome, subacromial bursitis, bursal reaction, partial thickness, full thickness and massive rotator cuff tear (Lewis, 2009).

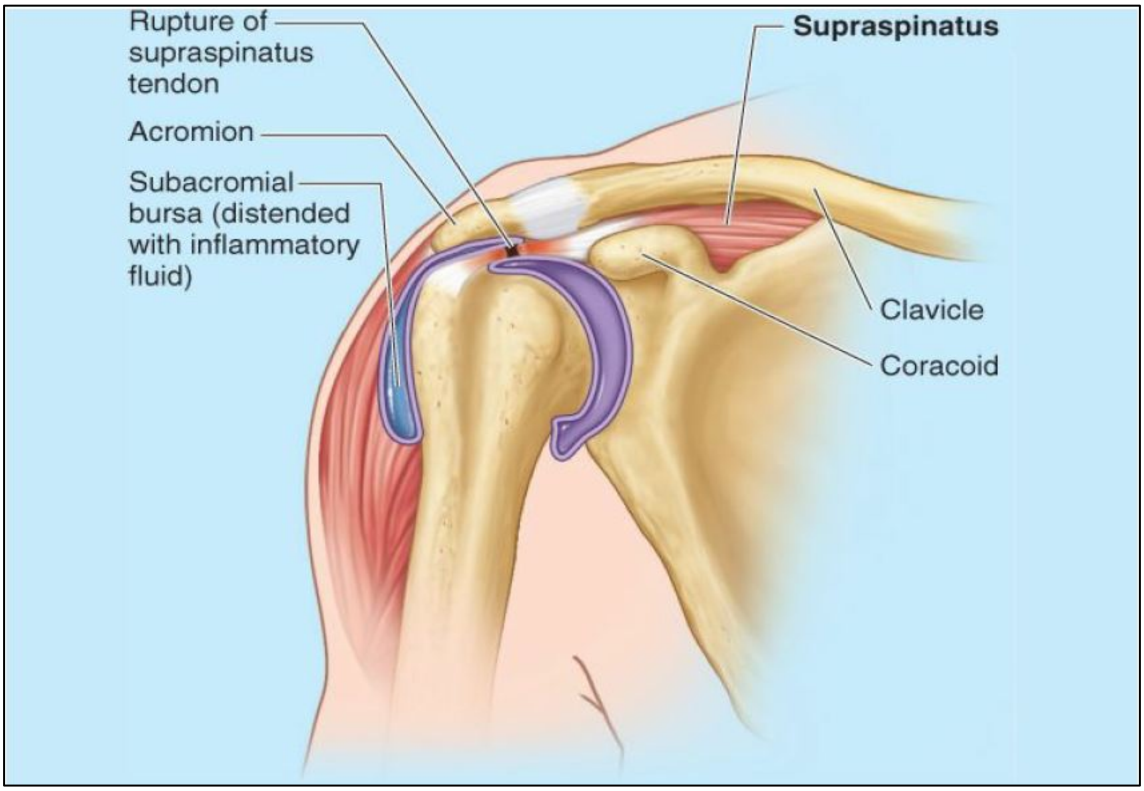


Figure 1.7 Illustration showing impingement of the rotator cuff and subacromial bursa underneath the coracoacromial arch (Moore *et al.*, 2013).

1.2.1 Epidemiology

Shoulder impingement syndrome is the most common shoulder disorder causing pain and dysfunction, being responsible for 44–65% of all shoulder pain complaints (Gomoll *et al*. 2004; Michener *et al*, 2003; van der Windt *et al*., 1995, 1996; Vecchio *et al*. 1995). Two previous studies have shown a high prevalence of this shoulder pain in Dutch and French populations (Bot *et al*., 2005; Roquelaure *et al*., 2006). The prevalence of shoulder pain incidence in the general population of different countries, including the United States, United

Kingdom, Scandinavia, Cuba, South Africa, Spain and Nigeria varies between 4.7% and 46.7% per year (Adebajo and Hazleman, 1992; Allander, 1974; Andersson *et al*., 1993; Badley and Tennant, 1992; Brattberg *et al*., 1989; Brattberg *et al*., 1996; Chard *et al*., 1991; Cunningham and Kelsey, 1984; Eriksen *et al*., 1998; Gomez *et al*., 1997; Jacobsson *et al*., 1989; Makela *et al*., 1999; Meyers *et al*., 1982; Mullersdorf and Soderback, 2000; Natvig *et al*., 1994; Pope *et al*., 1997; Reyes *et al*., 2000; Urwin *et al*., 1998), as reviewed by Luime *et al*. (2004). A high incidence of SIS was seen in overhead athletes and manual workers as a result of repetitive shoulder use (Kirchhoff and Imhoff, 2010; Maenhout *et al*., 2012; Page, 2011; Zanca *et al*., 2013). SIS was also positively associated with age, specifically for people aged 40 or over (Chard *et al*., 1991; Lehman *et al*., 1995; Milgrom *et al*., 1995; Sher *et al*., 1995; Yamaguchi *et al*., 2006).

1.2.2 Classification and Etiology of Shoulder Impingement Syndrome

There are two explanations of the pathophysiology of shoulder impingement syndrome: extrinsic and intrinsic theories. The extrinsic theory of impingement considers that external factors, other than the rotator cuff tendons, leads to narrowing of the subacromial space (supraspinatus outlet). Extrinsic impingement can be subclassified into: primary (subacromial, subcoracoid) and secondary (instability related) impingement. The intrinsic theory of impingement considers that internal factors related to the rotator cuff tendons lead to tendon degeneration and shoulder impingement (Lashgari and Redziniak, 2012; Woertler, 2009).

Based on these explanations, the factors leading to shoulder impingement syndrome are classified into intrinsic and extrinsic factors. Intrinsic factors include weakness of the muscles of the rotator cuff (Hammer, 2002; Nirschl, 1989), inflammation and thickening of the rotator cuff tendons or the subacromial bursa as a result of overuse of the shoulder (Uhthoff *et al*., 1988), and intrinsic degenerative tendinopathy due to aging causing tendon's fibrocartilage changes include calcification, fibrovascular proliferation and microtears (Kumagai *et al*., 1994; Ogata and Uhthoff, 1990; Tempelhof *et al*., 1999). The extrinsic factors include glenohumeral instability (Pieper *et al*., 1997; Putz *et al*., 1988), impingement by one or more of the coracoacromial arch components (Bigliani *et al*., 1986 and 1991; Neer, 1972; Ogawa *et al*. 2005), impingement on the posterosuperior aspect of the glenoid (Davidson *et al*., 1995; Jobe, 1995), and posttraumatic changes and mal-union or nonunion following fractures of the greater tubercle, coracoid or acromion (Gerber *et al*., 1985; Patte, 1990; Pyne 2004).

Anatomical or morphological variations in the coracoacromial arch may lead to a decrease in the dimensions of the subacromial space. This can lead to mechanical attrition or compression of the rotator cuff tendons underneath the coracoacromial arch during shoulder motion (Neer, 1972 and 1983; Wortler, 2009): Neer (1972) described this impingement as “subacromial impingement syndrome”. It is the most common type of impingement and is usually seen in patients more than 40 years of age. Alterations in the coracoacromial arch leading to subacromial impingement include: morphological and geometric variations of the acromion (Aoki *et al*., 1986; Balke *et al*., 2013; Banas *et al*., 1995; Bigliani *et al*., 1986 and 1991; Ogawa *et al*. 2005; Nyffeler *et al*. 2006); os acromiale, an unfused distal acromial epiphysis (Boehm *et al*., 2005;

Hutchinson and Veenstra, 1993; Mudge *et al*., 1984; Warner *et al*., 1998; Wright *et al*., 2000); acromial spur formation at the anterior edge of the acromion (Bigliani *et al*., 1986; Gohlke *et al*., 1993; Hamid *et al*., 2012; Tada *et al*., 1990); anatomical variations and degenerative changes of the CAL (Burman, 1949; Burns and Whipple, 1993; Masciocchi *et al*, 1993; Postaccini, 1989; Reichmister *et al*., 1996); degeneration of the acromioclavicular joint and formation of osteophytes (Edelson and Taitz, 1992; Hardy *et al*., 1986; Neer, 1972; Postacchini, 1989); and a large coracoid process (Dines *et al*., 1990; Ferrick, 2000).

Both intrinsic degeneration and extrinsic compression may play a role in the syndrome (Harrison & Flatow, 2011). However, Neer (1983) reported that rotator cuff tears are initiated by impingement wear in 95% of cases rather than circulatory impairment or trauma. The current study focused on the anatomical variations and morphological changes in the CAL that may lead to subacromial impingement syndrome and the development of rotator cuff tears and acromial spur formation.

1.2.3 Signs and Symptoms

The most common shoulder impingement symptom is anterolateral shoulder pain which intensities during shoulder motion, mainly during the pain arc, i.e. 60° to 120° shoulder abduction. With severe shoulder pain, patients may avoid using the shoulder, which in turn leads to shoulder muscle weakness, limited range of motion and/or shoulder stiffness. In chronic cases of shoulder impingement, osteophytes may form underneath the acromion and acromioclavicular joint that may lead to a severe tear in the rotator cuff tendons and degenerative shoulder joint disorders (Leroux *et al*., 1994; Neer, 1972, 1983). Neer (1983) summarised the progression of an impingement lesion into three stages: stage I edema and hemorrhage, stage II fibrosis and tendinitis, and stage III tears of the rotator cuff, biceps ruptures and bony changes.

1.2.3.1 Rotator Cuff Tears

Rotator cuff tears most frequently occur in the supraspinatus tendon and can be classified into acute and degenerative cuff tears (Woertler, 2009). Acute cuff tears usually result from trauma to a pre-existing degenerated cuff tendon or from shoulder dislocation. Degenerative cuff tears are the more common type of tears and usually occur in older individuals, being the result of chronic impingement and degenerative disorders of the rotator cuff tendons. Degenerative cuff tears can be classified into partial thickness and full thickness cuff tears, with partial thickness tears being more common than full-thickness tears (Olsewski and Depew, 1994; Ryu, 1992; Yamanaka and Fukuda, 1987). A partial cuff tear involves at least 50% of the tendon thickness, but does not lead to communication between the articular and bursal surfaces (Fukuda, 2003; Weber, 1997). Partial tears may present in different forms: articular-sided, bursal-sided and intratendinous (Figure 1.8). Articular cuff tears are more common than bursal and intratendinous partial cuff tears (Itoi and Tabata, 1992; Weber, 1997) and are usually associated with athletes as a result of overuse or secondary micro-instability. Full-thickness tears occur as transtendinous tears in one portion of the tendon leading to communication between the articular (glenohumeral) and bursal sides: they may develop into massive cuff tears resulting in complete disconnection of the tendon fibers and retraction of the muscle or involving more than one tendon (Woertler, 2009).

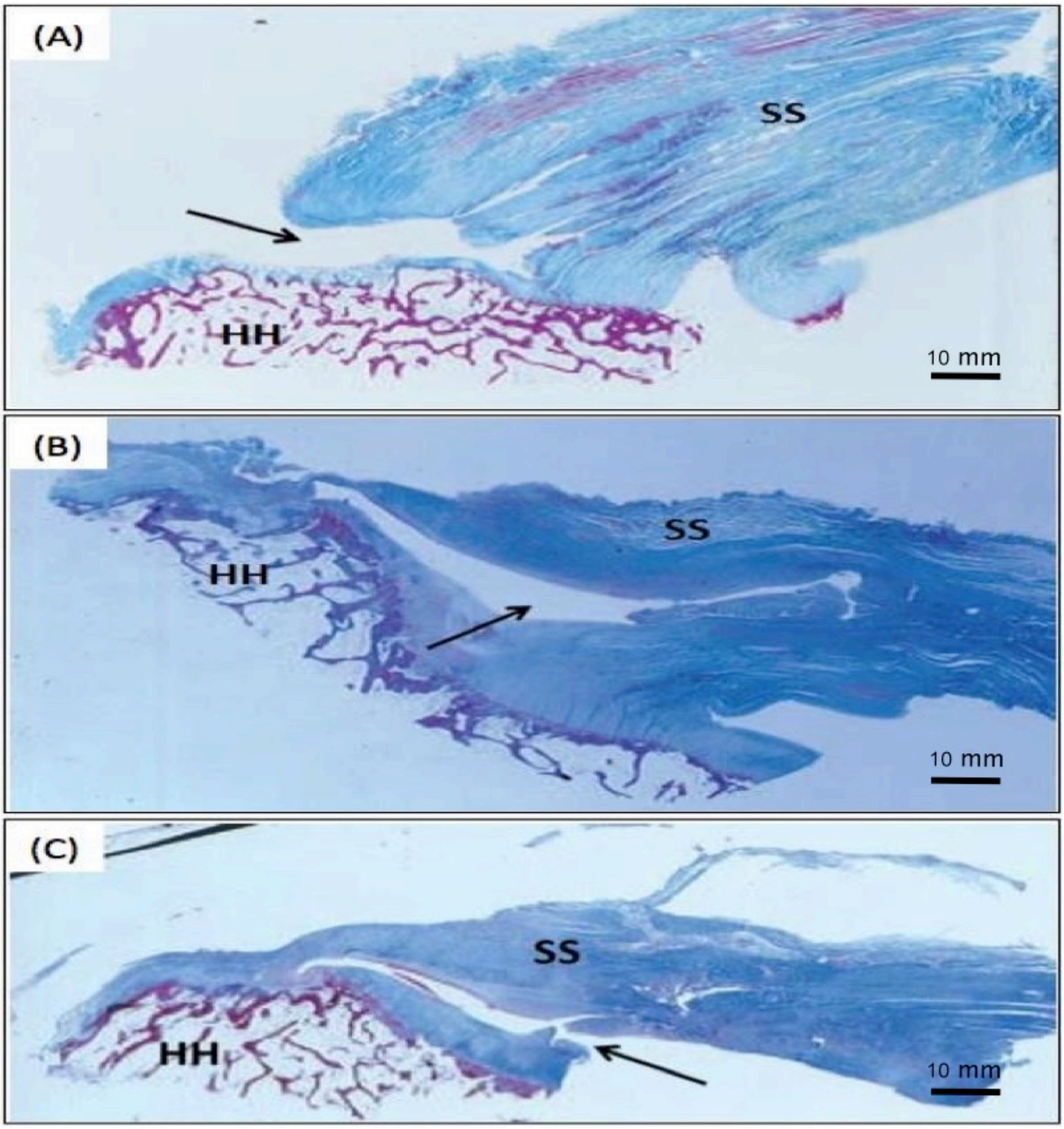


Figure 1.8 Photomicrographs of histological sections of partial-thickness rotator cuff tears developed from within 1 cm of the insertion of the supraspinatus tendon: (A) bursal partial-thickness tear, (B) intratendinous partial-thickness tear, and (C) articular partial-thickness tear. Humeral head (HH), supraspinatus tendon (SS), partial tear (arrow). (Stain: azan; original magnification, X1) (Fukuda, 2003).

1.2.4 Diagnosis

1.2.4.1 Physical Examination

Clinically, the Hawkins-Kennedy test and the Neer sign are commonly used to assess SIS (Hughes *et al*., 2012; Yamamoto *et al*., 2009). In the Neer impingement sign test (Figure 1.9: A) the examiner stands behind the seated patient and elevates their arm passively with one hand, somewhere between flexion and abduction, while the other hand holds the patients' scapula to prevent any rotation (Neer, 1983). In the Hawkins-Kennedy test (Figure 1.9: B) the examiner flexes the shoulder of the patient passively to 90° then fully rotates it internally (Hawkins & Kennedy, 1980). The positive impingement sign includes pain and a corresponding facial expression resulting from the greater tubercle impinging against the anteroinfereior surface of the acromion (Hawkins & Kennedy, 1980; Neer, 1983).

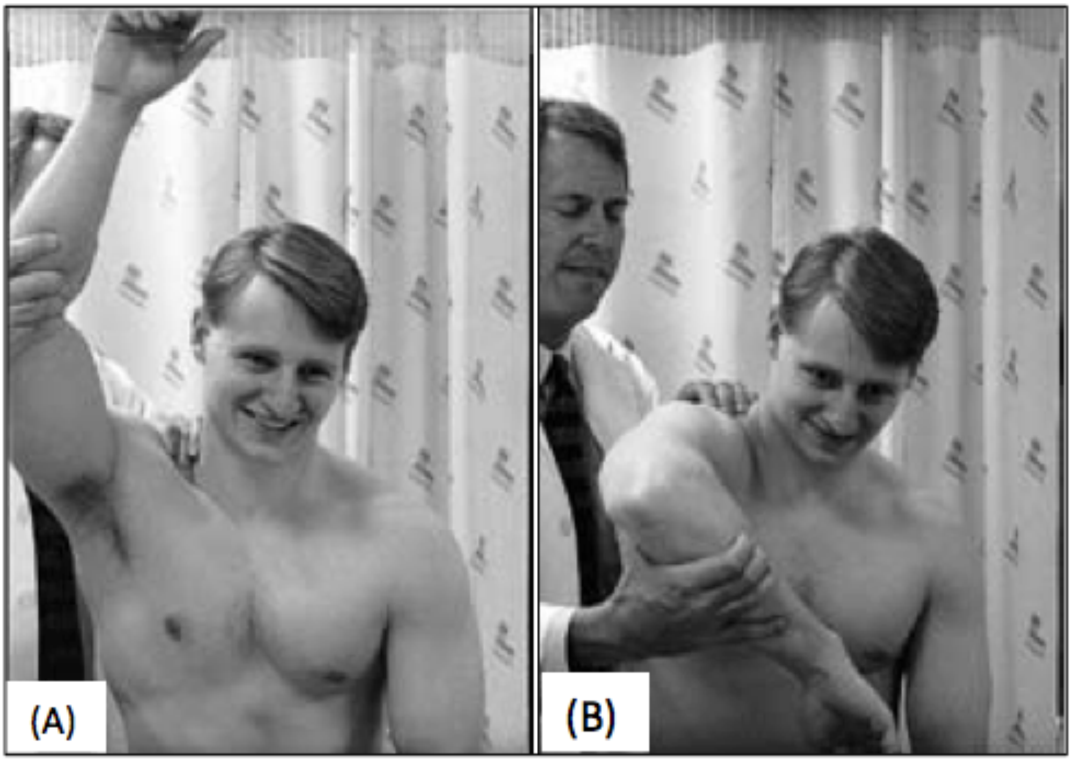


Figure 1.9 Physical examination in shoulder impingement syndrome: (A) the Neer impingement sign and (B) the Hawkins's impingement test (Rogerson, 2001).

1.2.4.2 Diagnostic (Medical) Images

Medical images may be used to investigate shoulder impingement including radiographs, ultrasound and magnetic resonance imaging (MRI). Radiographs with different views (anterosuperior, outlet (supraspinatus) and axillary) may be inspected to indicate: narrowing of the subacromial space; osteophyte formation underneath the acromioclavicular joint; acromial spurs; calcification of the CAL;

calcium deposits on the rotator cuff tendon; os acromiale; and shoulder dislocation (Gomoll *et al*., 2004; Warner *et al*., 1998; Weiner and Macnab, 1970) (Figure 1.10). Ultrasound (Figure 1.11) and MRI (Figure 1.12 A) may be used to determine the incidence and type of the rotator cuff tear (Teefey *et al*., 2000; Meister *et al*., 2004). Finally, arthroscopy may be used in cases when it has proved difficult to analyse the type of tear (Figure 1.12 B).

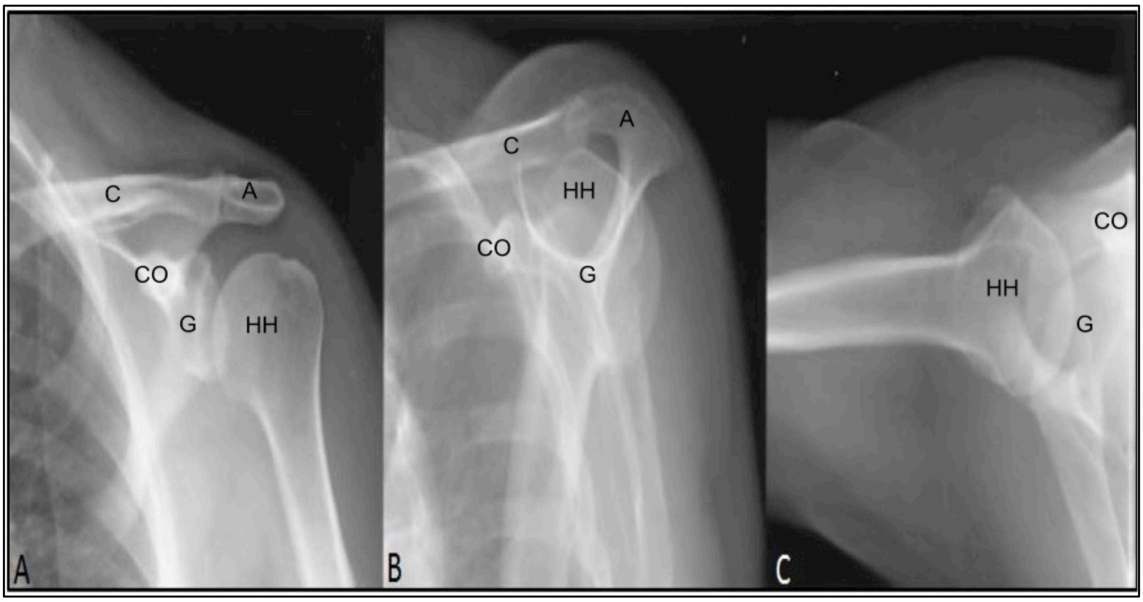


Figure 1.10 **Types of** radiographic view used during the diagnosis of shoulder impingement syndrome to inspect the bony structures: (A) anteroposterior view (normal), (B) outlet view (normal), and (C) axillary view (normal). Acromion (A), humeral head (HH), clavicle (C), coracoid (CO), glenoid (G) (Gomoll *et al*., 2004).

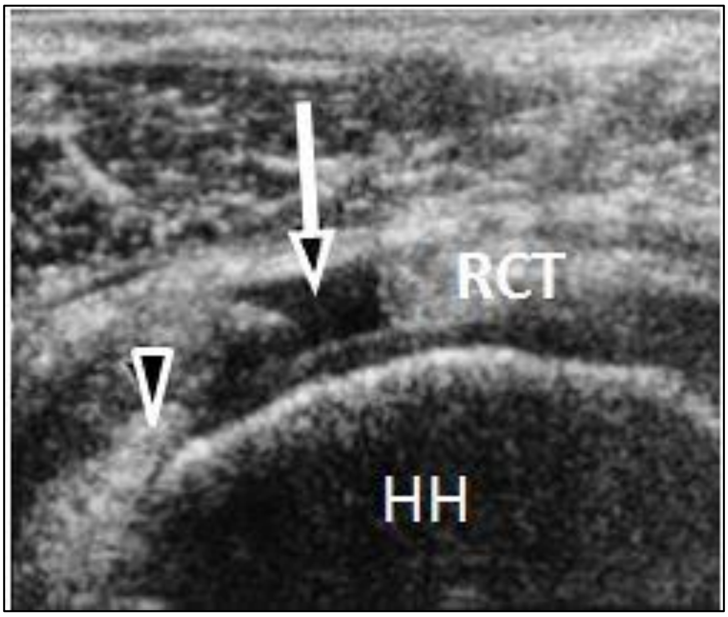


Figure 1.11 Ultrasonographic image in a plane perpendicular to the longitudinal axis of the tendon showing a rotator cuff tear (arrow) in which fluid separates the torn ends of the tendon. The arrowhead points to the tendon of the long head of biceps, to the left of the tear. Humeral head (HH), rotator cuff tendon (RCT), (Teefey *et al*., 2000).

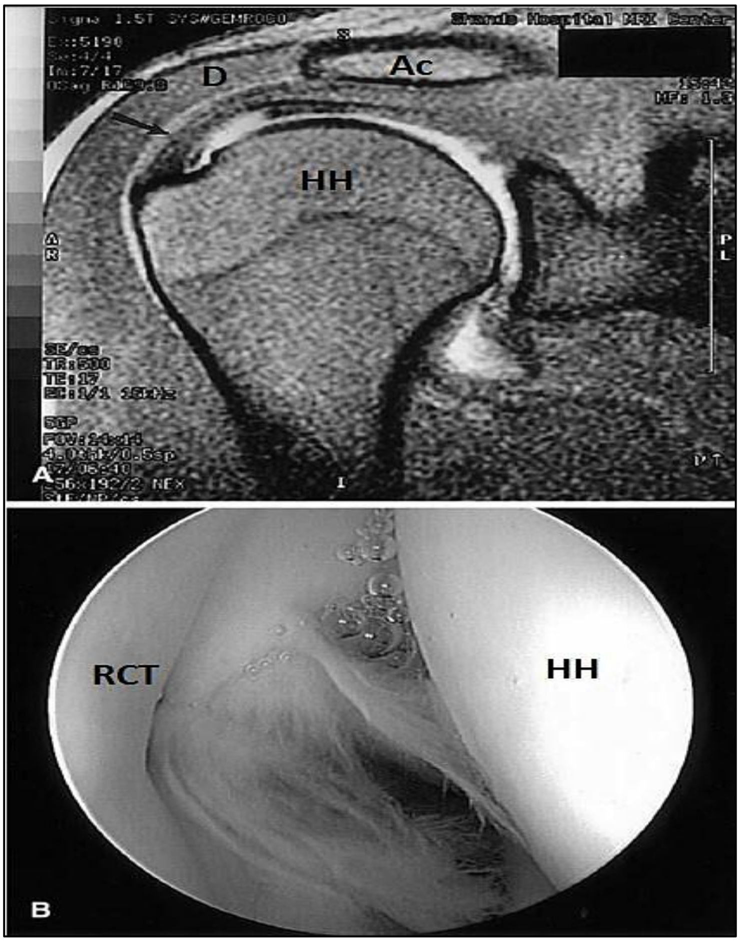


Figure 1.12 Partial-thickness cuff tear (arrow) in the undersurface of the rotator cuff tendon: shown in MRI (A) and arthroscopy (B). Acromion (Ac), deltoid (D), humeral head (HH), rotator cuff tendon (RCT), (Meister *et al*., 2004).

1.2.5 Treatment

Shoulder impingement syndrome treatment and management includes non-operative and operative treatments.

1.2.5.1 Non operative Treatment

Non-operative or conservative treatment includes rest, oral anti-inflammatory medication and shoulder exercise: it is often successful. Injection of 10.0 cc of 1.0% xylocaine into the subacromial space, beneath the anterior acromion, may be used to relieve severe shoulder pain. Non-operative treatment is indicated for patients with impingement stage I and II of 18 months duration. Otherwise, operative treatment is indicated to release the impingement if symptoms persist (Neer, 1983).

1.2.5.2 Operative Treatment

Operative treatment aims to release the impingement by decompressing the subacromial space. In 1972, Neer developed an anterior acromioplasty technique to decompress the subacromial space and relieve impingement on the rotator cuff. This procedure involves debridement of the inflamed subacromial bursa, resection of the coracoacromial ligament and any spurs that are present, resection of the anteroinferior aspect of the acromion, resection of overhanging osteophytes from the acromioclavicular joint or of the entire joint if there is preoperative tenderness, and repair of the rotator cuff tear. This procedure has become an accepted method for the treatment of impingement and has achieved a high percentage of satisfactory results (Frieman and Fenlin, 1995; Nielsen *et al*., 1994; Sachs *et al*., 1994). However, the procedure is criticised for its complications and the unsatisfactory clinical results associated with excessive removal of acromial bone (Bigliani *et al*, 1992; Neer & Marberry, 1981).

In 1987, Ellman described arthroscopic anterior acromioplasty as an alternative to open acromioplasty. This produced similar results to those of the open procedure (Ellman & Kay, 1991); however there were also complications associated with arthroscopic anterior acromioplasty, including an inadequate removal of bone, acromial fracture, and substantial injury to the origin of deltoid (Bigliani & Levine, 1997; Gartsman, 1990; Green *et al*., 2004; Matthews *et al*., 1994). Furthermore, previous studies have reported persistence or recurrence of shoulder symptoms in 40% to 50% of patients within one year of the first clinical visit (Chard *et al*., 1991; Croft *et al*., 1996; van der Windt *et al*., 1996). Finally, there remains the need for proper anatomical identification of structures in and around the impingement area, as well as high-quality studies on the pathology, etiology and management of shoulder impingement syndrome (Bilgliani and Levine, 1997; Green *et al*., 2004; Harrison and Flatow, 2011).

1.3 The Anatomy of the Coracoacromial Ligament

The coracoacromial ligament (CAL) is described as being a trapezoid (Gallino *et al*., 1995) or triangular ligament (Moorman *et al*., 2008; Ciochon and Corruccini, 1977) extending between the acromion and coracoid processes. Its apex originates from the anterior undersurface of the acromion, lateral to the clavicular facet, and twists as a helix to insert onto the posterosuperior border of the coracoid (the base). It completes an arch with the acromion and coracoid processes, the coracoacromial arch, above the head of humerus. This arch prevents superior dislocation of the humeral head, protects the rotator cuff muscles, and separates deltoid and supraspinatus (Ciochon and Corruccini, 1977).

1.3.1 Band Number

The CAL either originates as two bands before leaving the undersurface of the acromion, or diverges into two bands within 1 cm of the anterior margin of the acromion (Fealy *et al*., 2005). Williams *et al*. (1997) were the first to demonstrate bifurcation of the CAL in an arthroscopic view: this was considered uncommon. The anterolateral band commonly extends to the posterolateral aspect of the acromion (Fealy *et al*., 2005), whereas the third band of the ligament, when present, is usually hidden beneath the clavicle and can only be seen after dissection of the acromioclavicular joint and displacement of the clavicle (Pieper *et al*.,1997). Pieper *et al*. (1997) suggested that the third band could narrow the subacromial space and create impingement of the rotator cuff tendons. Therefore, they claimed that the previous unsatisfactory results of surgical treatment for subacromial pain could be caused by unsuccessful resection of the third band.

1.3.2 CAL Attachment

The anterolateral band has a constant origin from the lateral tip of the coracoid, while the insertion of the posteromedial band is variable and may be attached anywhere along the base of the coracoid (Brodie, 1890). Edelson and Luchs (1995) observed that the coracoid attachment of the CAL with a bipartite base extended to the base of the coracoid in one third of specimens. The posteromedial band of the three band ligament also inserted into the base of the coracoid process. However, the three bands have been observed to have discrete insertions on the coracoid, but were less well differentiated at their acromial attachment (Fealy *et al*., 2005). These bands join together at the anterior edge of the acromion to insert into the undersurface of the acromion (Moorman *et al*., 2008) covering the entire undersurface of the anterior medial acromion and a substantial portion or all of the acromioclavicular joint. The acromial insertion of the ligament continued along the lateral margin of the acromion for a variable distance. However, the CAL was adherent to the undersurface of the deltoid fascia along the lateral aspect of the acromion (Edelson and Luchs, 1995).

Hunt *et al*. (2000) studied the anatomical relationships and the effect of arthroscopic acromioplasty on the anterior acromial attachment of the CAL and deltoid. In their study, they examined the acromial attachments of the CAL and deltoid in 10 cadaveric specimens and found that the superior part of fibers of the CAL blended with the overlying deltoid muscle. Reflection of deltoid superiorly showed tethered fibrous tissue passing to the underlying CAL near its acromial attachment, there being no clear junction between the CAL and deltoid attachment. Histological examination of the blended area showed that the more superior collagen fibers of the CAL blended with collagen fibers of the tendinous insertion of deltoid before both structures gained attachment to the periosteum of the acromion. Hunt *et al*. (2000) called this bridge the coracoacromial-deltoid-periosteal complex (CALD-periosteal complex) (Figure 1.13). In addition, they reported that the acromial attachment of the CAL extended onto the inferior surface of the acromion and passed medially into the capsule of the acromioclavicular joint. They were unable to identify the medial and lateral margins of the CAL, which appeared to be continuous with the clavipectoral fascia medially and with the fascia on the undersurface of deltoid laterally. At the coracoid attachment site, the CAL was found to blend with the conjoined tendon of biceps and coracobrachialis (coracoacromial falx).

Salter *et al*. (1987) studied the anatomy of the acromioclavicular joint and its supporting ligaments in 63 cadaveric shoulders of unknown age. They also investigated the relationship of the CAL to the supporting ligaments of the acromioclavicular joint. They found that the acromial insertion of the CAL extended onto the inferior acromial surface through a broad area interconnecting with the inferior capsular ligament of the acromioclavicular joint. They assumed that the CAL acts to buffer this area from the subacromial soft tissues and to support the acromioclavicular joint. Furthermore, they found that the CAL interconnected with the coracoclavicular and coracohumeral ligaments at the coracoid attachment site.

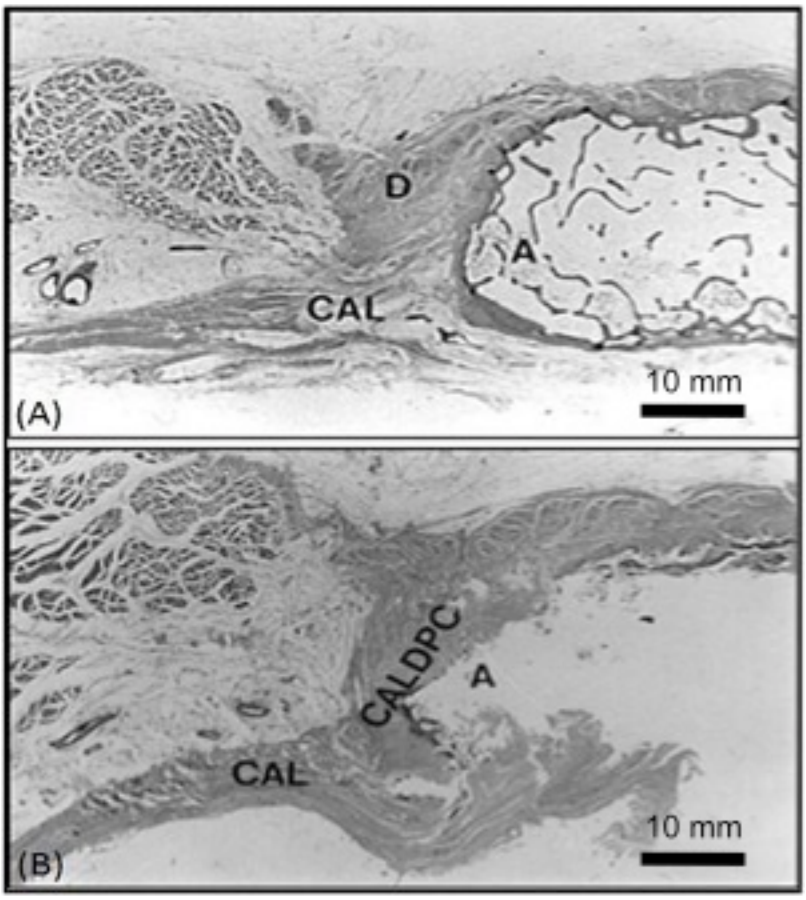


Figure 1.13 Sagittal sections at the anterior acromion: figure (A) shows the CAL and deltoid (D) have close attachment sites at the anterior edge of the acromion. Figure (B) shows the CAL gains attachment to the acromion (has been burred) via a bridge called the coracoacromial-deltoid-periosteal complex (CALDPC) (B). Division of anterior fibers of CAL is shown under burred acromion (Stain: Hematoxylin and Eosin) (Hunt *et al.*, 2000).

1.3.3 Coracoacromial Falx

At the lateral border of the coracoid process the lateral band of the CAL has been shown to be continuous with fibers from the conjoined tendons of the short head of biceps and coracobrachialis (Figure 1.14) (Brodie, 1890; Hunt *et al.*, 2000; Renoux *et al.*, 1986, Fealy *et al.*, 2005). Renoux *et al.* (1986) described this lateral extension of the CAL as the coracoacromial falx. However, previous studies have presented different descriptions of the falx at the conjoined tendon. The falx has been described as being continuous with the aponeurosis of coracobrachialis (Renoux *et al.*, 1986), the short head of biceps

(Brodie 1890; Birnbaum *et al.*,1998) and both the tendons of biceps and coracobrachialis (Hunt *et al*. 2000).

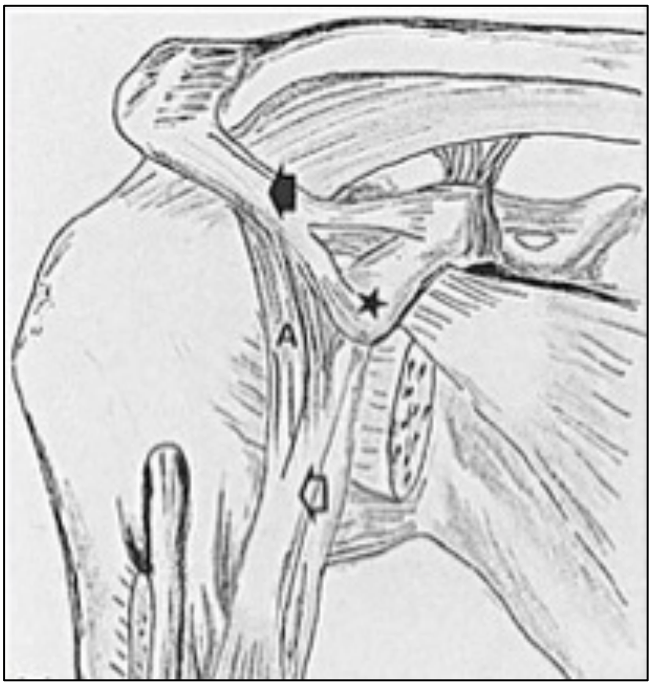


Figure 1.14 The coracoacromial falx: lateral view of the right shoulder showing the connection between the CAL (dark arrow) and the short head of biceps (outline arrow) via the coracoacromial falx (coracoid aponeurosis) (A) that extends along the lateral edge of the CAL (Birnbaum *et al.*,1998).

Fealy *et al*. (2005) observed the falx in 42 shoulders (75%). Posteriorly, it was present at the lateral lip of the acromion extending anterolaterally from the CAL along its whole course blending anteriorly with the conjoined tendon at the lateral aspect of the coracoid process. Lee at al. (2001) inspected 6 cadaveric shoulders, with an age range of 60-80 years, and noted an accessory tissue (falx) in all samples, which originated medially from the CAL and clavipectoral fascia, and laterally from the lateral margin of the rotator interval: the fibers inserted into the lateral fibers of the short head of biceps brachii. Release of the CAL resulted in laxity in the falx and coracohumeral ligament (Lee *et al.*, 2001).

1.3.4 Coracoacromial Veil

The coracoacromial veil is described as a L-shaped membranous tissue connects between the posteromedial band of the CAL and the anterosuperior rotator interval capsule (Moorman *et al*., 2008) or the subacromial bursa (Birnbaum *et al*., 1998). Jerosch *et al*. (1990) noted the coracoacromial veil in an unspecified number of 9 shoulders. In these shoulders, the coracohumeral ligament was noted to limit inferior glenohumeral subluxation and external rotation. Birnbaum *et al*. (1998) reported a subcoracoid connection between the CAL and the partial membrane of the subacromial bursa in 90% (72/80) of specimens (Figure 1.15). Furthermore, they noted a connection (coracoid aponeurosis) between the CAL and the short head of biceps brachii in 71% (57/80) of specimens. Functionally, they believed that these connections have a role in facilitating the gliding behavior of the subacromial bursa and the shoulder joint capsule in shoulder abduction. The gliding mechanism was lost when the CAL, subcoracoid attachment and the coracoid aponeurosis were released. Birnbaum *et al*. (1998) suggested that operative release of the CAL might compromise the gliding mechanism during shoulder abduction and cause subcoracoid impingement. Fealy *et al*. (2000) confirmed development of the coracoacromial veil at 14 weeks of gestation extending between the coracohumeral ligament and the CAL (Figure 1.16). However, Lee *et al*. (2001) supported an interaction between the CAL and the coracohumeral ligament through the coracoacromial veil.

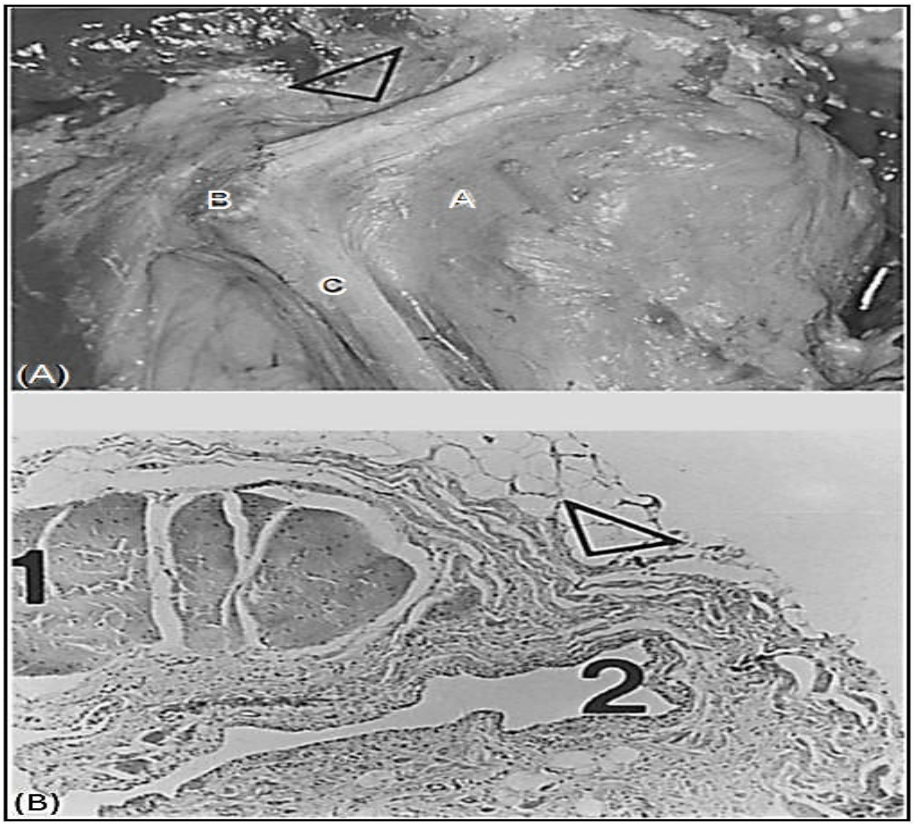


Figure 1.15 Lateral view of the shoulder showing the connection between the CAL and the subacromial bursa through a partial sheet: Figure (A) shows a direct connection between the CAL (arrow) and the subacromial bursa via a partial sheath (A), B: coracoid process, C: short head of biceps. Figure (B) is a hematoxylin-eosin stained section showing the connection between the CAL (1) and the subacromial bursa (2) via a direct transition of individual fibers of the CAL (arrow) (Birnbaum *et al*.,1998).

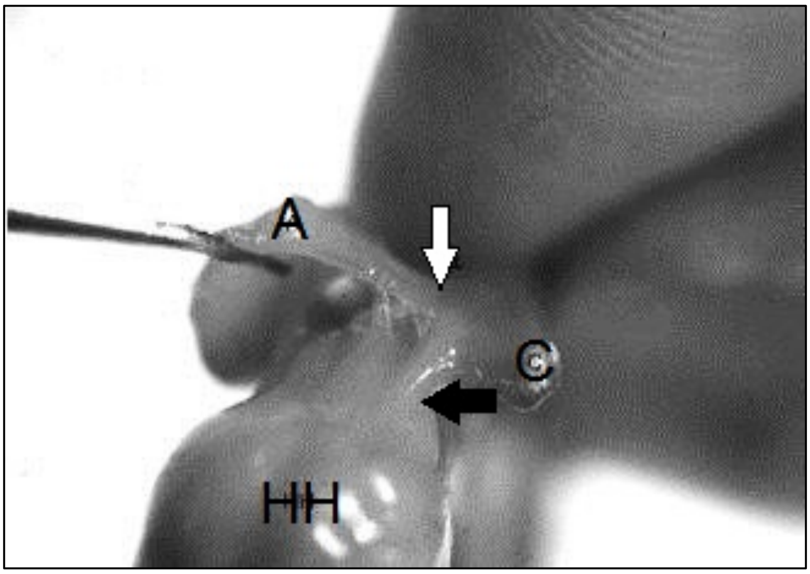


Figure 1.16 Lateral view of a fetal shoulder: the CAL and coracohumeral ligament (black arrow) are clearly seen at this age: 9-40 weeks of gestation. A thin band (white arrow) of ligamentous tissue is connected between the CAL and the coracohumeral ligament, posterolateral to their attachments to the coracoid process (C). Acromion (A), and humeral head (HH) (Fealy *et al*., 2000).

In 2008, Moorman *et al*. investigated the anatomy of the coracoacromial veil in 28 shoulders: it was present in all specimens, being anatomically distinct from the coracohumeral ligament and extended medially and posteriorly from the medial border of the coracohumeral ligament. Biomechanically, inferior traction of the humerus visibly increased tension of the coracoacromial veil and resulted in an inferior deflection of the posteromedial band of the CAL. Therefore, Moorman *et al*. (2008) assumed that the coracoacromial veil potentially stabilized the glenohumeral joint. Moreover, they suggested that a traumatic injury or procedural resection of the CAL might predispose patients to inferior instability of the shoulder. Histological examination of the coracoacromial veil revealed that it was composed of collagenous tissue. However, the coracohumeral ligament was directly inserted onto the CAL in only one specimen (3.6%). Moorman *et al*. (2008) also stated the existence of the structure in utero.

Moorman *et al*. (2012) investigated the role of the CAL and related arch structures in shoulder joint stability. Using 8 fresh-frozen shoulders they tested shoulder stability after three interventions: coracoacromial veil release, CAL release and anterior acromioplasty. Both deltoid and trapezius were removed in these shoulders. They reported that release of the coracoacromial veil caused a significant increase in inferior shoulder translation at low angles of abduction. However, CAL release and acromioplasty resulted in a significant increase in superior shoulder translation at all shoulder angles, and a small increase in anterior and posterior shoulder translation, but no difference in inferior shoulder translation. They concluded that the coracoacromial veil has a role in stabilising the shoulder joint against inferior humeral translation by working with the coracoacromial arch and glenohumeral joint capsule. Moreover, the CAL and acromion have a role in shoulder stabilization through limiting superior humeral translation. Moorman *et al*. (2012) advocate preserving these structures to improve surgical outcomes. However, Moorman *et al*. did not investigate resecting of these structures in living shoulders or in shoulders with active muscles.

1.3.5 The Morphology of the CAL

Previous studies reported different shapes of the CAL (Figure 1.17)(Edelson & Luchs, 1995; Holt and Allibone, 1995; Kesmezacar *et al*., 2008). Edelson and Luchs (1995) stated that a knowledge of the anatomical variation of the CAL could be important in the successful outcome of surgery involving it. Each type of CAL found by Kesmezacar *et al*. (2008) has a unique morphology (Figure 1.17). Both broad-band and quadrangular ligaments have a single band, with the broad-band characterized by presenting almost the same width (less than 2mm difference) at both attachments. The quadrangular ligament has a greater coracoid attachment width than its acromial attachment. The broad ligament extends from the acromion to the lateral posterior aspect of the coracoid process without any change in width. In contrast, the quadrangular ligament extends between the acromion and coracoid processes with a slight curve of the lateral and medial borders of the ligament. In addition, the quadrangular ligament has a similar morphology to the Y-shaped ligament, but without any division or diaphanous region.

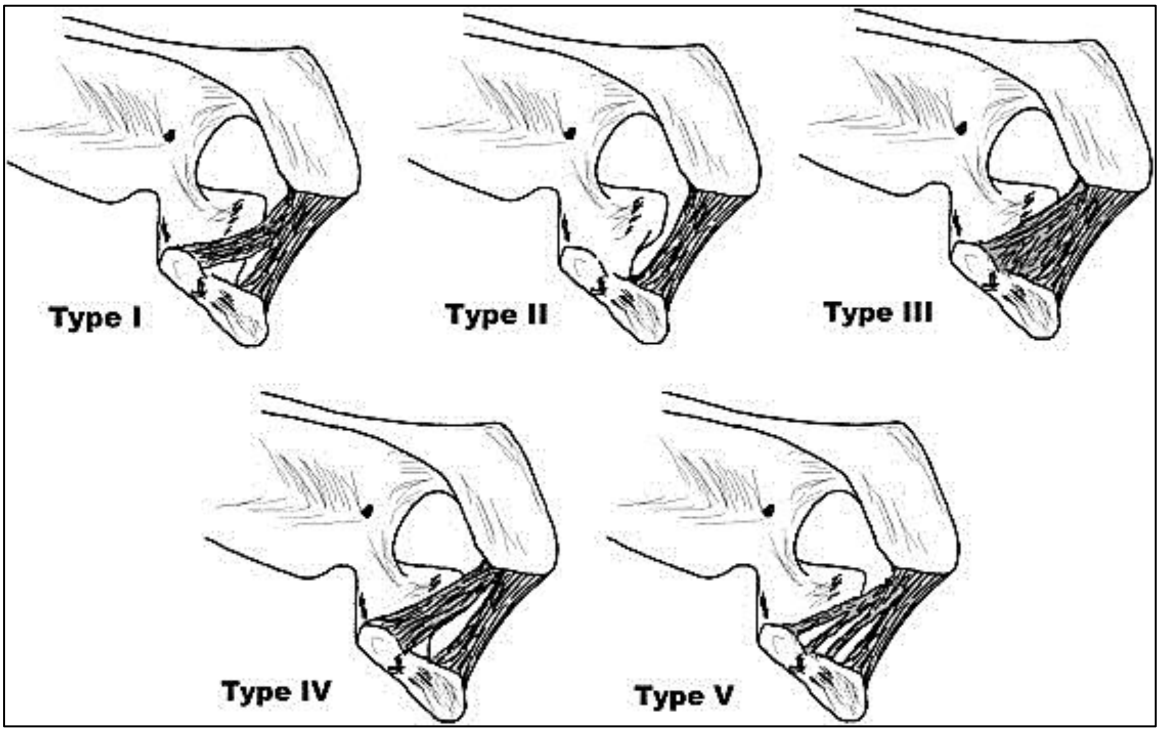


Figure 1.17 The five morphological types of the CAL: the Y-shaped ligament (type I), the broad band ligament (type II), the quadrangular band ligament (type III), the V-shaped ligament (type IV), and the multiple-banded ligament (type V) (Kesmezacar *et al*., 2008).

Each type of Y-shaped and V-shaped ligament is formed by 2 ligamentous bands, an anterolateral band and a posteromedial band (Kesmezacar *et al*., 2008). At the acromial attachment site, the Y-shaped ligament originates as a unique band, whereas the V-shaped ligament originates as 2 separated bands closer to each other than at the coracoid attachment site. Furthermore, the posteromedial band of the V-shaped ligament was thinner and inferior to the anterolateral band at the acromial attachment site. Both ligaments inserted into the posterior aspect of the coracoid as two separate bands with an intervening diaphanous membrane. At the coracoid attachment site the anterolateral band usually attached to the lateral tip of the coracoid, whereas the posteromedial band extended medially to the base of the coracoid. The multiple-banded ligament consisted of three or more ligamentous bands, which either started as a unique band or as multiple separated bands. Some multiple-banded ligaments also showed the morphology of the Y-shaped ligament with the posteromedial band dividing into 2 or more parts.

1.3.6 Diaphanous membrane

The diaphanous membrane is a thin membranous tissue filling the areas between the bands of the CAL. Histological inspection showed few fibers of true ligamentous (Brodie, 1890) or connective tissue (Moorman *et al.*, 2008), with a defect often present close to the coracoid process (Brodie, 1890; Holt and Allibone; 1995). Brodie (1890) observed pectoralis minor passing through this deficiency to insert into the shoulder joint capsule, with the membrane being either partially or entirely absent (Figure 1.18). Holt and Allibone (1995) noted that the tendon of pectoralis minor was involved in the CAL in 14% of specimens: 11% with a Y-shaped ligament and 3% with a broad band ligament. Furthermore, they found small vessels in 12 of 13 Y-shaped ligaments. The mean length of the diaphanous membrane from the coracoid was 3.8 mm. In shoulders with a Y-shaped ligament, the mean distance between lateral and medial bands was 6.8 ± 3.7 mm. Edelson and Luchs (1995) reported the gap between the two bands to be 5 to 15 mm.

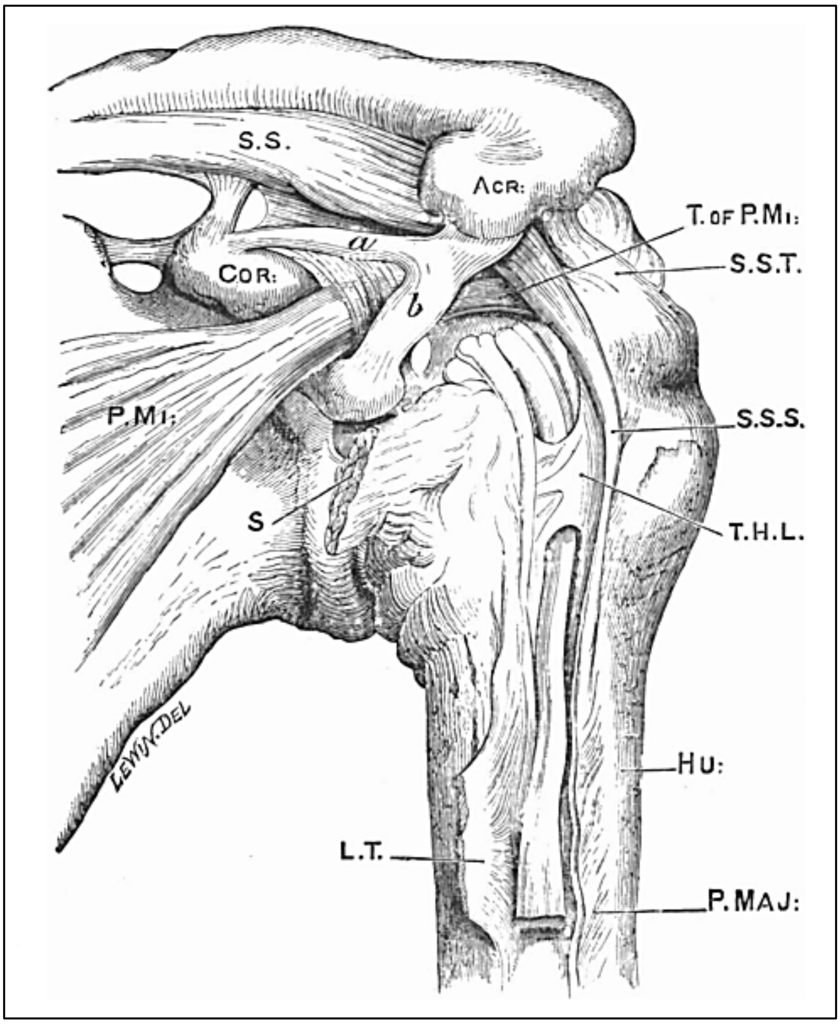


Figure 1.18 Anterior view of the shoulder showing the two bands (a and b) of the CAL separated by a diaphanous membrane: the tendon of pectoralis minor (P.Mi and T of P.M.) pass through a defect in the diaphanous membrane to insert into the shoulder capsule. (S.S) supraspinatus, (S.S.T.) supraspinatus tendon inserted into greater tubercle, (Acr) acromion, (CoR) coracoid, (T.H.L) transverse humeral ligament, (L.T.) latissimus dorsi (Brodie, 1890).

1.3.7 CAL Parameter

In previous studies (Table 1.1) the mean width of the acromial CAL attachment ranged from 7.90 to 21.0 mm and was 20.0 to 44.0 mm at the coracoid attachment site. Hu *et al*. (2009) found that the coracoid attachment of the CAL was wider than the acromial attachment. Holt and Allibone (1995) also found wider coracoid attachment in quadrangular, Y-shaped, and multiple-banded ligaments.

Table 1.1 Geometric data of the CAL in previous studies.

Study	N	AW (mm)	CW (mm)	LL (mm)	ML (mm)	MT (mm)
Holt & Allibone (1995)	48	Q: 19.4 Y: 19.4 B: 19.0 M: 21.0	Q: 32.8 Y: 31.2 B: 20.0 M: 44.0	Q: 23.1 Y: 25.0 B: 25.0		Q: 1.3 Y: 1.3 B: 1.2 M: 1.3
Pieper *et al*. (1997)	124		I: 27 II: 34 III: 37	I: 36.0 II: 35.0 III: 32.0		I: 1.4 II: 1.4 III: 1.4
Shaffer *et al*. (1997)	28	15.6 (12.0-20.0)		26.7 (15.5-31)		
Morisawa (1998)	23	11.70 ± 2.4		28.05 ± 5.3		
Fealy *et al*. (2005)	56	7.90 ± 3.4		31.0 ± 4.7	30.70 ± 5.3	
Fagelman *et al*. (2007)	7			39.6	29.2	
Kesmezacar *et al*. (2008)	80	Y: 15.60 ± 2.7 B: 13.66 ± 3.5 Q: 14.18 ± 4.7 V: 11.88 ± 2.4 M: 15.44 ± 2.8		Y: 34.57 ± 3.1 B: 35.11 ± 5.8 Q: 38.36 ± 8.9 V: 34.00 ± 4.7 M: 32.00 ± 2.7		
Hu *et al*. (2009)	9	15.86 ± 2.28	26.80 ± 10.24	31.90 ± 4.21	28.91 ± 5.56	1.16 ± 0.36
Wang *et al*. (2009)	50			31.20 ± 2.99		1.97 ± 0.49

- CAL parameters: acromial width (AW), coracoid width (CW), lateral length (LL), medial length (ML) and middle thickness (MT).
- CAL shapes: broad-band (B), quadrangular ligament (Q), Y-shaped ligament (Y), V-shaped ligament (V) and multiple-banded ligament (M).
- CAL band number: one band ligament (I), two band ligament (II) and three band ligament (III).

The mean length of the anterolateral band ranged from 23.1 to 39.6 mm, while the length of the posteromedial band extended from 28.91 to 30.70 mm. Both anterolateral and posteromedial bands have almost the same length according to Fealy *et al*. (2005) and Hu *et al*. (2009). However, Fagelman *et al*. (2007) reported that the anterolateral band was longer than the posteromedial band, being 39.6 mm and 29.2 mm respectively. The mean lengths of the subacromial insertion of the CAL were 12.3 (Shaffer *et al*., 1997) and 18.5 mm (Fealy *et al*., 2005), which covers the entire anterior acromial undersurface. Therefore the whole mean lateral length of the CAL was 39 mm (range 23 to 50 mm) (Shaffer *et al*., 1997).

The thickness of the CAL at its midpoint is between 1.16 mm and 1.97 mm. However, the anterolateral band has a thicker acromial attachment than coracoid attachment, whereas the posteromedial band has a thicker coracoid attachment than acromial attachment (Fealy *et al*., 2005). The CAL-humeral head distance ranges from 7 to 10 mm (Wang *et al*., 2009).

Comparing the anterolateral and posteromedial bands, the lateral band is usually stronger and broader than the medial band (Brodie, 1890; Holt and Allibone 1995). The thickness of the posteromedial band shows more variability than the anterolateral band (Moorman *et al*., 2008). Regarding the number of bands, Pieper *et al*. (1997) found no significant difference in length or thickness between the three types of ligaments. However, they noticed a significant positive correlation between the width of the complete ligament (coracoid attachment width) and the number of bands (Table 1.1). In shoulders with a Y-shaped ligament, the lateral band was larger than the medial band in 80% of specimens. The length of the lateral border of the CAL, or the distance between the acromion and coracoid, for each ligament were almost the same. Both quadrangular (32.8 mm) and Y-shaped (31.2 mm) ligaments had significantly greater coracoid attachment widths than the broad band (20.0 mm) type. However, a significant relationship was found between shoulders presenting with the broad band type and people taller than 180 cm (Holt and Allibone, 1995).

Kesmezacar *et al*. (2008) measured the length and coracoid attachment width of the medial band in different morphological and band numbers in Y-shaped, V-shaped and multiple-banded ligaments. They found that the quadrangular band ligament had a significantly greater lateral band width than the other ligament types. However, they observed no difference in the other CAL parameters between each type. They emphasized that the number of bands changed only the dimension of the coracoid attachment of the anterolateral band. CALs with one band characterized with wider coracoid attachment and longer lateral band than the lateral band of the other types (Kesmezacar *et al*., 2008). However, Kesmezacar *et al* did not compare the complete attachment width at the coracoid between CAL types.

1.3.8 The Origin of the CAL Morphological Variations

The development of the glenohumeral joint was investigated in 51 shoulders from 37 fetal specimens ranging in age from 9 to 40 weeks (Fealy *et al*., 2000). By 13 weeks, the CAL was clearly evident, as were the individual anterolateral and posteromedial bands by 14 weeks gestation (Figure 1.19). By 36 weeks, the collagen fibers of the CAL were well organized. According to Brodie (1890), the lateral band is better developed in the human fetus than the medial band: it also shows fibers passing to the short tendon of the biceps (the CAL falx).

It is not clear whether the different morphological variants of the CAL are the cause or the result of impingement and degenerative factors (Gohlke *et al*., 1993; Ogata & Uhthoff, 1990; Soslowsky *et al*., 1996; Soslowsky *et al*., 1994). Holt and Allibone (1995) hypothesized that the final shape of the CAL may be determined by loss of tissue within the quadrangular type ligament during embryologic development of the shoulder joint. Therefore, the open oriental fan (quadrangular type) can be closed (broad band type) or break into two (Y-shaped type) or more segments (multiple-banded type). This process could be influenced by two factors: stresses related to movement in the growing joint or by degenerative changes in the adult. However, Kopuz *et al*. (2002) identified three morphological types of the CAL in neonatal shoulders with similar features to those observed in adult shoulders (Figure 1.20).

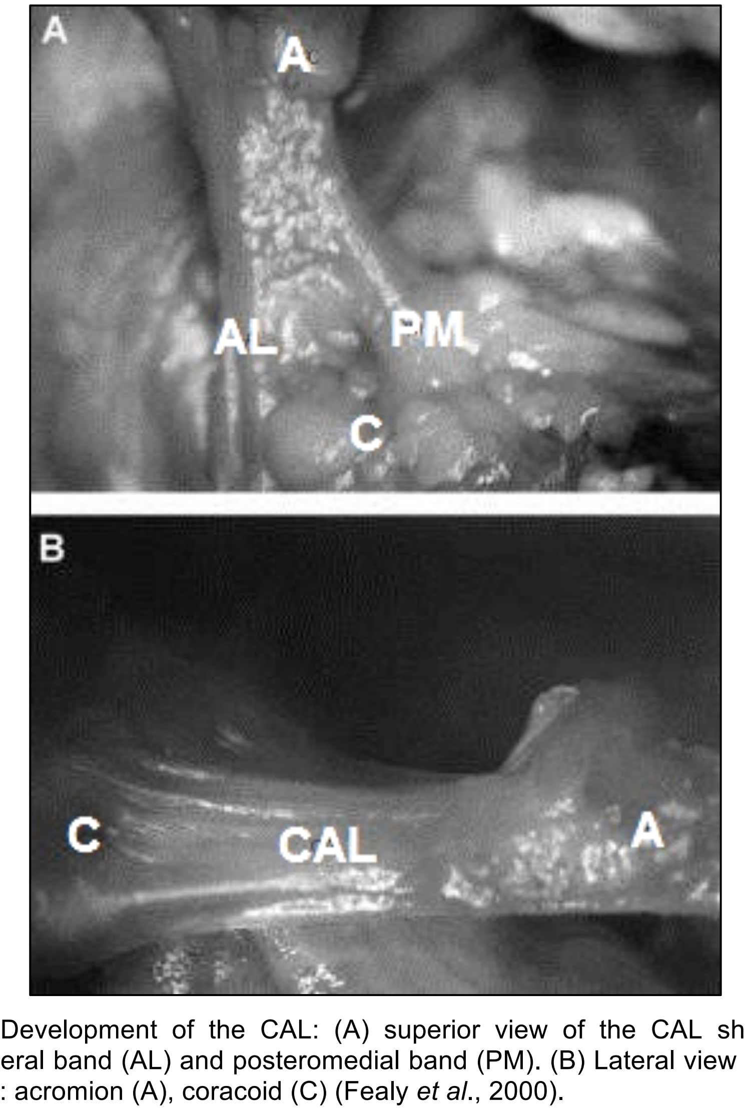


Figure 1.19 Development of the CAL: (A) superior view of the CAL showing 2 distinct bands: anterolateral band (AL) and posteromedial band (PM). (B) Lateral view of the CAL at 23 weeks gestation: acromion (A), coracoid (C) (Fealy *et al*., 2000).

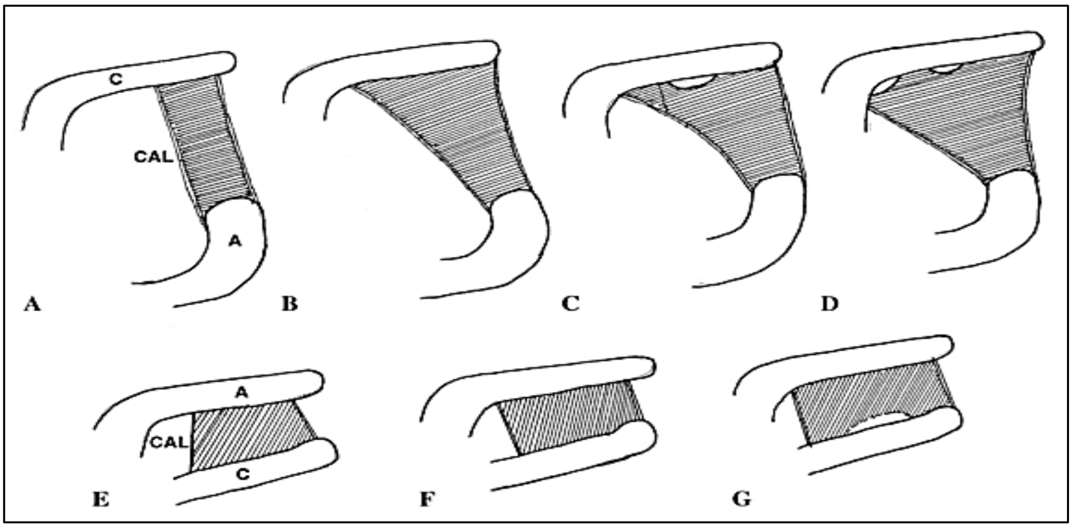


Figure 1.20 Anatomical variations of the CAL: (A-D) the shapes of the CAL seen in adults from Holt and Allibone (1995); the broad band (A), quadrangular band (B), Y-shaped ligament (C), and multiple band ligament (D). (E-G) the shapes of the CAL as observed in neonatal specimens by Kopuz et al. (2002); quadrangular band (E), broad band (F), and U-shaped ligament (G) (Kopuz et al., 2002).

1.3.9 CAL Blood and Nerve Supply

The CAL is supplied by the acromial branch of the thoracoacromial artery, which courses superior to the ligament some 5 mm from its acromial insertion, before forming an arterial net (rete acromiale) at the acromion (Okutsu *et al.*, 1992; Panni *et al.*, 1996). The vessels were observed to lie in a superficial fibro-fatty layer, within thin areas of loose connective tissue interspersed with bundles of collagen fibers in the mid-substance of the CAL (Panni *et al.*, 1996). However, Gallino *et al.* (1995) reported that the vessels found superior to the CAL were branches of the suprascapular artery.

The CAL is innervated by branches from the lateral pectoral nerve arising from the lateral cord of the brachial plexus. The lateral pectoral nerve pierces the clavipectoral fascia to pass beneath subclavius giving a small articular branch that runs laterally to cross the coracoid process giving small branches which innervate the coracoclavicular ligaments. At the superior aspect of the coracoid, the lateral pectoral nerve splits into two branches which pass inferiorly along the CAL to innervate the subacromial bursa and the anterior acromioclavicular joint (Aszmann *et al.*, 1996) (Figure 1.21).

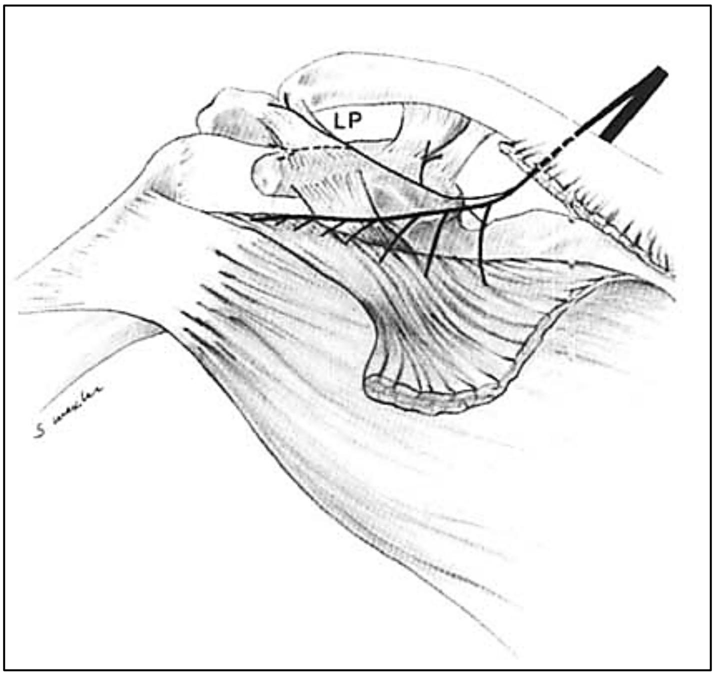


Figure 1.21 Anterior view of the shoulder joint: the clavicular attachment of pectoralis major has been reflected. The lateral pectoral nerve gives an articular branch that runs laterally to cross the coracoid process. It then gives small branches that innervate the coracoclavicular ligament before splitting into two branches that supply the subacromial bursa, coracoacromial ligament and the anterior acromioclavicular joint (Aszmann *et al.* 1996).

1.4 The Role of the CAL in Shoulders with Subacromial impingement Syndrome

The coracoacromial ligament plays a significant role in the development of subacromial impingement syndrome, especially in shoulders without bony abnormalities (large humeral head, hooked acromions, and large coracoid process) or articular deformities in the subacromial space or surrounding structures, such as acromial spurs, and acromioclavicular osteophytes (Uhthoff *et al.*, 1988; Fremerey *et al.*, 2000; Sarkar *et al.*, 1990). The impingement usually takes place at the CAL, which is the main impinging structure in subacromial impingement syndrome (Neer 1972). Patients who have shoulders with subacromial impingement syndrome present with painful tenderness over the CAL (Uhthoff *et al*., 1988). These shoulders also show various degenerative changes in both material properties and geometric parameters of the CAL leading to narrowing of the subacromial space (Uhthoff *et al*., 1988; Sarkar *et al*., 1990; Fremerey *et al*., 2000). However, other studies have debated that the CAL is not the primary cause of impingement syndrome, thus it is unclear whether degenerative and geometric changes of the CAL are the result or the cause of the impingement (Uhthoff *et al*., 1988; Soslowsky *et al*., 1994; Fremerey *et al*., 2000).

1.4.1 Implication of the CAL in Subacromial Impingement Syndrome

Impingement starts as friction of the rotator cuff tendon against the anterior edge and undersurface of the anterior third of the acromion, the coracoacromial ligament and sometimes the acromioclavicular joint during arm elevation (Neer, 1983). Previous studies have described various anatomical positions causing subacromial impingement against the CAL. Impingement of the greater tubercle with the free edge of the CAL has been reported during shoulder flexion of the internally rotated arm (Pujadas, 1970 cited in Postacchini, 1989). Furthermore, contact between supraspinatus and the CAL was seen in abducted shoulders during arm flexion and internal rotation (Eulert and Gekeler, 1975 cited in Uhthoff *et al*., 1988).

Muscle imbalance occurs between the muscles pulling the humeral head upward, such as deltoid, and those that hold the humeral head against the glenoid fossa, such as the rotator cuff muscles (Putz *et al*., 1988). This imbalance leads to a narrowing of the subacromial space, increased friction of the rotator cuff tendons against the coracoacromial arch, and finally tearing of the tendons and loss of shoulder motion (Pieper *et al*., 1997). Another muscular imbalance can also occur between pectoralis minor and the external rotator muscles of the arm (infraspinatus and terse minor). An increased tone in pectoralis minor leads to anterior positioning and internal rotation of the scapula (Pujadas, 1970 cited in Gallino *et al*., 1995). As a result, the CAL strain and thickness increase, leading to further increased friction (Gallino *et al*., 1995).

A tight CAL may narrow the subacromial space causing further impingement on the subacromial soft tissues. Narrowing of the subacromial space by a tight CAL was noted in 15 of 17 subacromial impingement patients (Uhthoff *et al*., 1988). In the absence of a thickened CAL and any bony encroachment, subacromial impingement could result primarily from over expansion of the subacromial structures against an unyielding CAL. This expansion is caused by lesions acquired through improper or overuse of the arm. As a result, a chronic strain of the CAL develops, which leads to degenerative changes, such as fibrillation, fatty infiltration and microtears. Both Watson (1985) and Uhthoff *et al*. (1988) suggest decompression of the subacromial space by a simple division of the CAL.

The subacromial portion of the CAL has been implicated pathologically in narrowing the subacromial space and causing impingement, especially in young patients. It has been suggested that the subacromial attachment of the CAL may form a small ridge that contributes to rotator cuff pathology (Burns and Whipple, 1993; Edelson and Taitz, 1992; Gohlke *et al*., 1993). Gallino *et al*. (1995) considered that the greater size and thickness of the subacromial portion of the CAL causes narrowing of the supraspinatus outlet, which is the origin of primary impingement syndromes seen in young patients. They excluded any relationship between subacromial impingement syndrome and bony alterations, articular instability and muscular imbalance. Penny and Welsh (1981) found that the main source of the impingement in younger patients was the CAL. In these patients, anterior acromioplasty was recommended only if there were osteophytes on the acromion, since no difference was observed between patients treated with anterior acromioplasty and those who only had CAL resection. However, Flatow *et al*. (1994) suggested the narrowing of the subacromial space in young patients due to hooked acromion.

1.4.2 Degenerative Changes in the CAL

Specimens of coracoacromial ligament taken from shoulders with chronic impingement have shown various degenerative changes including being thicker and having a lower failure load (Fremerey *et al*, 2000), the development of a calcified enthesopathy (Fealy *et al*., 2005) and microscopic changes including variegated cellularity with disarrangement of the extracellular matrix and fibrofatty tissue infiltration (Sarkar *et al*., 1990). Neer (1972) and Soslowski *et al*. (1994) reported that degenerative changes in the CAL present only in the anterolateral portion of the ligament. However, Pieper *et al*. (1997) noted degenerative changes of the CAL in nearly 75% of shoulders, with the changes seen in all parts of the ligament when present. Degenerative CAL changes were caused by an increased strain of subacromial structures beneath the coracoacromial arch, specifically the supraspinatus tendon and the tendon of the long head of biceps (Sarkar *et al*., 1990). This is supported by Konttinen *et al*. (1992) who found that CAL samples, taken after acromioplasty in patients with chronic rotator cuff tendinitis, were aneural and did not show any accumulation of inflammatory cells.

Shoulders with subacromial impingement syndrome and rotator cuff tears have thickened coracoacromial ligaments, which may decrease the subacromial space for rotator cuff excursion (Burns and Whipple, 1993). Burman (1949) described impingement of the supraspinatus tendon by a tight enlarged coracoacromial ligament in a 23 year old man, while Postaccini (1989) reported an uncommonly thick CAL at operation. Masciocchi *et al*. (1993) inspected 54 MRI images from impingement syndrome patients to verify the impingement points in the shoulder. They found critical impingement points in all patients: 65% between acromioclavicular arthritis and the supraspinatus tendon, 35% between acromioclavicular arthritis and supraspinatus, and 44% between the CAL and the supraspinatus tendon. The CAL was partially thickened in 25% of cases and completely thickened in 75%. Gallino *et al*. (1995) noted a variable thickness of the subacromial portion of the CAL, with an average thickness of 3.9 mm (range 2 mm- 5.6 mm) and over 4 mm at the anterior acromion compared to less than 2 mm in control shoulders (Soslowsky *et al*., 1994; Wu *et al*., 2010a and b). Finally, Watson (1985) found that the CAL was thickened and stiff and stated that it was a primary cause of impingement in 34 of 103 patients.

Ossification of the coracoacromial ligament and formation of an acromial spur are other degenerative changes seen in shoulders with impingement syndrome and rotator cuff tears. Conventional radiographs of 8 patients with impingement symptoms showed that all had ossification or calcification of the CAL (Figure 1.22) (Reichmister *et al*., 1996). There is a strong association between ossification of the CAL observed on conventional radiographs and the presence of rotator cuff pathology of the shoulder. Ossification of the CAL is rarely formed and may either be the result of a response to previous injury, or related to chronic degeneration secondary to repetitive stress, or related to abnormal calcium or phosphate metabolism. It has been reported that ossification of the CAL is strongly associated with calcification of the coracoclavicular ligament (Chen and Bohrer, 1990; Morimoto *et al*., 1988). An acromial spur may also form at the anterior edge of the acromion inside the acromial attachment of the CAL as a traction osteophyte due to increasing traction forces transmitted through the ligament (Fealy *et al*., 2005). Subacromial impingement syndrome may be caused by irritation of the supraspinatus tendon by an acromial spur (Neer, 1972).

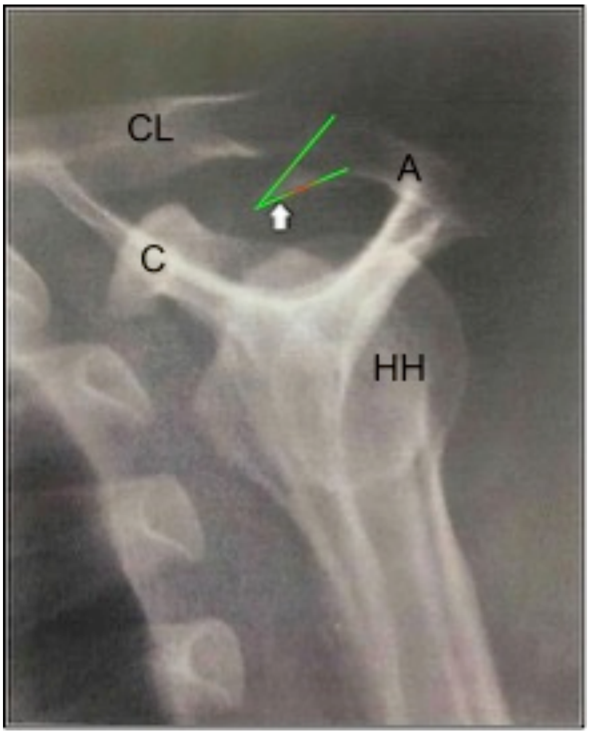


Figure 1.22 Lateral view radiograph showing an enlarged CAL with an osteophyte at the anterior edge of the acromion (arrow and outlined). Acromion (A); coracoid (C); clavicle (CL); humeral head (HH), (Reichmister *et al*., 1996).

It has been suggested that the degenerative changes seen in the coracoacromial ligament are caused by an increase in subacromial tension on the ligament. Uhthoff *et al*. (1988) observed degenerative changes in the CAL in the elderly patients and it was also a frequent finding in patients with impingement syndrome. They assumed that subacromial impingement syndrome would result from expansion of the rotator cuff, which would then cause trauma to the CAL leading to degenerative changes. This theory is supported by Putz and Reichelt (1990) who examined the histomorphology of the CAL in 133 operative specimens taken from the acromial attachment of 3 patient groups who had rotator cuff tears, tendinosis calcarea, and calcareous tendonitis syndrome. They observed moderate to severe degenerative signs in 85% of specimens and suggested that intermittent local pressure on the origin of the ligament in these conditions could lead to chondroid changes near its acromial attachment. Sarkar *et al*. (1990) also noted structural and metabolic changes in the CAL of shoulders with subacromial impingement syndrome, hypothesizing that an increase in volume of the structures in the subacromial space would lead to these changes through excessive tension on the CAL. Therefore, degenerative changes in the CAL would not be the primary cause of the impingement. Furthermore, Burns and Whipple (1993) noted that an increase in compression of the subacromial space contents (the supraspinatus tendon and the long head of biceps) on the coracoacromial arch during elevation of the arm in the scapular plane would increase tension on the CAL, specifically on the acromial junction. Finally, Nirschl (1989) assumed that the bursal thickening in shoulders with impingement and rotator cuff tears may increase pressure against the coracoacromial arch.

1.4.2.1 Changes in the Subacromial Insertion of the CAL

Previous studies reported degenerative changes and wearing in the subacromial insertion of the CAL in shoulders with rotator cuff tears (Ozaki *et al*., 1988; Ogata and Uhthoff, 1990; Tada *et al*., 1990). Ozaki *et al*. (1988) inspected the degenerative changes on the subacromial surface in relation to rotator cuff tears, which revealed a smooth and glossy synovial tissue covering the surface in shoulders with intact cuff tendons (Figure 1.23: A), an attritional lesion on both the CAL and anterior third or subacromial surface in shoulders with partial bursal tears and with complete tears (Figure 1.23: B), and eburnated bone in shoulders with massive rotator cuff tears (Figure 1.23: C). However, shoulders with partial tears on the articular side of the rotator cuff presented an intact smooth surface (Ozaki *et al*., 1988). Histological inspection of the subacromial surface of shoulders with a normal rotator cuff show four layers of tissue at the anterior third: synovial, collagenous, fibrocartilaginous and osseous, each of which showed a regular pattern of fiber tissue. The posterior two-thirds of the subacromial surface is composed of two layers only: synovial and osseous (Figure 1.24). On the other hand, shoulders with rotator cuff tears revealed several changes: an irregular pattern of collagen fiber bundles, attrition of the fibrocartilage, and/or hypertrophy of the osseous trabeculae (Figure 1.25). Ozaki *et al*. (1988) found that the severity of histological changes observed on the subacromial surface was positively correlated with the severity of the rotator cuff tear.

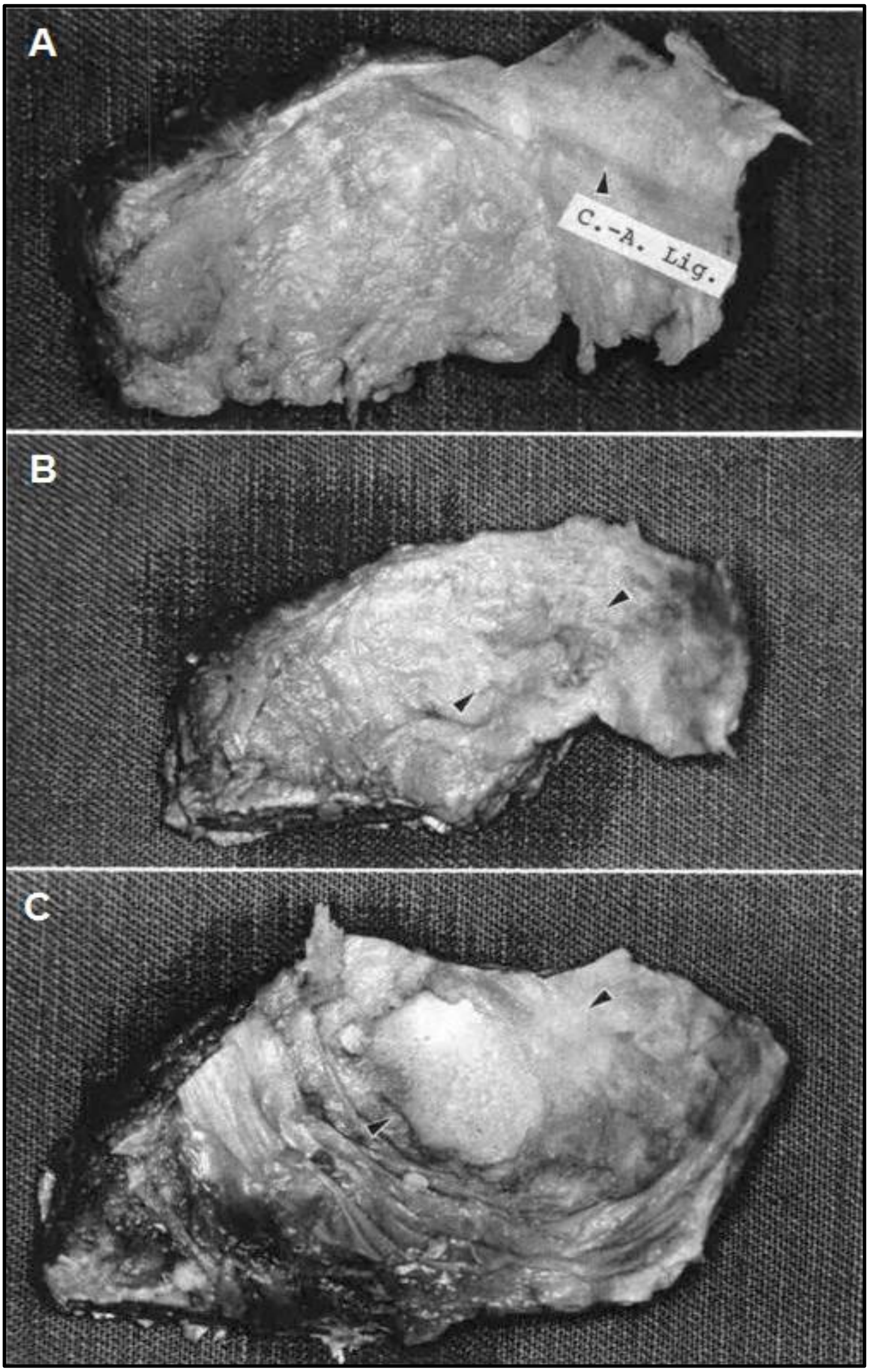


Figure 1.23 Gross inspection of the subacromial surface in relation to rotator cuff tears: the subacromial surface in shoulders with normal rotator cuff tendons is covered with a smooth glossy synovial tissue (arrow) (A). However, shoulders with bursal tears, both partial and full-thickness, show an attritional lesion (arrows) on both the CAL and anterior third or subacromial surface (B). In shoulders with massive rotator cuff tears, eburnated bone (arrows) was seen on the subacromial surface (C) (Ozaki *et al*., 1988).

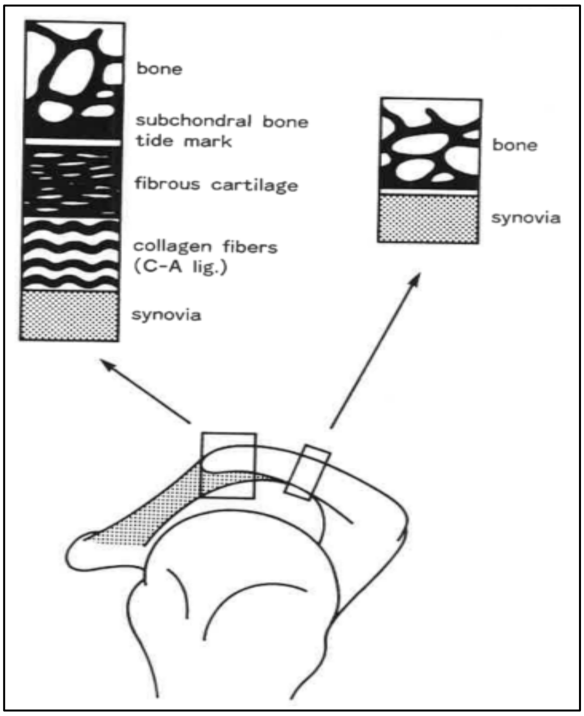


Figure 1.24. Illustration of the normal histological structure of the subacromial surface (Ozaki *et al*., 1988).

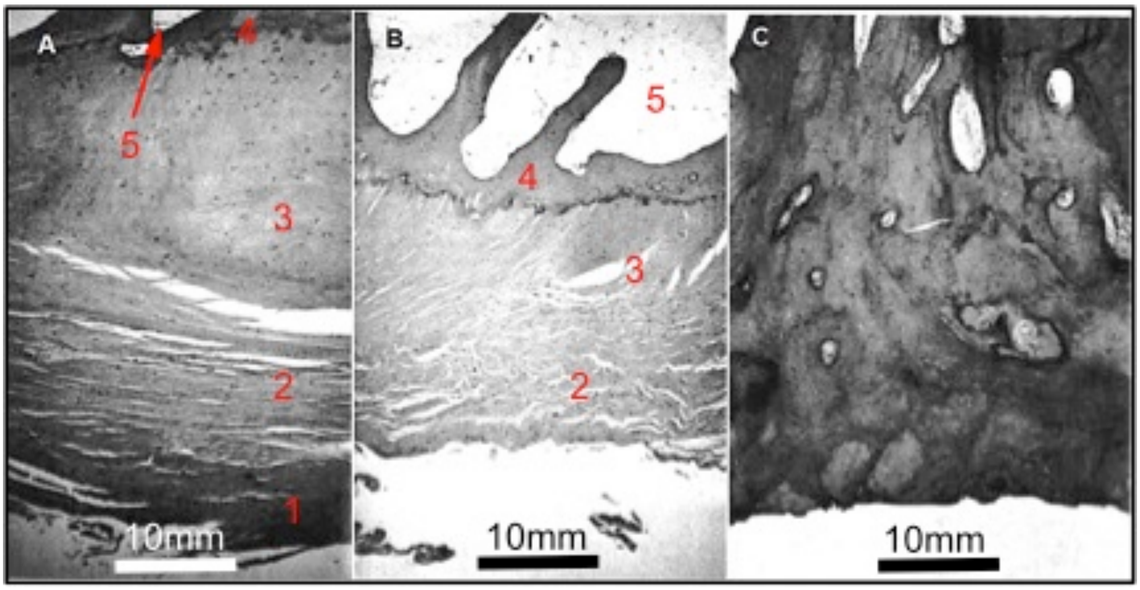


Figure 1.25 Histological micrographs of the subacromial surface in relation to a rotator cuff tear (stain: hematoxylin and eosin): shoulders with bursal partial-thickness tears show defects in the synovial layer and an attritional lesion of the collagenous layer (A). Shoulders with full-thickness rotator cuff tears show an irregular pattern in the collagenous and fibrocartilaginous zones (B). Shoulders with massive rotator cuff tears have a large defect in the fibrocartilaginous layer and hypertrophy of the trabeculae (C): synovial membrane (1), collagen fibers (2), fibrous cartilage (3), subchondirdal tissue (4), bone (5) (Ozaki *et al*., 1988).

Ogata and Uhthoff (1990) also inspected the degenerative changes of subacromial surface in shoulders with rotator cuff tears. Normally, the subacromial surface is covered by a fibrofatty tissue making a smooth concave surface (Figure 1.26: A). Both the fibrofatty tissue and the insertion of the CAL are covered by loose areolar tissue constituting the outer wall of the subacromial bursa. These normal features were observed in 16 specimens (21.1%), whereas degenerative changes were observed in 86% of shoulders with articular-side partial tears and in all shoulders with full thickness tears. Ogata and Uhthoff (1990) classified the degenerative changes at the acromial insertion into four grades (Figure 1.26).

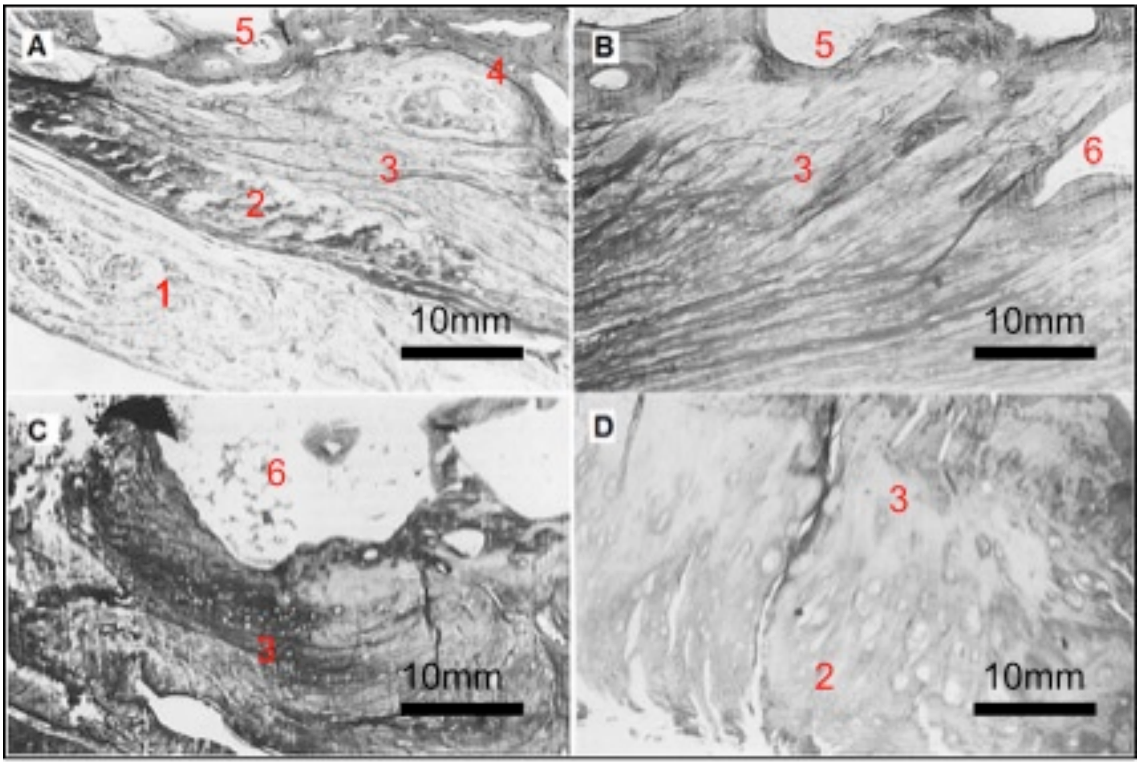


Figure 1.26 Histological micrographs representing classification of degenerative changes at the acromial insertion of the CAL (stain, azan; magnification, X40): a smooth concave surface covered by fibrofatty tissue was observed in normal subacromial surface (A) Both the fibrofatty tissue and the insertion of the CAL were covered by loose areolar tissue constituting the outer wall of the subacromial bursa. In grade I, the subacromial surface shows localized loss of the areolar tissue with or without small excrescences: osseous protrusions from the underlying bone are surrounded by a layer of fibrocartilage in the direction of the anchoring fibers of the CAL (B). Grade II is characterized by thickening of the fibrocartilage layer and projection of a spur at the anteroinferior corner of the acromion (C). Grade III shows an irregular surface and broken up fibers of the CAL, in which the collagenous and fibrocartilaginous layers at the undersurface of spur are eroded (D): synovial membrane (1), collagen fibers (2), fibrous cartilage (3), subchondirdal tissue (4), bone (5), spur (6) (Ogata and Uhthoff, 1990).

1.4.2.2 Contact Geometry at the Undersurface of the Acromion

Lee *et al*. (2001) assumed that the contact geometry at the subacromial surface is important in the pathogenesis of rotator cuff tears since the rotator cuff impinges at a certain part of the subacromial surface. They evaluated the contact geometry at the subacromial surface of the acromion in relation to rotator cuff tears in 40 shoulders. The contact between the rotator cuff and the subacromial surface was measured using Fuji Prescale super low-pressure-sensitive film when the shoulder was held at 20° abduction with an applied axial compressive force of 25 kg. Gross inspection showed that shoulders with intact rotator cuff tendons had a smooth subacromial surface with a prominent CAL insertion, whereas it was frayed and hypertrophied in shoulders with rotator cuff tears. Furthermore, statistical analysis of contact Fuji film imprints showed no difference in the anteroposterior dimension, whereas there was a difference in the mediolateral dimension (Figure 1.27). Lee *et al*. (2001) stated that the results of anteroposterior dimension imprints support the view that there is no relation between acromion shape in the supraspinatus view and rotator cuff tears.

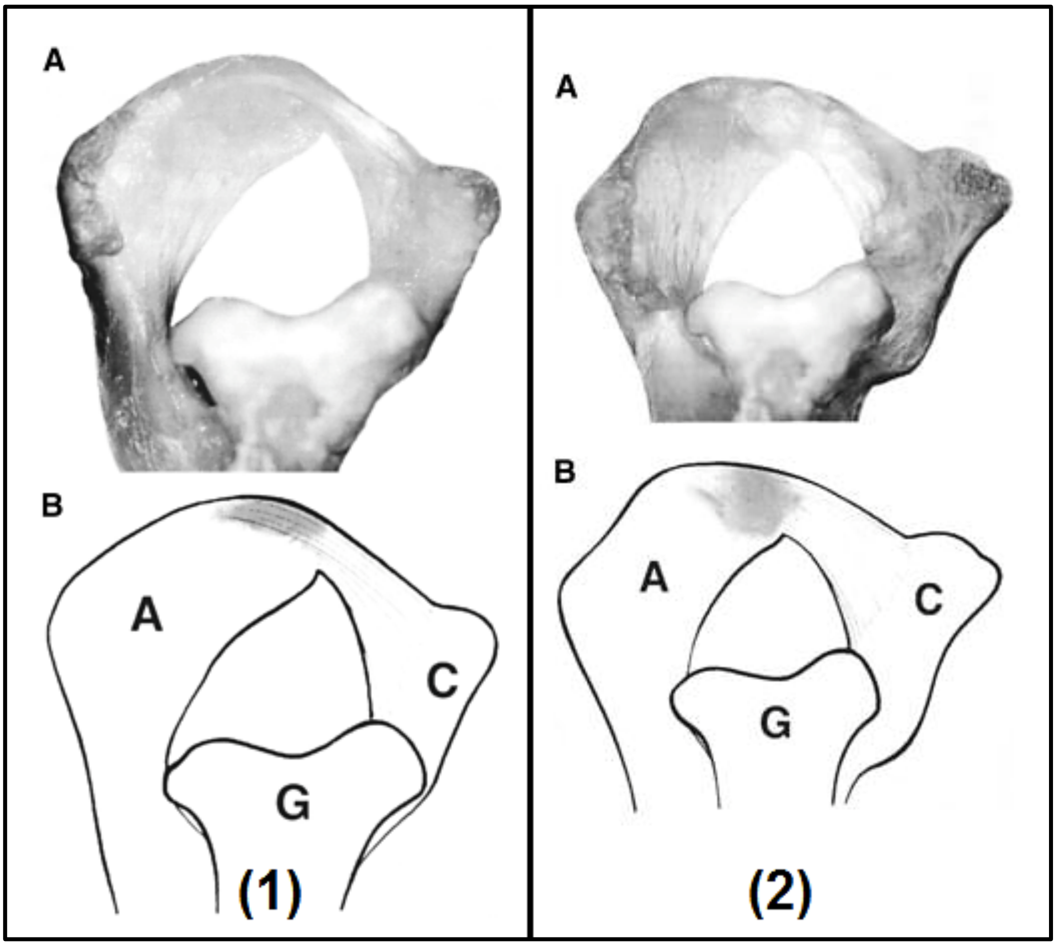


Figure 1.27 Contact imprint on the undersurface of the acromion: the intense imprint area in the intact group (I) was thin and located anterolaterally at the insertion of the CAL. In the tear group the imprint area was broader and was over the excrescence (II) (Lee *et al*., 2001).

1.4.3 Geometric Changes in CAL Parameters

Both Solowsky *et al*. (1994) and Fremerey *et al*. (2000) found that the CAL in shoulders with rotator cuff tears had larger cross-section/thickness areas than those in normal shoulders (Table 1.2). Furthermore, Fremerey *et al*. (2000), Kesmezacar *et al*. (2008), Soslowsky *et al*. (1994) and Zuckerman *et al*. (1992) support the view that the lateral band of the CAL is shorter in degenerated shoulders. Soslowsky *et al*. (1994), Neer (1972) and Kesmezacar *et al*. (2008) observed no change in the medial band dimensions between normal and degenerated shoulders. In contrast, Fealy *et al*. (2005), Fremerey *et al*. (2000), Pieper *et al*. (1997), Zuckerman *et al*. (1992), and Salter *et al*. (1987) observed similar pathologic changes in all parts of the CAL, i.e. medial and lateral bands, with degenerated rotator cuff tendons. Comparing both lateral and medial bands of the CAL, the lateral band was significantly stronger, wider, thicker and had a larger cross-sectional area (Fremerey *et al.*, 2000). Shoulders in older patient groups with rotator cuff tears also had a significantly greater cross-sectional area of the lateral band than normal shoulders. However, Wu *et al.* (2010a, 2012) found no difference in the thickness, length and humeral height of the CAL between the tear and normal groups, symptomatic shoulders and asymptomatic shoulders, and dominant and nondominant hands (Tables 1.3 and 4). The painful shoulder, however, was always associated with the dominant hand side.

Table 1.2 Geometric parameters of the CAL in shoulders with and without rotator cuff tears (Soslowsky *et al.*, 1994).

CAL Parameters	Lateral Band		Medial Band	
	Normal Cuff (n = 10)	Tear Cuff (n = 10)	Normal Cuff (n = 10)	Tear Cuff (n = 10)
Length (mm)	34 ± 4.2*	26.6 ± 4.8	32.4 ± 3.1	25.5 ± 13.8
Thickness (mm)	0.96 ± 0.33	1.21 ± 0.36	0.99 ± 0.35	0.83 ± 0.61
Width (mm)	8.0 ± 2.1	10.2 ± 2.8	6.3 ± 1.6	4.8 ± 2.9
Thickness Area (mm^2)	8.0 ± 3.8	12.0 ± 3.8*	6.2 ± 2.7	5.3 ± 4.9

- Significant difference (*): $P < 0.050$.

Table 1.3 ltrasonographic parameters of the CAL in shoulders with impingement pain and a control group (Wu *et al.*, 2010a)

CAL Parameters	Pain Group (n =10)		Control Group (n= 16)	
	Symptomatic	Asymptomatic	Dominant Hand	Non-Dominant Hand
Length (mm)	30.7 ± 3.1	31.5 ± 2.4	31.3 ± 2.9	31.7 ± 4.6
Thickness (mm)	1.1 ± 0.3	1.0 ± 0.2	1.0 ± 0.2	1.1 ± 0.3

Table 1.4 Ultrasonographic parameters of the CAL in shoulders with and without rotator cuff tears (Wu *et al*., 2012b).

CAL Parameters	Normal Cuff (n= 20)	Tear Cuff (n= 20)
Length (mm)	29.1 ± 4.0	27.0 ± 3.0
Thickness (mm)	1.0 ± 0.2	1.0 ± 0.1

Although significant differences were observed in the geometric parameters of the coracoacromial ligament in shoulders with rotator cuff tears, no significant association was detected in relation to the morphology of the ligament (Pieper *et al*., 1997; Kesmezacar *et al*., 2008). Pieper *et al*. (1997) found no association between the incidence of a rotator cuff tear and the number of CAL bands: 34.4% had one band, 44.6% two bands, and 27.8% three bands. Kesmezacar *et al*. (2008) detected no significant correlation between CAL morphology and the incidence of rotator cuff tears. Regarding the morphology of the CAL, the incidence of rotator cuff tears was observed as follows: 39% were associated with Y-shaped ligaments, 28% with broad band ligaments, 0% with quadrangular ligaments, 44% with V-shaped ligaments and 56% with multiple-banded ligaments. In turn, Kesmezacar *et al*. (2008) classified the specimens into two groups: one bundle group, which included the broad band and quadrangular ligaments (29 specimens), and multiple bands, which included the Y-shaped, V-shaped and multiple-banded ligaments (51 specimens). They found a significant relationship between multiple bands and rotator cuff tears: these ligaments were characterized with a longer lateral border and a larger coracoid insertion.

Both Soslowsky *et al*. (1994) and Fremerey *et al* (2000) agree that the dimensional changes in the lateral band of the CAL decrease the subacromial space and thereby leave less clearance for the supraspinatus tendon. No statistical differences were found in the medial band of the CAL between the tear and normal groups, indicating that the medial band was not present in the impingement region. However, they could provide no evidence that if the changes seen in the CAL were the cause or result of the impingement. On the other hand, Kesmezacar *et al*. (2008) noted a rare incidence of rotator cuff tears in shoulders with broad and quadrangular band ligaments, which were characterized by longer and broader lateral bands. They agree that the lateral band plays an important role in resisting superior translation of the humeral head and releasing the tensile forces. Therefore, CALs with a unique band, which have a longer and broader coracoid attachment, have a role in dampening tensile forces through concentrating them in a unique area. Conversely, multiple bands have a shorter coracoid attachment than the unique band, concentrating the tensile forces mostly on the lateral band.

1.5 Function of the CAL

The coracoacromial ligament is sacrificed during a variety of shoulder surgical procedures (Kummer *et al*., 1996). Morimoto *et al*. (1988) claim that the CAL plays no role in shoulder stability during sport or daily life activities, except when an excessive strain is taken that may cause humeral head dislocation. However, previous studies have suggested various functions of the CAL: a superior buttress preventing superior dislocation of the humeral head (Uhthoff *et al*., 1988), protects the rotator cuff tendon against attrition with acromion undersurface through the subacromial insertion (Rothman *et al*., 1975 cited in Kummer *et al*., 1996), a mechanical stabilizing ligament to provide stability of the acromion and coracoid processes (Jiang *et al*., 1990 cited in Kummer *et al*., 1996), a fulcrum for the anterior deltoid which enhances the moment arm of the deltoid (Nirschl, 1989), supporting the acromioclavicular joint through attaching to its inferior aspect (Salter *et al*., 1987), and finally to protect the shoulder joint against trauma (Uhthoff *et al*., 1988).

1.5.1 Dynamic Brace Ligament

Biomechanical studies suggest that the CAL works as a dynamic brace ligament transferring tensile forces between the acromion and coracoid to distribute the muscle forces applied to these two processes (Putz *et al*., 1988; Gallino *et al*., 1995). Both the acromion and coracoid processes are under opposite directional forces exerted by the muscles attached to them. The CAL reduces these forces by counteracting the action of pectoralis minor, coracobrachialis and the short head of the biceps (Tillmann, 1990 cited at Gallino *et al*., 1995). However, the impact of these forces tends to be seen more on the acromion than on the coracoid. Putz *et al*. (1988) measured the impact of these forces on both processes and found that the acromion was significantly more distorted than the coracoid. Harris and Blackney (1993) found that the acromion and coracoid were flexible structures and that distraction forces (~300 N) can produce 15 mm of separation between the two processes, with eventual failure of the ligament at its acromial insertion. However, Kummer *et al*. (1996) criticized this idea stating that the CAL works as a constraint or protection because acromial fracture, subacromial inflammation or superior subluxation are not common clinically after acromioplasty and CAL resection.

Gallino *et al*. (1995) emphasized the important mechanical role of the CAL in transmitting forces from pectoralis minor to the acromion, with its extension being affected by the size of the applied tension. Muscular imbalance between a strong pectoralis minor and weak external humeral rotators puts the shoulder in an anterior position with internal rotation of the scapula. This muscular imbalance increases the tension in the CAL, which may increase its thickness and lead to further friction with respect to supraspinatus. These transmission forces may also lead to spur formation at the anterior edge of acromion causing organic subacromial stenosis, or may change the shape of the acromion (Gallino *et al*., 1995; Chambler *et al*., 2003a). The dynamic loading of bone can lead to enhanced bone formation (Lanyon and Rubin, 1984), while changes in static tension of a ligament may cause ossification (Goodship *et al*.,1979).

Chambler *et al*. (2003b) evaluated tension in the CAL in five patients undergoing surgical repair of the rotator cuff tendons: it was found to be under continuous tension in all cases, with the tension being significantly greater in shoulder abduction compared to adduction. In this study, two types of the CAL tension were identified: inherent or static tension and mechanical tension. The static continuous tension is caused by the CAL extending between the acromion and coracoid, whereas dynamic tension is produced by upward subacromial forces during shoulder movements in impingement conditions. These tensions may vary between patients due to the following factors: age, use of the shoulder, arm dominance and the anatomic characteristics of the supraspinatus outlet itself. Chambler *et al*. (2003b) hypothesized that any alteration in tension of the CAL, either static or dynamic, may stimulate adaptive changes within the structure of the coracoacromial arch. These adaptive changes include acromial spur formation, ossification of the CAL, and with further impingement the possibility of a rotator cuff tear is increased. Tension in the CAL could be clinically affected by changes within the subacromial space caused by bursal thickening, cuff tendinitis and/or a rotator cuff tear (Chambler *et al*., 2003b).

1.5.2 Superior Humeral Restraint Ligament

Previous studies have confirmed that the CAL has a role as a superior humeral static restraint ligament that prevents superior dislocation of the humeral head (Lazarus *et al*., 1996; Moorman *et al*., 1996). During shoulder abduction the humeral head is pulled upwards by the superiorly directed force of deltoid. Normally, supraspinatus counteracts this movement by a compressive and downward action; however in shoulders with supraspinatus tendon tears excessive superior humeral head translation may occur. This may cause pressure on the undersurface of the coracoacromial arch resulting in CAL displacement (Chopp *et al*., 2011). The static function of the CAL has been assessed in two ways: measuring its displacement during shoulder motion or measuring humeral head translation before and after CAL resection (Chopp *et al*., 2011).

In three studies, Wu *et al*. (2010a, 2010b, 2012) used dynamic ultrasonography to check CAL displacement, with displacement being measured from the vertex of the CAL convexity to a line connecting the acromion and coracoid processes at the CAL attachment (Figure 1.28) (Wu *et al*., 2010a). In the first study, Wu *et al*. (2010a) measured CAL displacement in overhead athletes with painful shoulders during shoulder throwing simulation. They observed a significantly greater CAL displacement in symptomatic compared to asymptomatic shoulders. Wu *et al*. (2010a) assumed this difference was caused by functional instability that lead to abnormal superior translation of the humeral head, compressing the subacromial soft tissues against the coracoacromial arch causing shoulder pain and displacement of the CAL. In the second study, Wu *et al*. (2010b) inspected the difference in CAL displacement during shoulder motion between two age groups: the first group involved 30 volunteers with a mean age of 60 years and the second involved 26 volunteers with a mean age of 23.5 years. All individuals participating in the study were healthy with no shoulder pain. They found that the younger group had a significantly greater CAL displacement than the older group during both passive and active shoulder abduction and internal rotation. Wu *et al*. (2010b) believed that a stiffened CAL in the older group caused this difference since static examination of shoulder structures revealed no difference between the two groups. In the third study, Wu *et al*. (2012) checked CAL displacement in 20 shoulders with full thickness rotator cuff tears and 20 with normal cuff tendons. They observed a significantly greater CAL displacement in shoulders with cuff tears than intact shoulders during passive shoulder abduction and internal rotation. However, there was no significant difference between the two groups in CAL displacement during active shoulder abduction and internal rotation. Wu *et al* (2012) claimed that the greater displacement of the CAL in shoulders with cuff tears during passive motion occurred due to dysfunction of the static glenohumeral stabilizers. Finally, Wu *et al* (2010a and b) stated several factors that influence the degree of CAL displacement: the viscoelastic properties of the CAL, the thickness and compliance of the subacromial soft tissues and the degree of superior humeral translation.

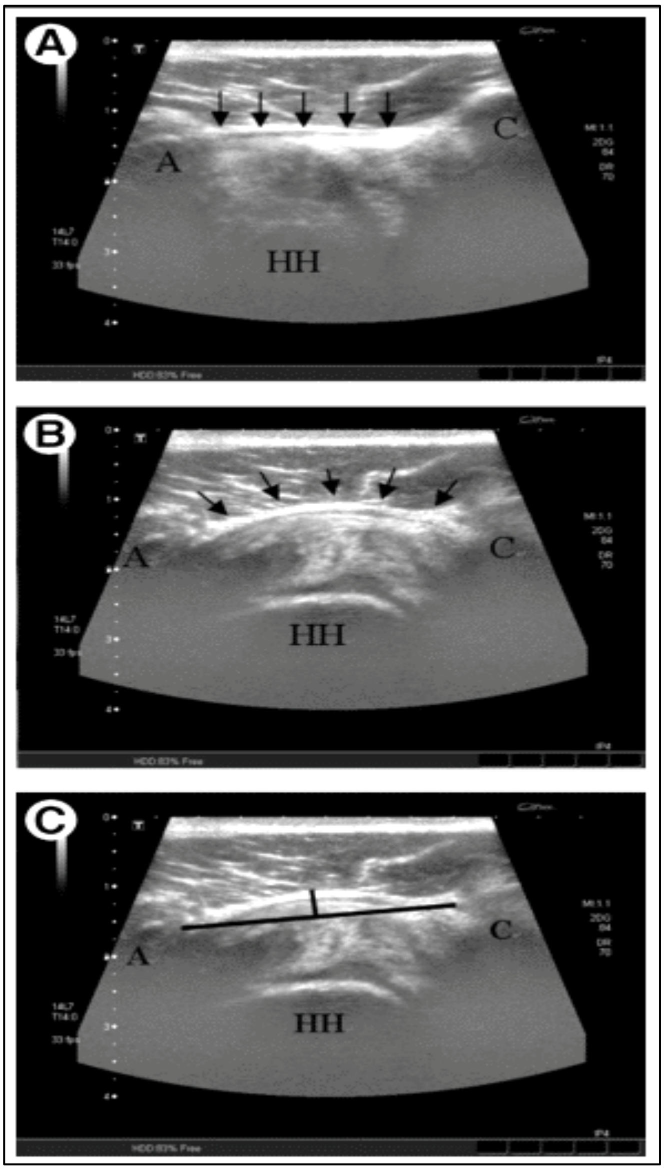


Figure 1.28 Measurement of the CAL using dynamic ultrasonography: (A) lateral view of the coracoacromial arch at rest, in which the CAL is flat. (B) the coracoacromial arch during shoulder throwing simulation, which produces a bulge in the CAL (arrows). (C) measuring the degree of displacement of the CAL by drawing a line from the vertex of the CAL bulge to a line down between the attachment insertions of the CAL. A: acromion; C: coracoid; HH: humeral head (Wu *et al*. 2010a).

The CAL is usually released during subacromial decompression to relieve the impingement (Neer, 1972). However, CAL release does not always lead to satisfactory results and may worsen existing clinical symptoms, which can lead to anterosuperior humeral head dislocation (Tibone *et al*., 1985; Wiley, 1991;

Scheibel *et al*., 2004). Several studies have reported high superior humeral translations following CAL release, with additional translation after acromioplasty (Chen *et al*., 2009; Fagelman *et al*., 2007; Hockman *et al*., 2004; Hu *et al*., 2009; Lee *et al*., 2001; Su *et al*., 2009; Wellmann *et al*., 2008; Wang and Huang, 2009). After CAL release Lee *et al*. (2001) noted a significant increase in glenohumeral joint translation in both the anterior and inferior directions at 0° and 30° of abduction. As glenohumeral abduction increased, the differences in translation between before and after CAL release decreased in all directions. Consequently, they concluded that the CAL works as a restraint to the glenohumeral joint at lower levels of abduction, and provides a suspension function that limits anterior and inferior translation through connecting with the coracohumeral ligament (coracoacromial veil). Moorman *et al*. (1996) studied superior humeral head translation in 25 fresh frozen cadaver shoulders. High translation was reported after CAL release and further translation after acromioplasty. They, therefore, recommended preserving the CAL in both cuff deficient patients and in patients with high functional demands who will not tolerate changes in inferior-posterior coupled motion, (such as throwing athletes). Lazarus *et al*. (1996) reported proximal humeral head displacement in five of six cadavers after CAL resection, concluding that the CAL arch is an important barrier to prevent anterosuperior humeral head displacement, particularly in cuff deficient patients.

Hockman *et al*. (2004) and Wang and Huang (2009) investigated the function of the CAL in hemiarthroplasty shoulders with a rotator cuff deficiency. Both noted a significant increase in displacement of the humeral head after excision of the CAL. Hockman *et al*. (2004) found that the CAL restricted anterosuperior displacement of the humeral component, even with a large prosthesis. Humeral anterosuperior dislocation took place only after excision of the coracoacromial ligament. As a result, they assumed that the CAL enhances the stability of the shoulder and works as a superior fulcrum that facilitates a smooth range of motion in the joint. Wang and Huang (2009) emphasised that the CAL has a role in limiting anterosuperior translation of the humeral head, especially in patients with a rotator cuff deficiency.

Some authors have suggested modifying subacromial decompression to reduce migration of the humeral head. Fagelman *et al*. (2007) examined the influence of CAL reattachment on the mechanics and function of the coracoacromial arch. They found that translation of the humeral head was significantly decreased after reattachment, there being no difference in humeral head translation between shoulders with intact CAL and shoulders with reattached CAL. Therefore, CAL reattachment in shoulders with massive rotator cuff tears provides the necessary stabilization forces to prevent excessive anterosuperior translation of the humeral head and possible humeral head dislocation. Fagelman *et al*. (2007) suggested removing only a minimal amount of bone from the undersurface of the acromion and preservation of the CAL during acromioplasty. Hu *et al*. (2009) investigated anterosuperior translation of the humeral head in 9 fresh-frozen cadaveric shoulders after transferring the lateral half of the conjoined tendon for CAL reconstruction. They found a significant difference in anterosuperior humeral head translation after release of the CAL. However, the translation was significantly decreased after transferring the conjoined tendon for CAL reconstruction. There was no significant difference in translation between shoulders with intact CAL and shoulders with a laterally transferred proximally based conjoined tendon. They advocated preserving or reconstructing the CAL during subacromial decompression, rotator cuff tear repairs and hemiarthroplasty for patients with massive rotator cuff deficiency.

1.5.3 Biomechanical Properties of the CAL

The CAL in older shoulders and shoulders with rotator cuff tears are stiffer, make contact with the rotator cuff tendons and have higher elastic moduli than those in normal and young shoulders. Soslowsky *et al*. (1994) and Fremerey *et al*. (2000) investigated the biomechanical properties of the CAL by fixing both bone ends of the lateral band of the CAL into a servohydraulic testing machine (Figure 1.29). The properties studied included structural/geometric and material properties of the CAL. The structural properties included failure load (applying a 2N preload and testing the specimens to failure in uniaxial tension at a cross-head rate of 100 mm/min), failure displacement (change in total specimen length), and stiffness (failure load divided by the failure displacement). The material properties included failure stress (failure load divided by the cross-sectional area) and strain (failure displacement divided by the initial length of the CAL).

The results of both studies revealed no significant difference in the structural properties of the lateral band of the CAL between shoulders with and without rotator cuff tears. However, the lateral band of the CAL in the tear group had significantly lower material properties than those in the control group. Fremerey *et al*. (2000) considered this difference to be due to tissue alteration and fiber disorganization of the CAL in shoulders with rotator cuff tears, which then caused a more complex and unidirectional loading environment. Fremerey *et al*.

(2000) suggest that these results also support the fiber disorganization observed in the CAL in shoulders with impingement caused by an increase in shear forces of the rotator cuff against the CAL. Furthermore, the loading-failure test revealed that more failure occurred at the acromial (26 specimens) than at the coracoid insertion (9 specimens) and midsubstance (3 specimens). The CAL in young shoulders showed a significantly higher failure load and greater stiffness than those from older shoulders. Fremerey *et al*. (2000) claimed that aging plays an important role in the alterations seen in the lateral band of the CAL. However, they could not state whether the alterations observed caused rotator cuff degeneration or vice versa.

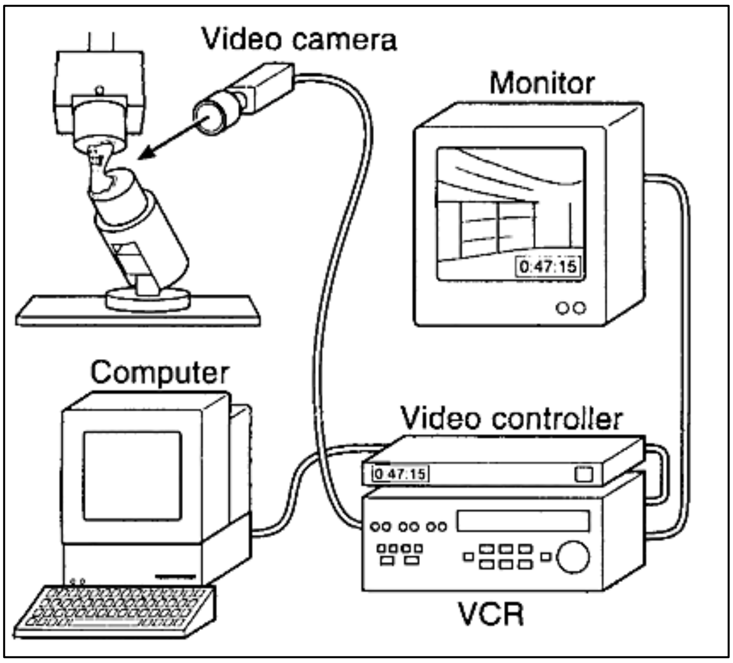


Figure 1.29 Schematic representation of the optical strain measurement system to evaluate the structure and material properties of the CAL: both bone ends of the lateral band of the CAL are fixed into a servohydraulic testing machine. Changes in CAL length during the strain/stress tests is measured through an optical system consisting of video camera, recorder, controller and image processing program (Soslowsky *et al*., 1994).

In an earlier study, Soslowsky *et al*. (1996) evaluated the *in situ* loads and viscoelastic properties of the CAL in relation to rotator cuff tears. The specimens, composed of bone-CAL-bone, were fixed in a servohydraulic testing machine for a strain/tension test, with the load measured directly by a load cell connected in series with the testing machine. The viscoelastic properties of the CAL were evaluated by both cyclic and stress relaxation experiments. The results showed no significant difference in the *in situ* load test between the tear and control groups. However, a greater difference was demonstrated in peak stress during the 15 cycles of the cyclic loading test. Conversely, no difference was observed between the two groups during the stress relaxation test.

In two studies, Kijima *et al*. (2009, 2013) evaluated CAL elasticity in shoulders with and without rotator cuff tears. In the first study, Kijima *et al*. (2009) used scanning acoustic microscopy to measure tissue sound speed, showed a positive correlation with elasticity. The CAL was divided into three portions: acromial, central and coracoid. Each portion was subdivided into two layers: superficial and deep. The results revealed that the sound speeds were higher in the tear and spur groups than in the control group. Furthermore, the sound speeds in the spur group were higher than those in the tear group, only in the acromial portion. The sound speeds were higher than those in the control group in both the acromial and coracoid portions. They found that the CAL in shoulders with rotator cuff tears and subacromial spurs showed higher elastic moduli than control shoulders.

In the second study, Kijima *et al*. (2013) used ultrasound elastography to determine the elasticity of the CAL in shoulders with rotator cuff tears (Figure 1.30). CAL elasticity was assessed using ultrasound elastography on the basis of the relative strain caused by the pressure of the ultrasound probe. They used the strain ratio of the CAL (the strain of the CAL to the strain of the rotator cuff) to represent the elasticity of the CAL. The results revealed a negative correlation (r= -0.825, P < 0.01) between the strain ratio of the control group and the subject’s age. The rotator cuff group showed a higher strain ratio than the older group. Within the rotator cuff groups, the symptomatic group showed a lower strain ratio than the asymptomatic group.

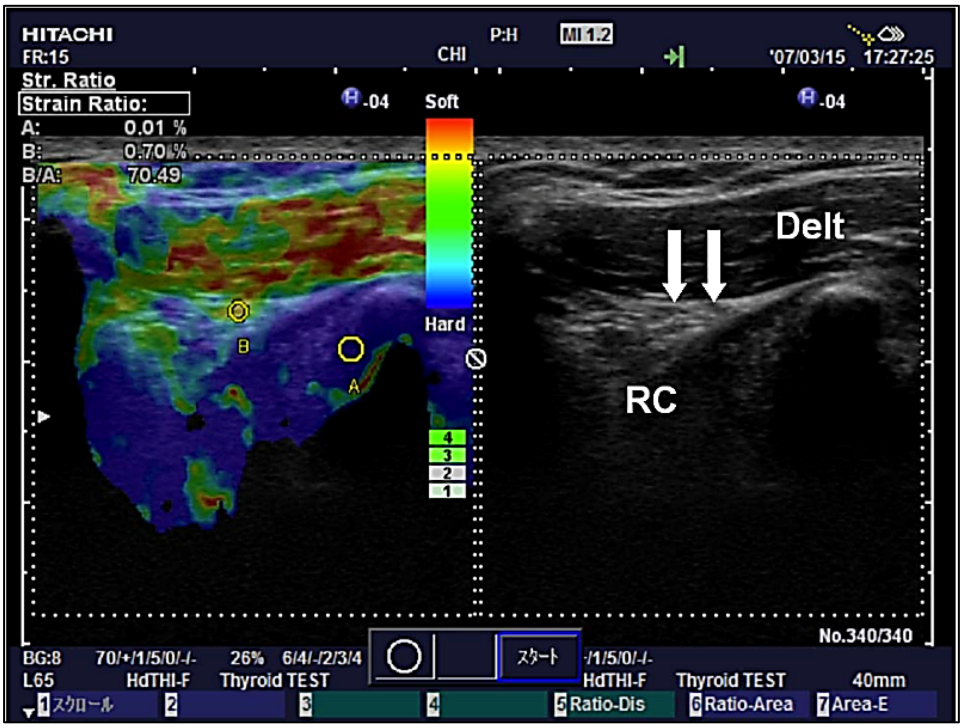


Figure 1.30 Evaluation of the elasticity of the CAL in shoulders with rotator cuff tears using ultrasound elastography: B-mode axial image of the CAL (right side) and the elastographic image of the ligament on the left side. The elasticity of the CAL was assessed on the basis of the relative strain caused by the pressure of the ultrasound probe. They used the strain ratio of the CAL (B/A), the strain of the CAL (B) to the strain of the rotator cuff (A), to represent the elasticity of the CAL. RC: rotator cuff; Delt: deltoid; and arrow: CAL (Kijima *et al.*, 2013).

Kijima *et al*. (2009, 2013) assumed that the CAL became stretched and stiffened by degeneration. Stiffening of the CAL leads to an increase in the contact pressure between the CAL and rotator cuff causing degeneration of the rotator cuff. Furthermore, CAL stiffening also leads to acromial spur formation. They also suggested that the prevalence of rotator cuff tears with aging was due to stiffening and degeneration of the CAL. These changes were also observed in shoulders without a rotator cuff tear. Shoulders with acromial spurs showed higher elastic moduli than those with rotator cuff tears. Kijima *et al.* (2009, 2013) suggested that softening of the CAL after a rotator cuff tear was due to the development of asymptomatic rotator cuff tears. This occurred after the CAL was subjected to abrasion through a rotator cuff tear causing collapse of the fiber structure of the ligament. Softening of the CAL may decrease the contact pressure between the CAL and the rotator cuff. Therefore, they assumed that decreasing the pressure under the CAL is an effective treatment method.

1.5.4 Subacromial Pressure/ Contact

The coordination between deltoid and the rotator cuff during elevation of the arm is referred to as a “force couple”. During arm elevation deltoid pulls the humeral head superiorly against the coracoacromial arch. The rotator cuff counteracts this action to prevent excessive superior humeral head migration and shoulder impingement. Humeral head migration produces subacromial pressure that presses the subacromial soft tissue against the subacromial surface of the coracoacromial arch. This pressure may damage the subacromial soft tissues and induce formation of osteophytes (acromion spurs). Any protruding structure into the subacromial space will increase pressure on the soft tissues and in time may result in a rotator cuff tear. However, supraspinatus acts more in synergy with deltoid and the other rotator cuff muscles infraspinatus, teres minor and subscapularis, act as prime antagonists of shoulder impingement to lessen excessive humeral head migration (Wuelker *et al.*, 1995). Previous studies recorded the highest pressure underneath the acromion, centered at the anterolateral border of the acromion, during active shoulder internal rotation and horizontal abduction, producing a bulge in the

CAL (Burns and Whipple, 1993; Hyvönen *et al*., 2003; Wang *et al*., 2009; Yamamoto *et al*., 2010).

In a cadaveric study of 5 fresh frozen shoulders, Burns and Whipple (1993) investigated the anatomic sites of the coracoacromial arch causing compression on the subacromial structures during shoulder motion. They found no evidence of impingement in a neutral shoulder position (at 0° of arm elevation and natural rotation), in which the supraspinatus tendon and the long head of biceps tendon lay inferolateral to the CAL and anterior to the acromion. Contact between supraspinatus and the greater tubercle inferiorly and the acromion-CAL junction superiorly was observed when the shoulder was flexed or externally rotated (Figure 1.31). Only the tendon of the long head of biceps was compressed against the lateral free edge of the CAL when the shoulder was flexed in the sagittal plane and externally rotated. However, extension or internal rotation of the shoulder shifted the contact toward the CAL-coracoid junction (Figure 1.32). Therefore, impingement against the CAL was observed in all maneuvers tested producing impingement pain. The greatest impingement between the rotator cuff and the uppermost portion of the CAL was observed when the arm was flexed and internally rotated. The pain due to impingement of supraspinatus and the tendon of the long head of biceps can be differentiated through specific shoulder movements. Shoulder abduction results in compression of only the supraspinatus tendon against the coracoacromial arch. Shoulder flexion combined with external rotation causes compression of the biceps tendon alone under the CAL near the acromion. This test is called the ’palm up test’ to evaluate bicipital tendonitis. Burns and Whipple (1993) believe that the CAL plays a major contributing factor in the impingement syndrome.

Passage of the greater tubercle beneath of the CAL causes an upward stretch in the CAL, which may explain the formation of acromial spurs on the anterior acromion in stage chronic stage of impingement syndrome.

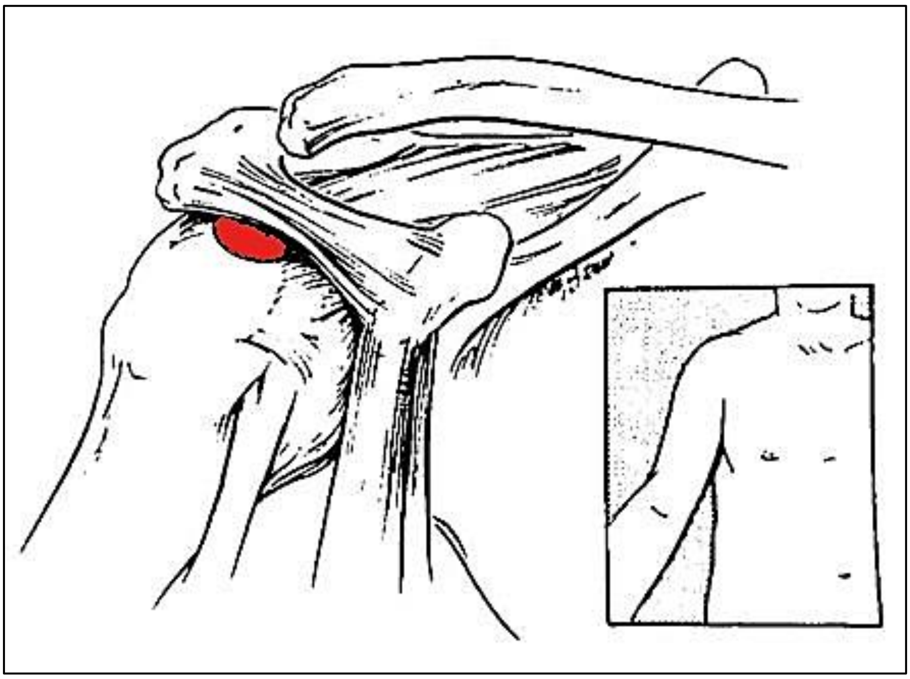


Figure 1.31 Compression of the subacromial soft tissue underneath the coracoacromial arch during anterior elevation of the arm in the scapula plane: a contact between supraspinatus and the greater tubercle (red circle) inferiorly and the acromion-CAL junction superiorly is observed (Burns and Whipple, 1993).

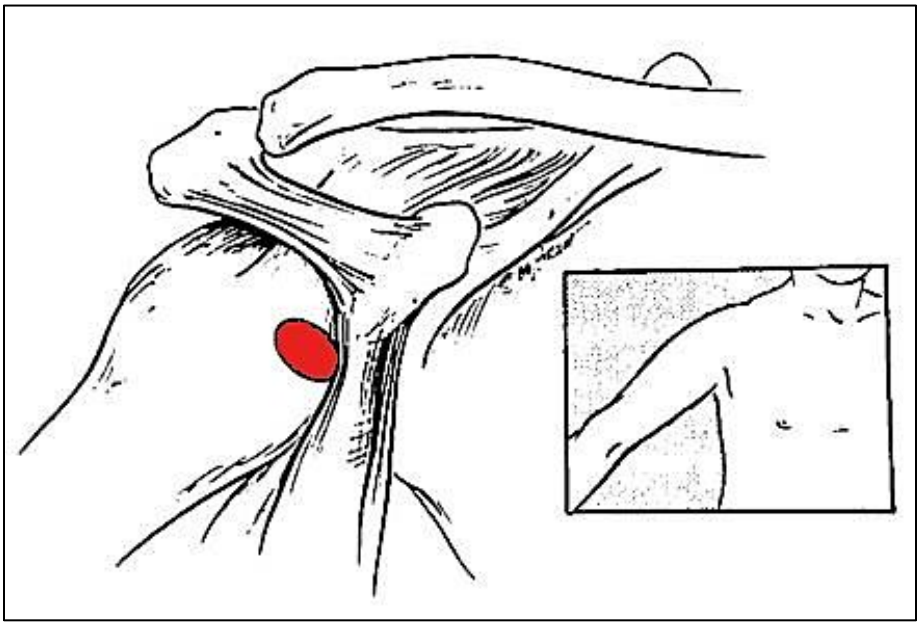


Figure 1.32 Compression of the subacromial soft tissue underneath the coracoacromial arch during posterior elevation of the arm with internal rotation: the contact is between supraspinatus and the greater tubercle (red circle) toward the CAL- coracoid junction (Burns and Whipple, 1993).

Hyvönen *et al*. (2003) evaluated subacromial pressure in 14 patients with shoulder impingement (Neer's stage II) using a 2-mm thick piezoelectric pressure transducer. Subacromial pressure was also measured in another 8 patients with acromioclavicular dislocation who served as control subjects. The subacromial pressure was evaluated at four locations: 1) anterolateral tip of the acromion as near to the borders as possible, 6 mm from the lateral and anterior borders; 2) anteromedial 6 mm distal to the acromioclavicular joint and posterior to the anterior border of the acromion; 3) posterolateral 25 mm posterior to point 1; and 4) posteromedial 25 mm posterior to point 2 (Figure 1.33). The recordings were taken with the arm abducted passively at 0°, 30°, 60° and 90° in neutral rotation. They found, in both groups, that the highest subacromial pressures were recorded under the anterior part of the acromion, particularly under the anterolateral acromion. In addition, the subacromial pressures under the anterolateral acromion at 60° and 90° abduction and under the anteromedial acromion at 90° abduction in impingement patients were significantly higher than those in the control group. The subacromial pressures were found to increase significantly during abduction in the impingement patients under the anterolateral acromion, between 0° and 30°, 60° and 90°, and under the anteromedial acromion between 0° and 60° and 90°. However, the pressure in the control group was not affected by increasing abduction angles. Hyvönen *et al*. (2003) supported the use of Neer's acromioplasty to relieve impingement from the anterior undersurface of the acromion. In addition, their results support the extrinsic theory of the pathogenesis of impingement. They assumed that increased subacromial pressure was caused by an acromial spur formed secondary to the primary degenerative changes in the cuff.

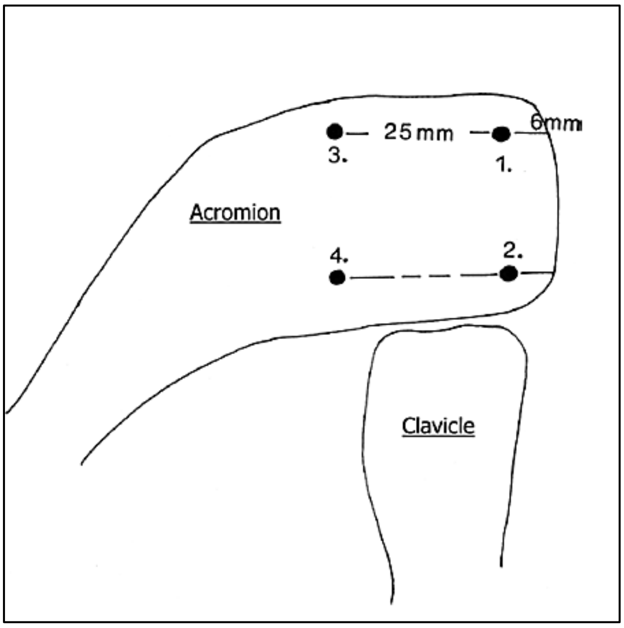


Figure 1.33 Evaluation of the subacromial pressure underneath the acromion at four locations: 1) anterolateral tip of the acromion as near to the borders as possible, 6 mm from the lateral and anterior borders; 2) anteromedial 6 mm distal to the acromioclavicular joint and posterior to the anterior border of the acromion; 3) posterolateral 25 mm posterior to point 1; and 4) posteromedial 25 mm posterior to point 2 (Hyvönen *et al*., 2003).

Wang *et al*. (2009) used ultrasound to evaluate CAL morphology during the different testing protocols of shoulder impingement. The results showed a greater CAL bulge/compression in the Hawkins-Kennedy impingement test, with arm internally rotated and 90° shoulder and elbow flexion, than in Neer's impingement syndrome test, with flex horizontally abducted shoulder. In addition, the CAL bulge in active movement tests was significantly higher than in passive movement tests, in both the Neer and Hawkins-Kennedy protocols. Wang *et al*. (2009) suggested the difference between the active and passive movement tests was due to supraspinatus contraction in active movement test causing relative stenosis of the subacromial space. During Neer's impingement test the tendon of the long head of biceps, the bicipital groove and greater tubercle appeared in the subacromial space. When the arm is flexed the greater tubercle approaches the coracoid process and lightly pushes the CAL out from the undersurface. However, the initial degree of shoulder flexion produced a slight bulge in the CAL, with more bulge produced after the arm was internally rotated (Wang *et al*, 2009). Whereas, during the Hawkins-Kennedy impingement test the tendon of the long head of biceps, the lesser and greater tubercles, and the supraspinatus tendon appeared in the subacromial space. When the arm was rotated internally, the greater tubercle plus the supraspinatus tendon pushed the CAL out from the undersurface. Further internal rotation of the arm (90°) caused the greater tubercle to approach the coracoid process (Wang *et al*., 2009).

Yamamoto *et al*. (2010) evaluated nonpathologic contact between the rotator cuff tendon and coracoacromial arch in 7 fresh-frozen cadaveric shoulders (mean age 74 years). They hypothesized that contact normally occurs during all shoulder motions and that the degree of contact is related to arm position. They also measured the bending deformation that occurred in the CAL as a result of contact beneath the coracoacromial arch (Figure 1.34). The results showed that the contact pressure observed beneath the acromion and the CAL ranged from 0.04 to 0.07 MPa at 0° of each motion. They also found a significantly increased contact pressure between the CAL and rotator cuff tendons as arm movement increased to greater than 90° flexion, 80° abduction, and 50° horizontal abduction. However, no change in contact pressure was observed between the CAL and rotator cuff tendon during internal and external rotation with the arm at 0° and 60° abduction. Yamamoto *et al*. (2010) observed the highest contact pressure beneath the CAL during shoulder flexion (0.114 MPa) and beneath the acromion during shoulder horizontal abduction (0.438 MPa). The contact pressure sites beneath the CAL shifted through the whole length of the ligament with an increase in arm motion. However, the contact pressure sites beneath the acromion were always concentrated at the anterolateral portion of the acromion. Bending deformation of the CAL was observed during all shoulder movements and increased significantly with arm flexion, abduction, internal rotation and horizontal abduction. The bending deformations of the CAL observed during shoulder flexion and horizontal abduction were significantly higher than those during other movements. No difference was observed in contact pressure between the curved and flat types of acromion. The contact pressure between the coracoacromial arch and the rotator cuff tendon was normally displayed by displacement of the CAL in an anterosuperior direction during all shoulder motions. Yamamoto *et al*. (2010) assumed that daily repetition of this contact might induce organic changes in the CAL and cause further progression of degenerative changes leading to stiffness of the ligament. In addition, they suggest that a stiff CAL might damage the bursal-side surface of the rotator cuff tendons. They concluded that contact pressure was normal and observed in nonpathologic shoulders.

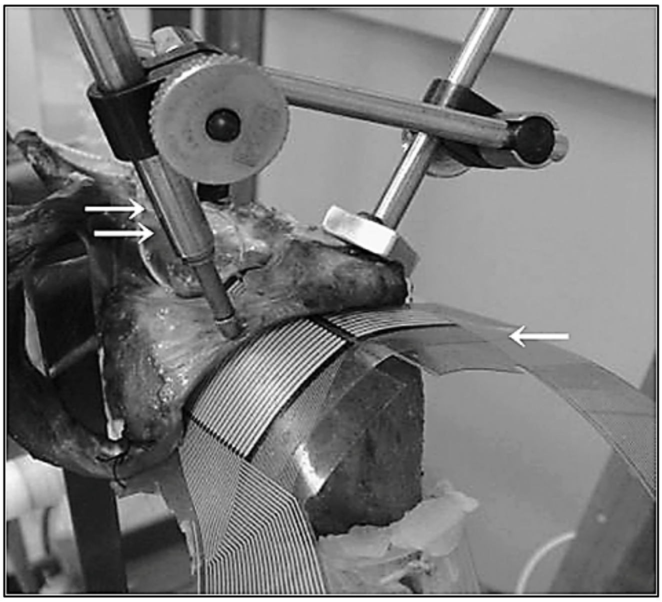


Figure 1.34 Evaluating nonpathologic contact between the rotator cuff tendon and the coracoacromial arch using pressure sensor (1 arrow) and a linear variable differential transducer (LVDT) sensor (2 arrows)(Yamamoto *et al*., 2010).

1.5.5 CAL Reflexes

Diederichsen *et al*. (2002) postulated that sensory nerves in the capsule and the CAL have a strong influence on muscle activity around the shoulder joint. However, more numerous mechanoreceptors are found in the CAL and musculotendinous junctions indicating that they have a greater influence than the small number of mechanoreceptors in the capsule and glenohumeral ligaments. Diederichsen *et al*. (2002) hypothesized that the specific reflex from sensory receptors found in the CAL play an important mechanical function for the ligament. This reflex inhibited deltoid, which may reduce anterosuperior translation of the humeral head during shoulder flexion and abduction. Hence, resection of the CAL in subacromial decompression leads to anterosuperior translation increasing the load on the supraspinatus tendon by reducing the reflex inhibition of deltoid. Diederichsen *et al*. (2002) advocated saving the CAL during acromioplasty unless it is calcified as it would give rise to mechanical impact.

1.6 Histology of the CAL

Histologically the CAL is composed of dense fibrous tissue consisting of tightly packed parallel oriented collagen fibers extending throughout the long axis of the ligament. These fibers are characterized by compressed fibrocytes between collagen fibers and the presence of small numbers of fine elastic fibers in the superficial layer (Figure 1.35) (Holt and Allibone, 1995; Panni *et al*., 1996). Panni *et al*. (1996) found the CAL is composed of different layers at its attachment sites. At the coracoid attachment site, it consists of 4 layers: ligament, fibrocartilage, mineralized fibrocartilage, and bone. However, the histological structure of the CAL is different between the anterior and the undersurface of the acromial attachment. At the anterior end of the acromion (Figure 1.36), the CAL is made up of 4 layers: fibrous tissue, fibrocartilage, mineralized fibrocartilage, and bone; whereas at the undersurface of the acromion (Figure 1.37), it is made up of a synovial layer coating a fibrous layer in direct contact with the bone surface. However, CAL specimens taken from aged shoulders and patients with impingement syndrome showed degenerative changes (Uhthoff *et al*., 1988; Panni *et al*., 1996; Sarkar *et al*., 1990). Histologically, the CAL also contains mechanoreceptors and sensory nerve endings that may improve shoulder function (Morisawa, 1998; Tamai *et al*., 2000).

Figure 1.35 Normal histological appearance of the CAL: tightly packed paralle, oriented collagen fibers extending throughout the long axis of the ligament. A considerable number of fine elastic fibers are present in the extracellular matrix (stained blue) parallel to collagen fibers and are particularly plentiful around blood vessels (V). (Fullmer-Halmi stain, original magnification X10); (Panni *et al*., 1996).

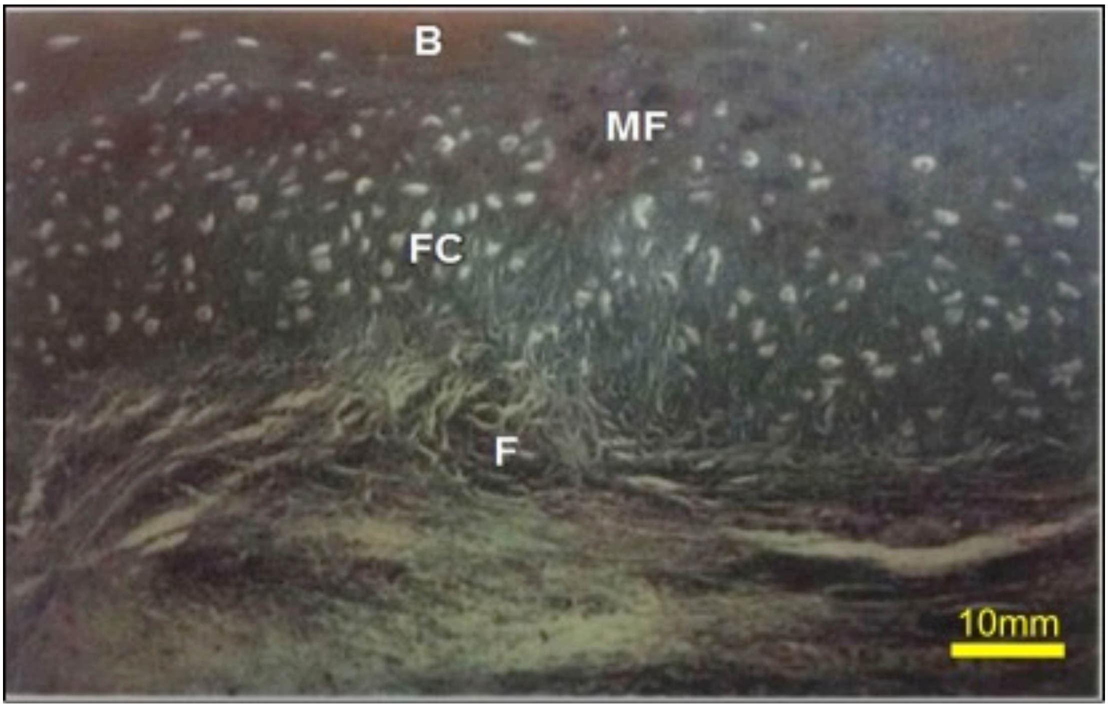


Figure 1.36 The histological appearance of the CAL-acromion junction at the anteroinferior part of the acromion: the CAL is made up of 4 layers: fibrous tissue (F), fibrocartilage (FC), mineralized fibrocartilage (MF), and bone (B). A layer of synovial tissue covers the fibrous tissue. (Fullmer-Halmi stain, original magnification X10) (Panni *et al.*, 1996).

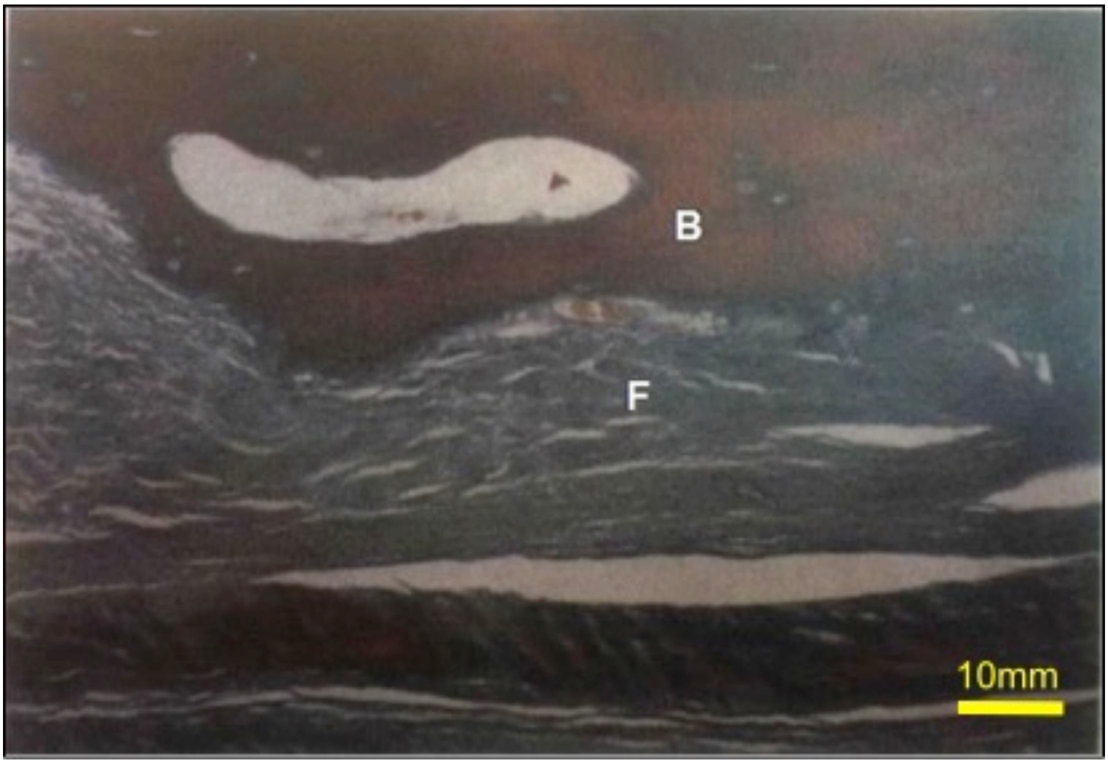


Figure 1.37 The histological appearance of the CAL at the posterior part of the acromial insertion: the ligament is made up of a synovial layer coating a fibrous layer (F) in direct contact with the bone surface (B) without an interposed fibrocartilaginous zone (Fullmer-Halmi stain, original magnification X20) (Panni *et al.*, 1996).

1.6.1 Histological Degenerative Changes of the CAL

Previous studies have shown different histological changes in the structure of the CAL as a result of aging and shoulder impingement syndrome (Uhthoff *et al*., 1988; Panni *et al*., 1996; Sarkar *et al*., 1990). These changes range from changes in the shape of the collagen fibers or cell nuclei, to tears or calcification of ligament bundles and spur formation (Uhthoff *et al*., 1988; Panni *et al*., 1996). The histological appearance of CAL specimens taken from patients with impingement syndrome and partial-thickness tears of the rotator cuff showed degenerative changes and inflammatory cells without evidence of chronic inflammation (Benson *et al*., 2009).

Histological analysis of cadaveric CAL samples taken from two different age groups show age related changes (Uhthoff *et al*., 1988). Samples from individuals in their second decade show thick, wavy, closely packed collagen bundles and slender, elongated cell nuclei without discernible cytoplasm, whereas samples from individuals in their seventh or eighth decade show straight collagen bundles and an increased number of cells with heteromorphic nuclei. Poor vascularity was also noted in the substance of the ligament, but an abundance of blood vessels were seen in the periligamentous connective tissue. Histological analysis of a CAL biopsy specimen from a young patient (34 years old) with impingement syndrome showed marked fibrillation and rupture of the bundles, with consequent loss of band-like configuration. However, the CAL biopsied specimen from an older patient (72 years old) showed irregular tears near the bony insertion, with the torn margin covered with fibrin (Figure 1.38).

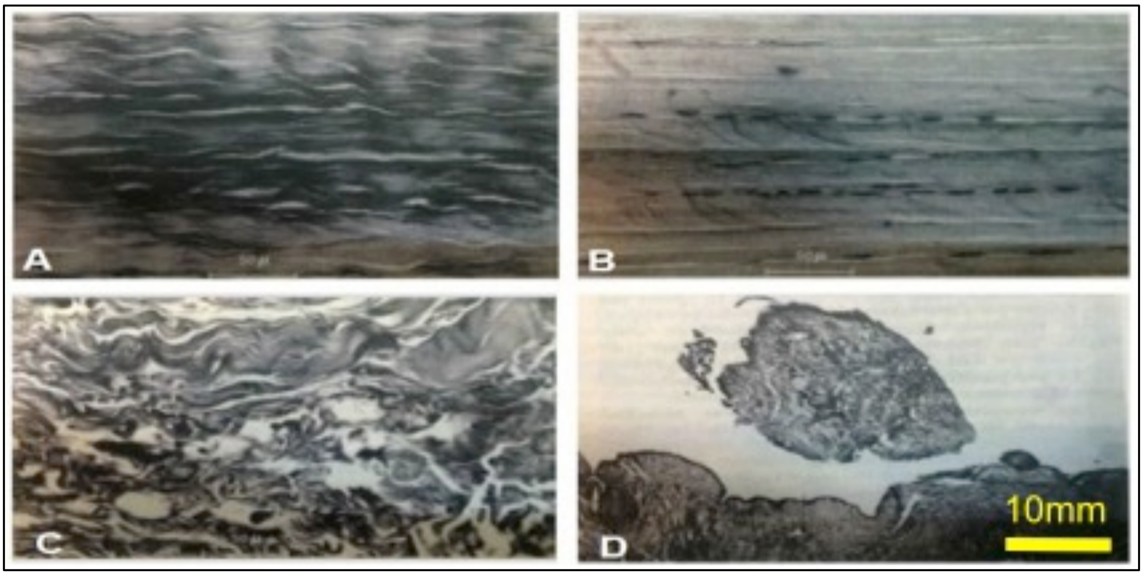


Figure 1.38 Different histological appearances of the CAL in relation to age and shoulder impingement syndrome (hematoxylin and eosin): (A) sample from a second decade cadaver showing the normal histological appearance of the CAL. The collagenous bundles are thick, wavy, closely packed with slender, elongated cell nuclei without discernible cytoplasm (50 μm). (B) sample from seventh decade cadaver showing straight collagenous bundles with an increase in the number of cells with heteromorphic (50 μm). (C) showing the histological appearance of the CAL in a 34-year old patient with impingement syndrome characterized with: marked fibrillation, rupture of the bundles, and consequent loss of band-like configuration (50 μm). (D) a 72-old patient with impingement syndrome showing irregular edges of a tear in the CAL with dark-staining fibrin material at the margins (magnification power X75) (Uhthoff *et al*., 1988).

Panni *et al*. (1996) analysed the coracoacromial arch in 80 shoulders (with a mean age of 58 years) to investigate age-related changes and rotator cuff tears. At the CAL mid-substance they observed several morphological changes including: less orientation and organization of the collagen fibers, reduction in cell number and vascularization, and reduction in elastic fibers (Figure 1.39). No histological changes were observed in the coracoid junction of the CAL. In contrast, they observed various signs of degenerative and proliferative changes in the acromial junction of the CAL. These histological changes in the acromial junction were classified into three grades. In grade I the fibrous layer showed areas of fibrillation and signs of cell damage, the fibrocartilage layer had some clusters of chondrocytes, the mineralized fibrocartilage layer showed layers of calcium deposits and bone spurs from the bone layer (Figure 1.40 G1). In grade II the fibrous and fibrocartilage layers presented signs of fibrillation and fissuring, the mineralized fibrocartilage layer was thick and showed plentiful calcified deposits, with fragmentation of the tidemark (Figure 1.40 G2). In grade III the fibrous and fibrocartilage layers had large areas of fissuring and fragmentation, the mineralized fibrocartilage layer showed large areas of ossification and was no longer clearly separated from the bone, and the bone layer presented clear signs of cortical sclerosis with an irregular outline (Figure 1.40 G3). Degenerative changes were found in the mid-substance of the CAL in 45 shoulders (56.3%), with a significant difference between shoulders with a normal ligament (mean age 45.6 years) and shoulders with a degenerative ligament (mean age 68.3 years).

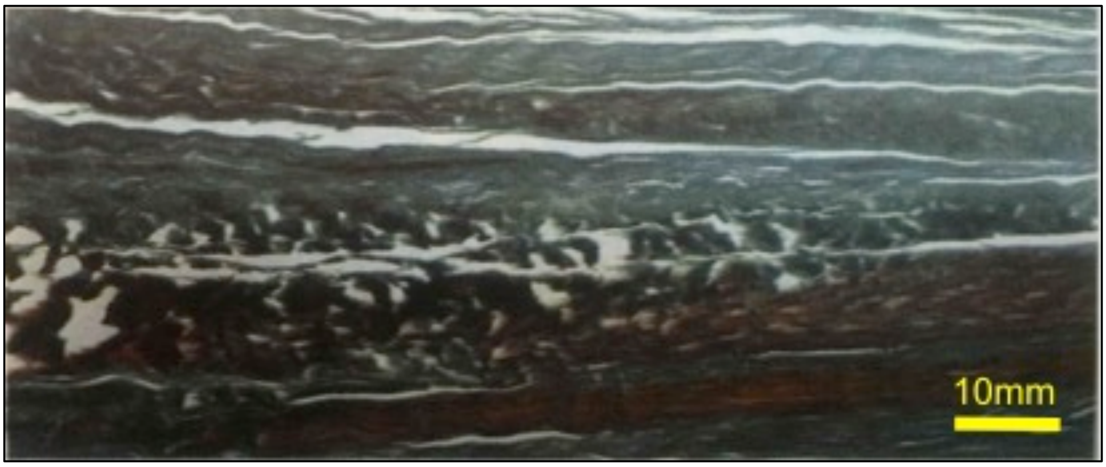


Figure 1.39 Degenerative changes presenting at the mid-substance of the CAL: less orientation and organization of the collagen fibers, reduction in cell number and vascularization, and reduction in elastic fibers with areas of fragmentation and fibrillation (Fullmer-Halmi stain, original magnification X20) (Panni *et al.*, 1996).

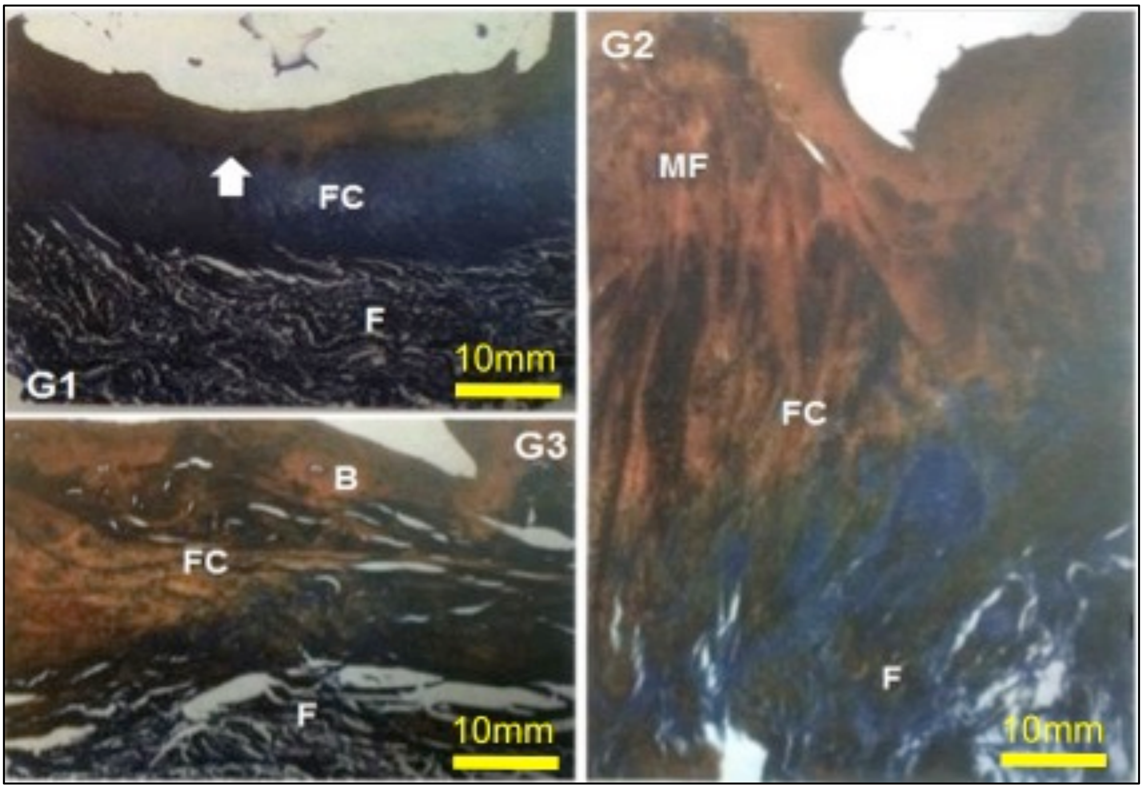


Figure 1.40 Degenerative changes at the acromial attachment of the CAL (Fullmer-Halmi stain): Grade 1 (G1) the fibrous layer (F) shows areas of fibrillation and signs of cell damage. The fibrocartilage layer (FC) had some clusters of chondrocytes. The mineralized fibrocartilage layer shows layers of calcium deposits, bone spurs from the bone layer, and irregularities in the profile of the tidemark (arrow) (original magnification X10). Grade 2 (G2), the fibrous (F) and fibrocartilage layers (FC) present signs of fibrillation and fissuring. The mineralized fibrocartilage layer (MF) was thick and showed many calcified deposits, with fragmentation of the tidemark (original magnification X20). Grade 3 (G3) the fibrous (F) and fibrocartilage layers (FC) have large areas of fissuring and fragmentation. The mineralized fibrocartilage layer shows large areas of ossification and is no longer clearly separated from the bone, and the bone layer (B) presents clear signs of cortical sclerosis with an irregular outline (original magnification X10) (Panni *et al*., 1996).

The histological changes of the CAL on the undersurface of the acromion were investigated by Panni *et al*. (1996) and observed to be normal in 32 shoulders (40%) (mean age 45.7 years), and degenerative in 48 shoulders (60%): grade I changes in 12 shoulders (15%) (mean age 59.7 years), grade II changes in 33 shoulders (41.5%) (mean age 69 years), and grade III changes in 3 shoulders (3.75%) (mean age 70.7 years). Unilateral incidence of degeneration was found in 2 shoulders, whereas bilateral incidence of the same grade were found in 16 shoulders and of a different grade in 17 shoulders. Significant differences were found between the mean ages in normal shoulders and each of grade I, grade II and grade III; grade I and each of grade II and grade III. Comparison of the mean age of the rotator cuff tears with degenerative changes in the acromial attachment of the CAL showed a significant difference in the normal cuff group between normal (mean age 45 years) and each of grade I (mean age 59.7 years) and grade II (mean age 70.7 years), and between grade I and grade II. In addition, in the group with grade II changes, there was a significant difference between the mean age of individuals with bursal-side partial tears (mean age 59.5 years) and those with a normal cuff (mean age 70.7 years) (Panni *et al*., 1996).

Panni *et al*. (1996) reported a close correlation between CAL degenerative changes (mid-substance and acromial grade II and grade III) and bursal-side cuff tears, whether partial or full-thickness tears. However, they did not know if these changes were the cause or the result of the cuff tears. They observed that the greatest incidence of coracoacromial arch degenerative changes occurred bilaterally. As a result, they believed that the degenerative changes in the coracoacromial arch may be the result of a natural degenerative process of ageing, even in the absence of a rotator cuff tear. However, a rotator cuff tear can cause or aggravate these changes at an early age.

On the other hand, Sarkar *et al*. (1990) believed that the degenerative changes in the CAL were not a primary factor for the development of impingement syndromes. They instead suggested that they were secondary to irritation caused by a chronic strain on the ligament, which could be produced by an increase in the size of the soft tissues in the subacromial space. For example, in shoulders with rheumatoid arthritis the subacromial bursa could produce considerable strain on the CAL (Sarkar *et al*., 1990). Furthermore, Neer (1983) stated that the CAL in shoulders with impingement lesions would be exposed to an extra-sustained strain caused by either edema, hemorrhage, or fibrotic thickening of the subacromial soft tissue.

1.6.2 Mechanoreceptors in the Coracoacromial Ligament

Morisawa (1998) investigated the morphology of mechanoreceptors in the CAL, their distribution and age-related changes. The study involved a total of 23 specimens that were removed at operation from patients that who had fractures of the humeral head and scapula (5 samples), subacromial impingement (2 samples), and rotator cuff tears (16 samples). Each CAL sample was divided into three portions: acromial, central and coracoid. The results showed that the CAL contained four typical types of specific nerve endings: Pacinian corpuscles, Ruffini receptors, Golgi tendon organ-like receptors, and free nerve endings of no specific morphology (Figure 1.41). There was also a non-typical morphology of Pacinian corpuscles and Ruffini receptors. These nerve endings were more prevalent in the acromial (61.6 ± 9.7%) than in the coracoid (26.3 ± 9.1%) and central (12.0 ± 7.3%) portions. Furthermore, more nerve endings were seen in the subacromial side (inferior) of the CAL than in the deltoid side (superior). The number of nerve endings inside both the fracture and subacromial impingement groups tended to decrease with age. The subacromial impingement group contained fewer nerve endings than the fracture group at all ages. Comparing the distribution of the type of nerve endings only the typical nerve endings (Pacinian corpuscles and Ruffini receptors, and Golgi tendon organ-like receptors, and free nerve endings of typical morphology) tended to decrease with age.

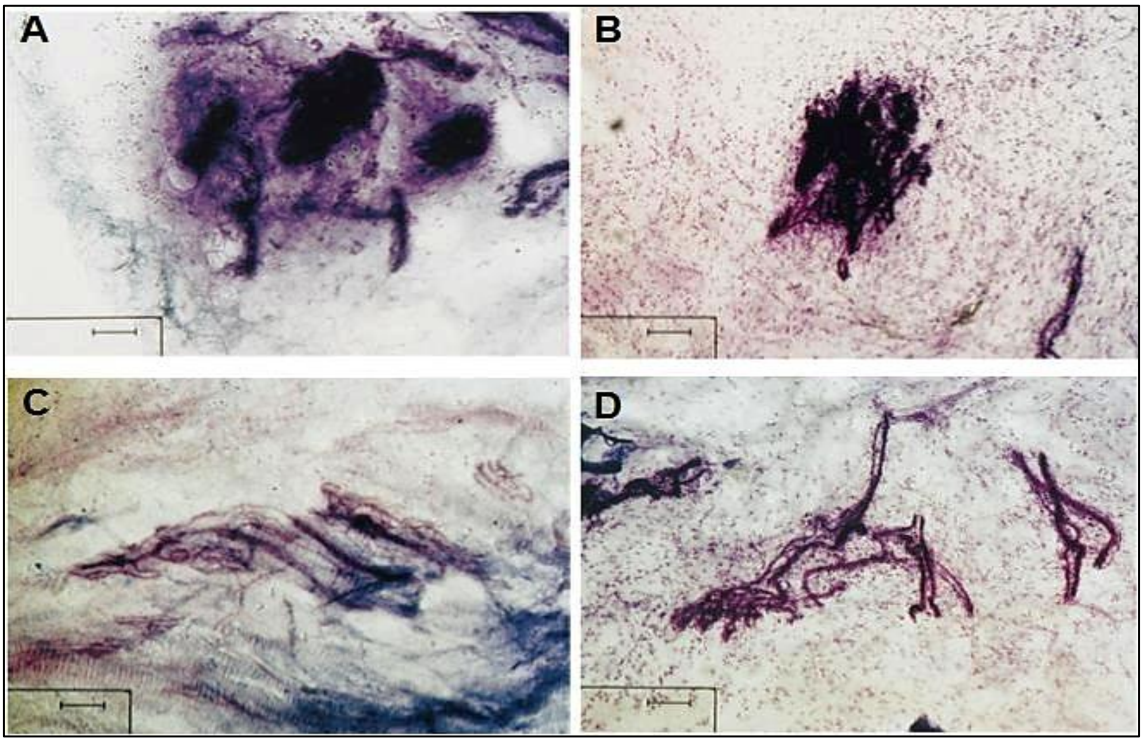


Figure 1.41 Four typical types of specific nerve endings present in the CAL: Pacinian corpuscles (A) characterized with a spherical to cylindrical body and a capsule (Bar = 50 μm). Ruffini receptor (B) have a dendritic appearance (Bar = 100 μm), Golgi tendon organ-like receptors (C) showing a helical or spindle structure (Bar = 125 μm), and free nerve endings (D) showing axons characterized with no consistent shape (Bar = 80 μm) (Morisawa, 1998).

Functionally, Pacinian corpuscles adapt to rapid movement which detect the acceleration applied at the beginning and end of movement. Both Ruffini receptors and Golgi tendon organ-like receptors adapt slowly to movement as they determines the position and angle of rotation of the joint. The free nerve endings work as pain receptors. A higher incidence of nerve endings in the acromial portion of the CAL supports the view that they are distributed preferentially to sites, which are sensitive to mechanical stimuli, such as tension or pressure. Morisawa (1998) suggested than during shoulder elevation the humeral head applies pressure or tension on the CAL: the nerve endings in the CAL perceive and transfer this information to the central nervous system.

Therefore, they help in controlling and maintaining the rhythm of shoulder joint elevation, which acts to prevent the development of subacromial impingement.

Morisawa (1998) showed that the CAL is innervated by branches of the suprascapular nerve at both the acromial and coracoid ends. Morisawa (1998) also found that the number of nerve endings in the CAL decreased with age, which suggest that the feedback mechanism controlling shoulder movement becomes impaired with age. In turn, this impairment may lead to the development of an unbalanced elevation rhythm in the shoulder joint causing subacromial impingement and shoulder joint contracture.

1.6.3 Neural Distribution in the CAL

Tamai *et al*. (2000) investigated the distribution of sensory nerves in the CAL using the immunohistochemical antibodies antiprotein gene product 9.5 (antiPGP9.5): “as general nerve marker”; and anticalcitonin gene related peptide (antiCGRP): “as nociceptive neural marker”. The study involved 27 human CALs obtained from 15 patients who had rotator cuff tears (mean age 58.2 years) and 12 patients who had shoulder dislocation (mean age 26.7 years). The ligaments were divided and classified into three portions: acromial, central and coracoid. Each portion was then divided vertically into two pieces, histologically prepared and fixed with immunohistochemical antibodies. A light microscopic and reversal film were used to observe and analyze each histological section.

The CAL of the dislocation group shoulders consisted of two layers: a periligamentous bursal tissue (surface layer) and the ligament parenchyma (deep layer) (Figure 1.42: 1). These layers were recognized through all three areas of the CAL. The authors did not observe any histological changes in any specimens in the dislocation group, whereas various histological changes were observed in the specimens from the tear group. The histological changes observed seen in the tear group included villous growths, multiplication of synovial cells and proliferation of blood vessels (Figure 1.42: 2): the changes were observed in all three CAL areas. Nerve fibers immunoreactive to antiPGP9.5 (Figure 1.43: 1 and 2) and antiCGRP (Figure 1.43: 3 and 4) antibodies were observed in the periligamentous bursal tissue in all three areas of both groups. In the ligament parenchyma tissue layer, nerve fibers immunoreactive to antiPGP9.5 antibody were observed only around blood vessels, whereas no nerve fibers immunoreactive to antiCGRP antibody were recognized (Tamai *et al*., 2000).

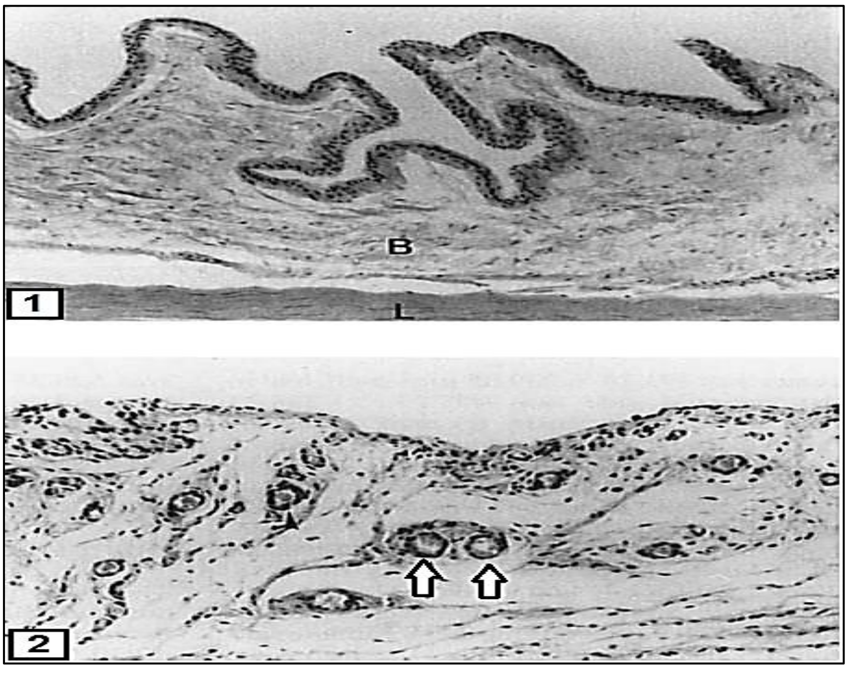


Figure 1.42 The histological structure of the CAL in dislocated shoulders and shoulders with rotator cuff tears: (A) CAL specimen from a dislocated shoulder showing two structural layers: the periligamentous bursal tissue (surface layer) (B), and the ligament parenchyma (deep layer) (L). (B) CAL specimens from a shoulder with rotator cuff tear showing proliferation of blood vessels (arrows) in the periligamentous bursal tissue (hematoxylin and eosin staining, X480) (Tamai *et al*., 2000).

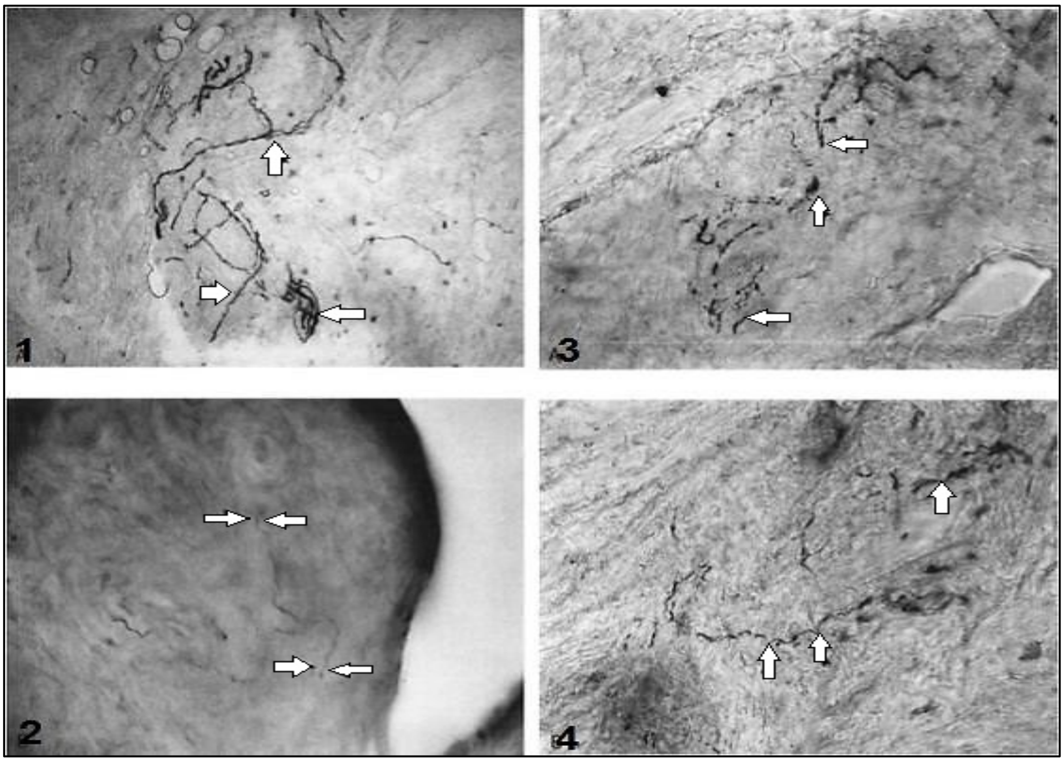


Figure 1.43 Many nerve fibers (arrows) immunoreactive to antipGP 9.5 (1 and 2) and antiCGRP (3 and 4) antibodies: in the periligamentous bursal tissue in patients with shoulder dislocation (1 and 3) and patients with rotator cuff tears (2 and 4) (magnification, X480) (Tamai *et al*., 2000).

In both antibody stains, Tamai *et al*. (2000) found that the nerve densities in all three areas of the CAL in the rotator cuff tear group were significantly greater than those in the shoulder dislocation group. They assumed this increase was induced by inflammation after the rotator cuff tear and would have caused shoulder pain in those patients. However, Tamai *et al*. (2000) were unclear if these nerve fibers had an influence on shoulder function. Consequently, they recommended anterior acromioplasty and excision of the CAL for pain relief in patients with rotator cuff tears.

1.7 Acromial Spur Formation and Degenerative Changes in Shoulders with Subacromial Impingement Syndrome

An acromial spur was first described by Graves (1922) as an elevated plaque of bone at the tip and undersurface of the acromion (Figure 1.44): since then it has been descried by a variety of terminologies (Table 1.5). This has caused confusion in the literature with regard to describing acromial architecture, specifically with Bigliani's classification of a hooked acromion. Chambler and Emery (1997) clarified that "a hook can be a spur, but a spur should never be described as a hook". An acromial spur is the most commonly used term; however Chambler and Emery (1997) prefer to use enthesophyte to describe a plaque.

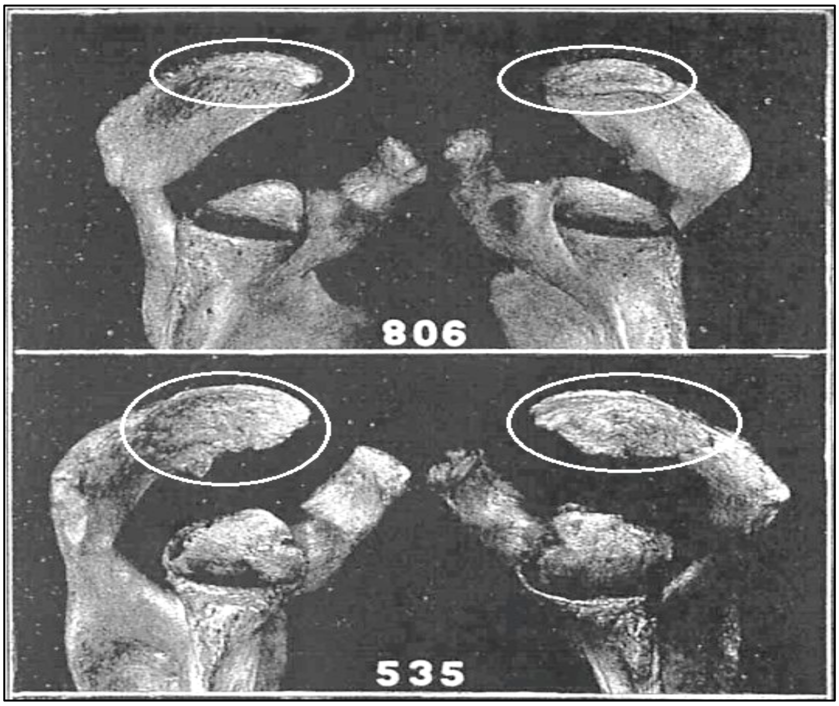


Figure 1.44 Formation of an acromial spur at the tip of acromion: in 1922, Graves first described formation of a spur (white circles) at the tip of the acromion as plaques corresponding to the acromial attachment of the CAL. Upper figure (806) shows oval spurs formed at the undersurface of acromion that extend beyond and parallel to the deltoid margin (male, 35 years). In the lower figure (535) larger spurs (22 x 35 mm), extensive oval or cup-shaped, have formed at the anteroinferior surface of acromion and extend beyond the tip of acromion (male, 50 years) (Graves, 1922).

Table 1.5 Terminology used to describe the formation of an acromial spur at the anterior edge of the acromion.

Study	Terminology
Graves (1922)	Plaque
Codman (1934)	Hypertrophic changes
Gray (1942)	Facet
Neer (1972)	Spurs and excrescences
Cone *et al*. (1984)	Spur and bony excrescences
Nasca *et al*. (1984)	Hook/Curved-like facet
Aoki *et al*. (1986)	Spur
Bigliani *et al*. (1986)	Spur
Hardy *et al*. (1986)	Bony proliferation
Ozaki *et al*. (1988)	Spur and osteophytes
Postacchini (1989)	Osteophytic anterior margin
Ogata and Uhthoff (1990)	Enthesophyte, beak, and spur
Tada *et al*. (1990)	Spur
Edelson and Taitz (1992)	Traction spur and eburnated facet
Ono *et al*. (1992)	Spur
Gohlke *et al*. (1993)	Spur
Chun and Yoo (1994)	Spur
Hernigou (1994)	Ossification/ Enthesopathy
Edelson (1995)	Enthesophyte hook
Edelson and Luchs (1995)	Enthesopathic calcification
Kitay *et al*. (1995)	Spur
Toivonen *et al*. (1995)	Spur (hooked)
Flatwo *et al*. (1996)	Spur
Getz *et al*. (1996)	Enthesophytes
Miles (1996)	Subacromial facet
Nicholson *et al*. (1996)	Spur
Panni *et al*. (1996)	Acromial osteophytosis
Wang and Shapiro (1997)	Spur
Mahakkanukrauh and Surin (2003)	Osteophyte
Fealy *et al*. (2005)	Spur
Ogawa *et al*. (2005)	Spur
TaheriAzam *et al*. (2005)	Spur
Ko *et al*. (2006)	Spur
Natsis *et al*. (2007)	Enthesophytes
Sangiampong *et al*. (2007)	Spur
Paraskevas *et al*. (2008)	Enthesophytes
Oh *et al*. (2010)	Spur
Hamid *et al*. (2012)	Spur

Acromial spur formation is usually described as ossification of the acromial insertion of the CAL (Edelson, 1995; Fealy *et al*., 2005; Uhthoff *et al*., 1988; Hernigou, 1994; Natsis *et al*., 2007). It corresponds to the acromial attachment pattern of the CAL (Figure 1.45) (Edelson and Luchs, 1995). Initially, it starts as an enthesis at the subacromial attachment of the CAL, with repetitive impingement [stress] on the enthesis a spur is formed and extends within the CAL (Tada *et al*., 1990), mainly the anterolateral band of the CAL (Fealy *et al*., 2005, Flatwo *et al*., 1996). However, spur formation at the undersurface of the acromion is described as a subacromial facet that results from ossification of the subacromial bursa (Miles, 1996). It is also described as an accessory articular facet (Williams *et al*., 1989) and is said to be responsible for narrowing the subacromial space (Nasca *et al*., 1984).

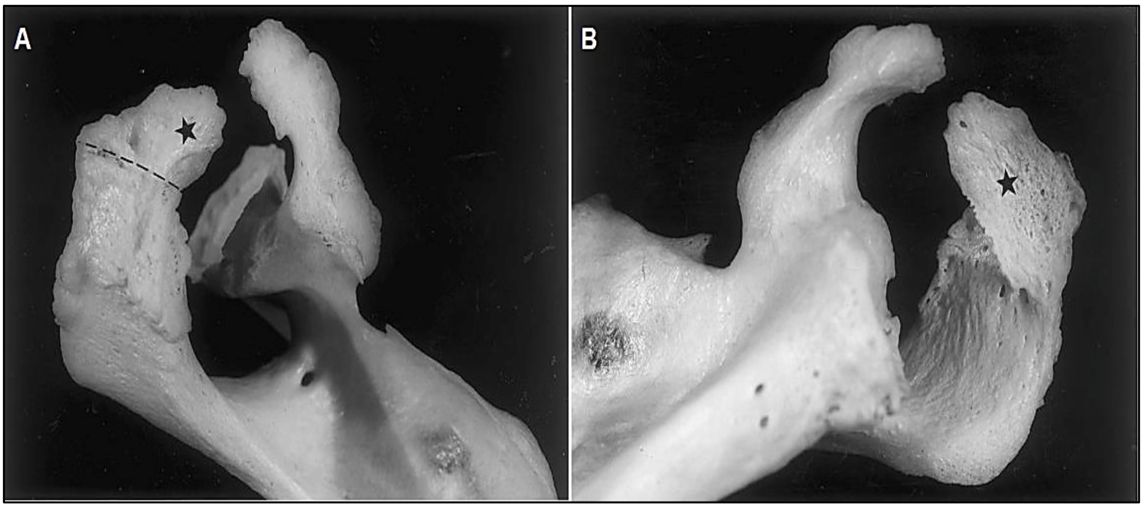


Figure 1.45 Formation of spur at the anterior acromion in right female scapula, 92 years: Figure-A shows a superior view of an acromial spur. The anterior border of the acromion is marked with a dotted line. The spur extends anteriorly inside the CAL to the coracoid, which decreases the distance between the acromion and coracoid processes. Figure-B shows the inferior surface of the acromion with an eburnated subacromial facet (star) that is usually seen in very old specimens or in chronic cases of shoulder impingement syndrome. (Prescher, 2000).

The relationship between an acromial spur and rotator cuff tear was first described in 1972 by Neer. Several studies later confirmed this relationship

(Bigliani *et al*., 1986; Postacchini, 1989; Ogata and Uhothoff, 1990; Zuckerman *et al*., 1992; Hernigou, 1994; Panni *et al*., 1996; Yoshida and Ogawa, 1996). Neer (1983) considered that acromial spur formation comes in the third stage of impingement syndrome. Thus, a subacromial spur can be used as presumptive evidence for shoulder impingement (Cone *et al*., 1984). However, other studies suggested that acromial spurs developed secondary to the presence of established rotator cuff tears (Codman, 1934; Loehr and Uhthoff, 1987; Ozaki *et al*., 1988; Uhthoff *et al*., 1988; Sarkar *et al*., 1990; Yoshida and Ogawa, 1996; Chambler *et al*., 2003a; Pearsall *et al*., 2003). To relieve the impingement from a rotator cuff tear, Neer (1983) advocated removing the acromial spur.

1.7.1 The Eetiology of Acromial Spur Formation

An acromial spur may be either genetically determined or an acquired phenomenon associated with ageing (Graves, 1922; Codman, 1934; Cone *et al*., 1984; Nicholson *et al*., 1996). Acromial extension and the direction of acromial spurs imply that they are the result of ossification of the acromial attachment of the CAL. However, since some spurs develop on the subacromial surface, with a different form, size and thickness, this supports the view that they form as a result of ossification of the subacromial bursal wall and other contiguous structures (Graves, 1922). This view was also supported by Miles (1996) who assumed that the subacromial facet formed at the undersurface of the acromion is the result of ossification of the subacromial bursa, whereas enthesophytes formed at the anterior edge of the acromion result from traction forces exerted on the CAL or tendinous muscle attachments. Miles (1996) also supported the view that superior translation of the humeral head caused impingement on the CAL leading to enthesophyte formation.

1.7.1.1 Intrinsic Factors

Ossification of the CAL and formation of acromial spurs have been associated with several pathological or intrinsic factors such as chronic renal failure, miscellaneous and diffuse idiopathic systemic hyperostosis (Chen and Bohrer, 1990; Noda and Mizuno, 1998). Furthermore, spur formation was detected at the attachment of the coracoclavicular ligament in a 9-year-old girl with rheumatoid arthritis (Caffey, 1985 cited in Chen and Bohrer, 1990). On the other hand, mechanical or extrinsic factors, such as trauma, repetitive impingement and attrition, mechanical alteration of CAL tension and dynamic loading of bone have been assumed to cause spur growth (Chambler *et al*., 2003a; Gallino *et al*., 1995; Neer, 1972; Ogata and Uhthoff, 1990; Sarkar *et al*., 1990; Tada *et al*., 1990; Uhthoff *et al*., 1988).

Soft tissue calcification is common in patients with chronic renal failure. Chen and Bohrer (1990) reviewed 46 calcifications and/or ossifications of the coracoclavicular ligament and CAL in 36 patients with an average age of 52 years (range, 26-79 years). The appearance of ossification in the coracoclavicular or CAL region was categorized into three types: punctate calcification, ossification with or without joint formation and mass-like tumoral calcification. Calcification and ossification of the CAL was associated with the coracoclavicular ligament and was detected in 54%. It correlated with the patients' history: 36% of cases had trauma, 28% had renal failure and 36% had miscellaneous associations. Furthermore, Chen and Bohrer (1990) classified the cause of soft tissue calcification into three types: metastatic calcification related to a disturbance in calcium and phosphorus metabolism; calcinosis with deposition of calcium in skin and subcutaneous tissues in the presence of normal calcium and phosphorus metabolism; dystrophic calcification related to calcium deposition in damaged or devitalized tissue in the absence of generalized metabolic derangement. However, calcification of the soft tissues often has the same appearance.

The formation of spurs at other skeletal sites suggests that it is more likely the result of an intrinsic factor. Noda and Mizuno (1998) studied the relationship between the incidence of acromial spurs and systemic hyperostosis in 60 macerated skeletons. Spurs (≥ 3mm) were found to form in 8 different extra-spinal skeletal bones: acromion (35%), olecranon (3.4%), iliac crest (16.7%), pubis (3.3%), ischium (9.2%), sacroiliac joint (18.3%), patella (6.5%), and calcaneus (1%). In addition, three of six cases showed giant spurs (≥ 4 mm) at both acromions and five or more spurs elsewhere due to systemic hyperostosis. They proposed that acromial spur formation was either influenced by diffuse idiopathic systemic hyperostosis (DISH) or by an intrinsic factor other than acquired impingement and overuse.

1.7.1.2 Extrinsic or Mechanical Factors

Formation of acromial spurs on the inferior surface of the acromion, rather than on the superior surface, suggests a relationship with the acromial attachment of the CAL (Oh *et al*., 2010). Neer assumed that the presence of spurs and degenerative changes, erosion and eburnation on the undersurface of the acromion was caused by chronic impingement and increased tension in the CAL (Neer, 1972). This view has been subsequently supported by several studies that have confirmed that repetitive attrition and impingement of the rotator cuff and greater tubercle against the subacromial arch influences spur formation (Cone *et al*., 1984; Aoki *et al*., 1986; Tada *et al*., 1990; Prescher, 2000; Mahakkanukrauh and Surin, 2003; Ko *et al*., 2006).

Aoki *et al*. (1986) suggest that subacromial degenerative changes are secondary to the repetitive stresses of subacromial impingement with aging. In turn, these changes lead to rotator cuff tears and then cause degenerative changes to the greater tubercle. Tada *et al*. (1990) observed that some spurs (13.5%) formed on the coracoid process along the CAL, which is not usually a site for impingement, and suggested that the development of spurs was associated with impingement. Furthermore, Ko *et al*. (2006) suggested that repeated attrition of the rotator cuff against the subacromial surface, as a result of overuse, trauma or malunion of the greater tubercle, leads to reactive and degenerative osseous changes and formation of acromial spurs at the CAL insertion.

However, Ozaki *et al*. (1988) found degenerative changes present on the subacromial surface in shoulders with bursal partial cuff tears, but not in those with articular side cuff tears: they believed these changes were secondary to a bursal side tear. Chambler *et al*. (2003a) also support this view: the acromial spur formed secondary to the presence of established rotator cuff tears. On the other hand, Panni *et al*. (1996) believed that an acromial spur is an age-related change and can be formed even in the absence of a rotator cuff tear. In addition, they stated that a cuff tear could accelerate acromial spur formation by increasing the tension on the CAL causing a proliferative stimulus on the acromial attachment.

Another mechanical factor leading to spur formation and degenerative changes in the CAL is increasing, or changing, tensile forces applied to the CAL. Anterior acromion spurs have been described as osteophytes formed at the CAL attachments due to increased attraction forces applied to the ligament (Neer, 1972; Uhthoff *et al*., 1988; Ogata and Uhthoff, 1990; Sarkar *et al*., 1990; Tada *et al*., 1990; Gallino *et al*., 1995; Chambler *et al*., 2003a). Changing or increasing tensile forces can be transmitted through the CAL either by a muscular imbalance, between those attached to the acromion and coracoid processes, or by upward subacromial forces during shoulder movements in impingement shoulders (Gallino *et al*., 1995; Chambler *et al*., 2003a).

Ogata and Uhthoff (1990) believe that an acromial spur is caused by increased tensile forces transmitted through the ligament, while the thickened subacromial insertion of the CAL is caused by the impingement. Edelson and Taitz (1992) believe the common degenerative signs seen in the acromion result from long-standing impingement caused by the humeral head. However, they did not find any of these signs on the coracoid process, which they attribute to the triangular shape of the CAL. The broad coracoid attachment of the CAL distributes the transmitted tensile forces through the ligament thus preventing spur formation, while the narrow acromial attachment of the CAL concentrate the tensile forces on the acromion influencing spur formation.

In turn, increased pressure or tensile forces transmitted through the CAL apply dynamic loading on the attached bone, which enhances bone formation (Lanyon and Rubin, 1984; Gohlke *et al*. 1993). However, Goodship *et al*. (1979) report that changes in static tension of the ligament causes ossification.

Chambler *et al*. (2003a) investigated the enzymatic activities within the acromial spur insertion into the CAL in shoulders with rotator cuff tears. Results demonstrated active bone turnover at the CAL insertion. In addition, the enthesial ligament cells, those cells present near the acromial attachment site, had similar characteristics of enthesophyte that form at the edge of spur. Chambler *et al*. (2003a) suggested that cuff tendonitis or tears produced bursal inflammation that may be applied loads on the CAL influencing both static and dynamic tension. As result, this alteration increases tension in the CAL provoking changes in local cell behavior leading to the formation of acromial enthesophytes. Thus, Chambler *et al*. (2003a) support the view that acromial spur formation is secondary to the presence of established rotator cuff tears.

Furthermore, a higher G6PD activity has been found in bone and ligament cells in the inferior aspect of the CAL attachment to the acromion (Chambler *et al*., 2003a). They believe that these localized increases in CAL entheses indicate increasing bone formation activity as a result of a persistent loading-related elevation of local osteogensis. This is supported by previous studies (Dodds *et al*., 1993; Skerry *et al*., 1989) which showed that a short period of mechanical loading on bone resulting in high G6PD activity for at least 24 hours after loads are applied.

1.7.2 Incidence of Acromial Spurs

In previous studies (Table 1.6) spur incidence ranges from 5% to 97%, with the average incidence being 30.6%. Variable incidence of acromial spurs in previous studies may be caused by the age of individuals and type of specimens studied. Previous studies also report a significant association between spur incidence and age (Graves, 1922; Cone *et al*., 1984; Tada *et al*., 1990; Edelson, 1995; Getz *et al*., 1996; Panni *et al*., 1996; Ogawa *et al*., 1996; Mahakkanukrauh and Surin, 2003; Oh *et al*., 2010), in which individuals with acromial spurs were older than those without (Cone *et al*., 1984; Tada *et al*., 1990; Panni *et al*., 1996) (Table 1.7). With respect to side, acromial spurs were reported more in right shoulders than left shoulders (Gray, 1942; Edelson, 1995; Panni *et al*., 1996; Miles, 1996; Mahakkanukrauh and Surin, 2003; Ogawa *et al*., 2005). In addition, previous studies found more acromial spurs in males than females (Tada *et al*., 1990; Edelson, 1995; Ogawa *et al*., 2005; Paraskevas *et al*., 2008; Hamid *et al*., 2012). However, other studies reported no difference in acromial spurs incidence between males and females (Mahakkanukrauh and Surin, 2003; Oh *et al*., 2010).

Table 1.6 Iincidence of acromial spurs reported in previous studies.

Study	Type	N	Age	Spur
Gray (1942)	Dry scapulae	1085	> 60	240 (22.1%)
	Dry scapulae	80	<60	5 (6.2%)
Neer (1972)	Dry scapulae	100	60	8 (8%)
Cone *et al*. (1984)	Shoulders with pain (RDGs)	103	52	26 (25%)
	Pathological specimens (OP)	80	*	18 (23%)
	Fluoroscopic examination	12	*	9 (75%)
Aoki *et al*. (1986)	Dry scapulae	130	57.5 (34-83)	38(29.2%)
Hardy *et al*. (1986)	Patients with acute SIS (RDGs)	38	56 (22-89)	26 (68%)
Postacchini (1989)	Patients with SIS (OP)	18	44 (21-67)	3 (17%)
Tada *et al*. (1990)	Cadaveric shoulders	74	76.8 (44-93)	34 (46%)
Ono *et al*. (1992)	Shoulders with SIS (RDGs): - Anteroposterior view - 30° Caudal tilt view	73	60.1 (25-79)	27 (37%) 52 (71%)
Edelson & Taitz (1992)	Dry scapulae	200	30-70	46 (23%)
Gohlke *et al*. (1993)	Cadaveric shoulders	57	75(47-90)	22 (38.6%)
Hernigou (1994)	Patients with RCTs (RDGs)	50	*	12 (24%)
Chun and Yoo (1994)	Patients with SIS (RDGs) Patients without SIS (RDGs)	100 100	*	52 (52%) 5 (5%)
Edelson & Luchs (1995)	Dry scapulae	300	> 60	69 (23%)
Flatwo *et al*. (1996)	Cadaveric shoulders	16	77.8 (50-94)	10 (62.5%)
Getz *et al*. (1996)	Dry scapulae	394	(20-89)	157 (40%)
Panni *et al*. (1996)	Cadaveric shoulders	80	58.4 (26-82)	35 (43.7%)
Nicholson *et al*. (1996)	Dry scapulae	420	21-70	61 (14.5%)
Mahakkanukrauh & Surin (2003)	Dry scapulae	692	15-100	200 (28.9%)
Ogawa *et al*. (2005)	Shoulder without pain (RDGs)	644	44 (16-79)	193 (30%)
	Cadaveric shoulders	241	77 (38-96)	169 (70%)
	Shoulders with RCTs (OP)	144	46 (18-66)	120 (83.3%)
TaheriAzam *et al*. (2005)	Patients with SIS (RDGs)	89	56.4 (34-80)	8 (9%)
Ko *et al*. (2006)	Patients with partial RCTs (OP)	66	52.2 (25-72)	64 (97%)
Natsis *et al*. (2007)	Dry scapulae	423	*	66 (15.6%)
Sangiampong *et al*. (2007)	Dry scapulae	154	49 (16-87)	23 (14.9%)
Paraskevas *et al*. (2008)	Dry scapulae	88	*	19 (21.5%)
Oh *et al*. (2010)	Patients with FT RCTs (RDGs)	106	59.6 (49-78)	83 (78%)
	Patients without RCTs (RDGs)	102	57.5 (45-79)	59 (58%)
Hamid *et al*. (2012)	Patients with asymptomatic RCTs (RDGs)	216	64.8 (37-90)	49 (23%)
Total		6477	15-100	1981 (30.7%)

- Type: radiographs (RDGs), operational study (OP), subacromial impingement syndrome (SIS), rotator cuff tears (RCTs), full thickness rotator cuff tears (FT RCTs).
- Age: no data found (*).

Table 1.7 Comparison of the age of specimens in previous studies according to the presence of acromial spurs.

Study	Shoulders without Spurs (years)	Shoulders with Spurs (years)
Cone *et al*. (1984)	47	59*
Tada *et al*. (1990)	73.4	80.9*
Panni *et al*. (1996)	48.9	70.5*
Hamid *et al*. (2012)	64	67.2

- Significant difference (*): P < 0.050.

1.7.3 Observation of Acromial Spurs in Radiographs

The radiographic view taken may influence the observation of acromial spurs. Small acromial spurs could not be detected in radiographs by Uhthoff *et al*. (1988). In 1992, Ono *et al*. evaluated two ways of observing acromial spurs from radiographs in 73 shoulders with subacromial impingement syndrome: anteroposterior view and 30° caudal tilt view. They identified acromial spurs in only 37% of the anteroposterior radiographs, while more spurs (71%) were detected in the 30° caudal tilt radiographs, since small spurs could not be detected on anteroposterior radiographs. Thus, the 30° caudal tilt radiograph gives a better view of the anterior portion of the subacromial surface revealing the exact architecture of an acromial spur (Figures 1.46 and 47). Therefore, Ono *et al*. (1992) recommended using this view during preoperative planning and postoperative evaluation.

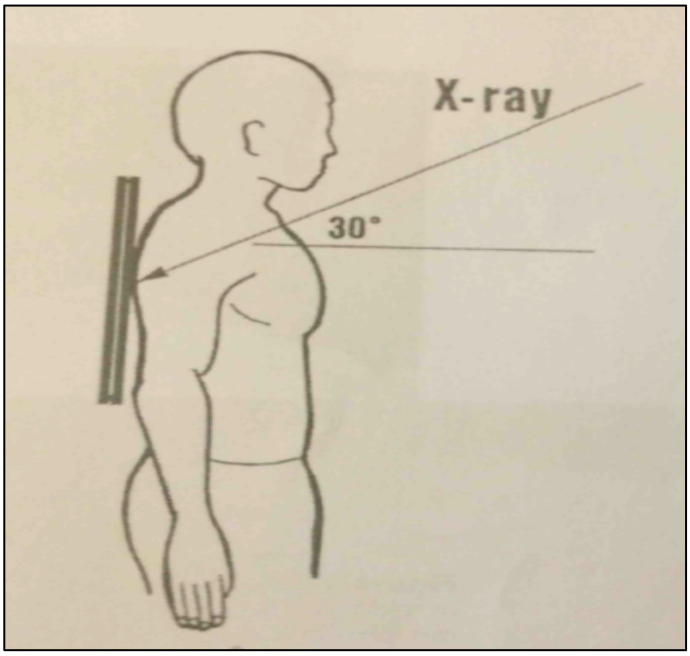


Figure 1.46 30° caudal tilt view radiograph: the film is placed behind the patient's shoulder, the angle between the film and the anterior direction of the x-ray beam being 30° (Ono *et al*., 1992).

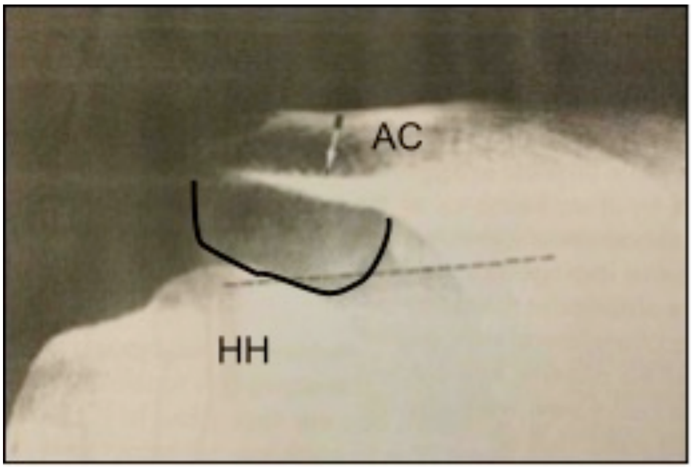


Figure 1.47 30° caudal tilt radiograph of a normal shoulder: showing a posterior view of the acromion (arrow; outline) and the inferior surface of the acromion (horizontal line). The anterior edge of the acromion is represented by the bony area below the horizontal line: acromion (AC); humeral head (HH) (Ono *et al*., 1992).

A study by Kitay *et al*. (1995) supports the reliability of the 30° caudal tilt view in visualizing acromial spurs. In this study, they compared different radiographic views, including anteroposterior, axillary, 30° caudal tilt, and supraspinatus outlet views, in order to be able to visualize and measure the length of acromial spurs. The 30° caudal tilt view was found to have higher acceptability and reliability than other views, with a positive response of large spurs confirmed surgically in 74% in this view compared to 50% with the supraspinatus outlet view and 33% with the axillary view.

However, both Baumgarten *et al*. (2011) and Hamid *et al*. (2012) reported that radiographs were unreliable in observing or measuring the size of acromial spurs. Baumgarten *et al*. (2011) reported fair to moderate interobserver reliability in determining the presence of an acromial spur; however poor interobserver reliability was demonstrated in measuring the size of the acromial spur. Consequently they recommend using digital radiographs with a computerized measuring device to get more reliable results. Hamid *et al*. (2012) also reported substantial agreement on the reliability of the presence and size of acromial spurs in the supraspinatus outlet view.

1.7.4 Classification of Acromial Spurs

1.7.4.1 Morphological Classification

An acromial spur usually has an oval or nearly oval shape with a smooth concaved surface. Beyond the anterior tip of the acromion it has a convex dorsal surface, often with a serrated or digitated tip margin (Graves, 1922). Gray (1942) described an acromial facet in 240 (22.12%) of 1085 cadaveric scapulae and classified them with regard to their protrusion or depression on the subacromial surface into elevated (62%) or sunken (15%). The surface appearance of facets was also classified into three types: smooth (34%), polished (eburnated) (7%) and rough or reactive (55%). About 36% of these facets were elevated and also showed a rough surface. Neer (1972) observed eburnation and erosion on the subacromial surface and related these changes to advanced stages of impingement. These changes were suggested for grinding of the head of humerus on the acromion undersurface (Prescher, 2000).

Hardy *et al*. (1986) classified the severity of subacromial spurs in anteroposterior radiographs into mild spurs observed in 62% of specimens, with moderate and severe spurs seen equally in 19% of patients. Tucker and Synder (2004) reported keeled acromion spurs in 1.2% of patients who underwent arthroscopic treatment for impingement syndrome. They described these spurs as downward sloping spurs that developed longitudinally on the central of the subacromial surface (Figure 1.48). Rotator cuff tears were detected in 60% of patients with a keeled acromion. Furthermore, Oh *et al*. (2010) reported 6 shapes of acromial spur in anteroposterior radiographs: heel, lateral traction, anterior traction, lateral bird beak, anterior bird beak and medial (Figure 1.49).

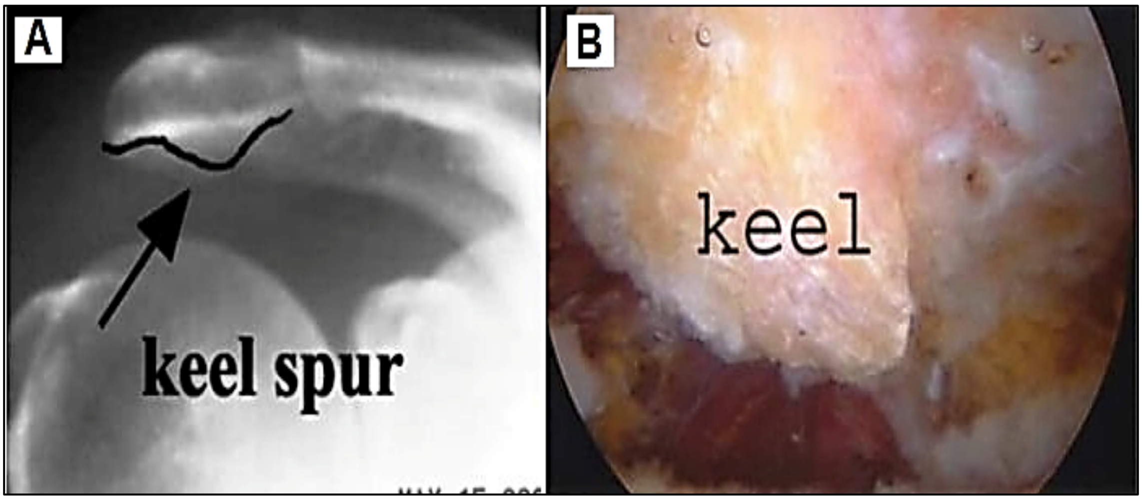


Figure 1.48 The keeled acromion or spur: the anteroposterior radiograph (A) shows the outline of the spur at the inferior surface of the acromion. Arthroscopic view (B) shows the posterior bursal aspect of a keeled spur (Tucker and Snyder, 2004).

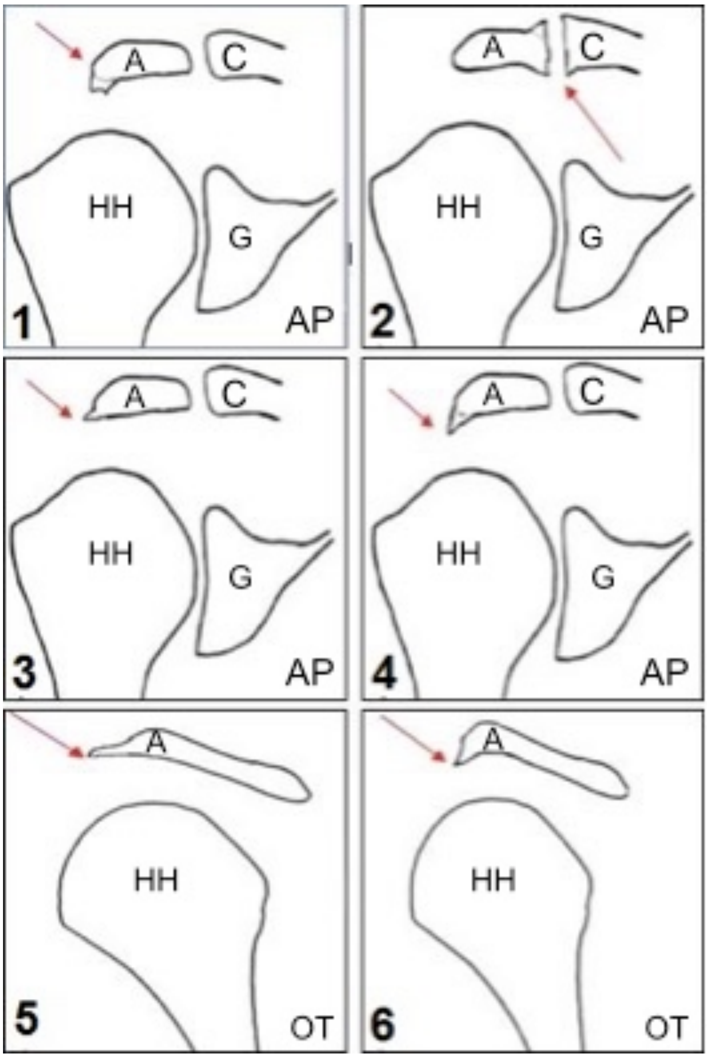


Figure 1.49 Morphological appearances of acromial spurs in radiographs: Oh *et al*. (2010) identified 6 shapes of acromial spur based on its radiographic appearance: heel (upper left), medial (upper left), lateral traction (middle left), lateral bird beak (middle right), anterior traction (lower left), and anterior bird beak (lower right): Acromion (A); clavicle (C); humeral head (HH); glenoid fossa (G). Radiographs view: anteroposterior view (AP) and outlet view (OT).

Ono *et al*. (1992) classified the anterior protrusion of acromial spurs in the 30° caudal tilt radiographs into sharp spurs and wide round based spurs (Figure 1.50). Both Cone *et al*. (1984) and Mahakkanukrauh and Surin (2003) classified the morphology of the anterior acromial spur based on its curve. Cone *et al*. (1984) classified anterior acromial spurs into anterior, inferior and anterior-inferior projections. However, Mahakkanukrauh and Surin (2003) classified anterior acromial spurs into a traction spur (straight) and a claw spur (curved or hooked) (Figure 1.51).

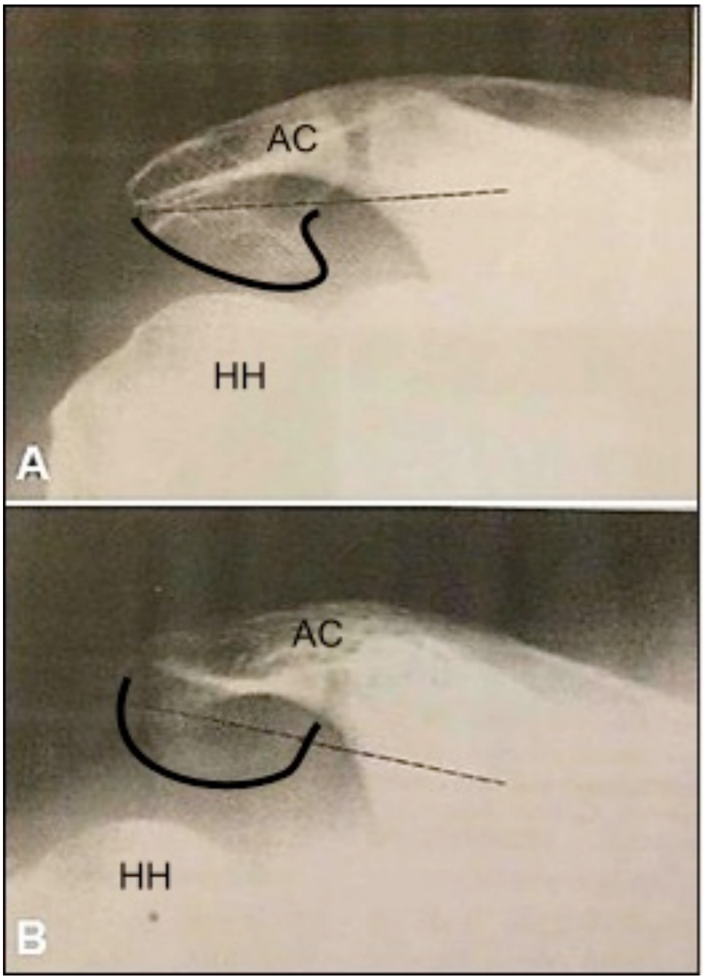


Figure 1.50 Anteroposterior views show morphological classification of the anterior edge of acromial spurs into sharp (A) and round (B). The dashed line indicates the anterior edge of the acromion: acromion (AC), humeral head (HH) (Ono *et al*., 1992).

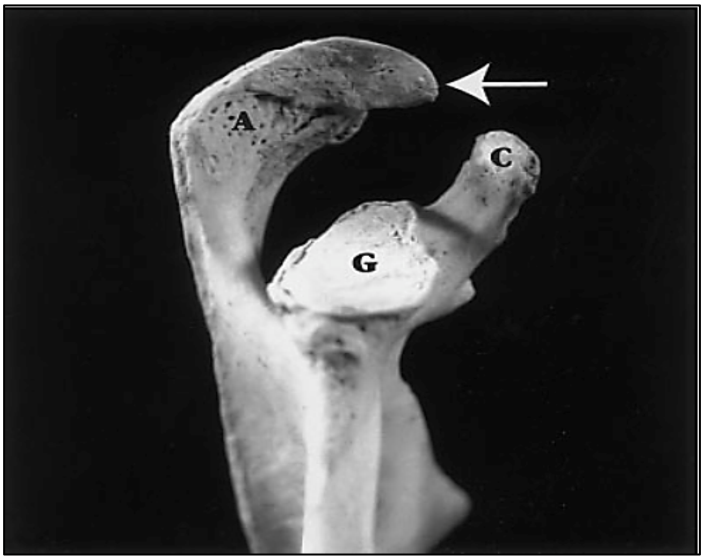


Figure 1.51 Lateral view of the scapula showing a curved or claw type of acromial spur (arrow): acromion (A); coracoid (C); glenoid fossa (G) (Mahakkanukrauh and Surin, 2003).

1.7.4.2 Geometric Classification

Acromial spurs increase the tip of the acromion by 2 to 8 mm or more. The geometric parameters of the spur are as follows: 2 mm thick, 5 to 35 mm along the anteroposterior axis, and 4 to 25 mm along the mediolateral axis. The large size of an acromial spur may interfere with shoulder function and is often associated with other scapular degenerative changes (Graves, 1922). The size of an acromial spur can be classified into three types: large (14%), medium (63%), small (23%), (Gray, 1942). Cone *et al*. (1984) observed different forms of spur at the subacromial surface which varied from small bony excrescences to large well-formed spurs with concave sclerotic inferior margins. In their study, however the size of acromial spurs was described subjectively not objectively; without giving any indication of spur size.

In 1990, Tada *et al*. used an axial view radiograph to classify acromial spurs into three stages according to their extension inside the CAL. In the first stage, spurs were small prominences (19%) developed at the attachment of the CAL on the anterior edge of the acromion (Figure 1.52: A); in the second stage (16.2%) they had a length less than 1 cm along the CAL and were accompanied by bony trabeculae (Figure 1.52: B); in the third stage spur length extended to more than 1 cm with sclerotic and clear bony trabeculae. Anteriorly, the spur extended into the middle third of the CAL, whereas it is limited to the insertion area of the ligament posteriorly: this type was observed in 8 specimens (10.8%) (Figure 1.52: D). However, axillary view radiographs were found inappropriate for the assessment of acromial spurs since they show poor reliability compared to operative findings (Kitay *et al*., 1995).

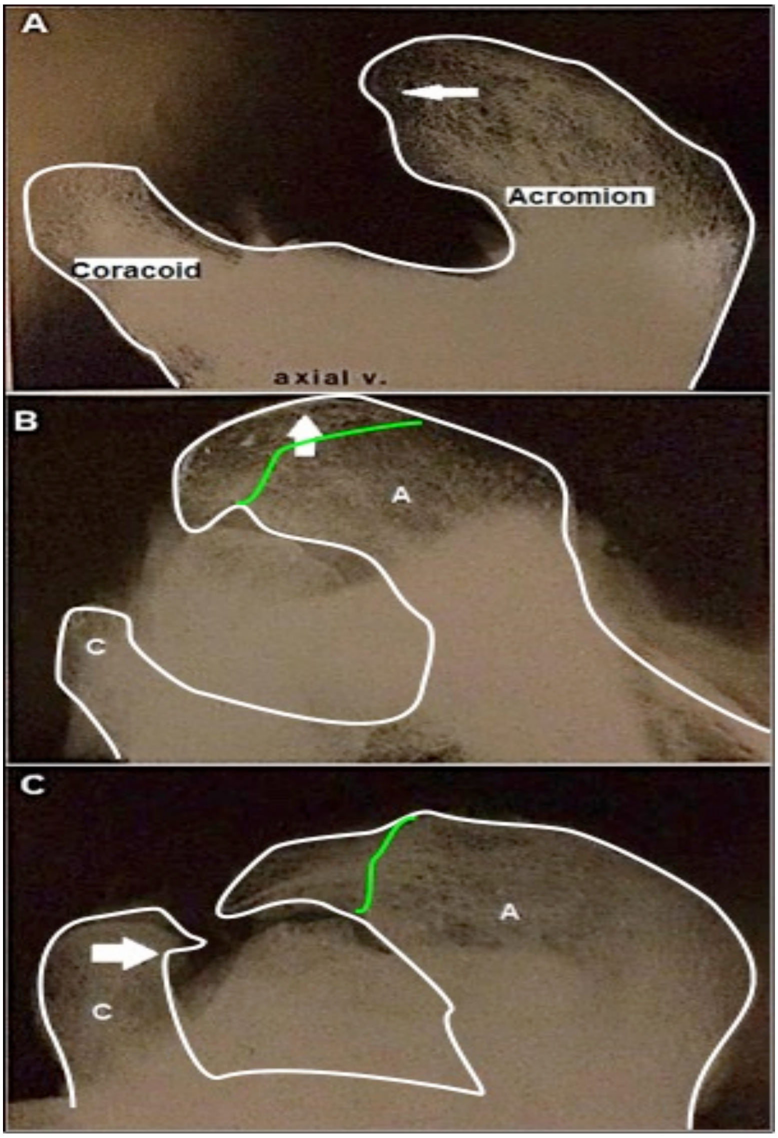


Figure 1.52 Axial radiographs of the acromion showing three stages of spur (arrows) extension into the CAL: in the first stage (A), a small prominence of spur develops at the attachment of the CAL on the anterior edge of the acromion. In the second stage (B), < 1 cm spur length (green outline) extends into the CAL accompanied by bony trabeculae. In the third stage, the spur length is > 1 cm (green outline)along the CAL and is accompanied by sclerotic and clear bony trabeculae (Tada *et al*., 1990).

The length of acromial spurs has also been debated in other radiographic studies. Ono *et al*. (1992) described the length of the spur in the 30° caudal tilt view as the distance between the tip of the spur and a line extending laterally from the anteroinferior border of the distal clavicle. The length of spur was classified into three types: small (< 5mm), medium (5-10 mm) and large (>10 mm) (Figure 1.53). Kitay *et al*. (1995) described spur length as a line extending from the inferior aspect of the acromion to the distal tip of the spur. However, Baumgarten *et al*. (2011) found that the spur-humeral distance was more reliable than spur length in measuring the size of spurs in radiographs. The spur-humeral distance extends from the inferior tip of the spur to the humeral head (Figure 1.54).

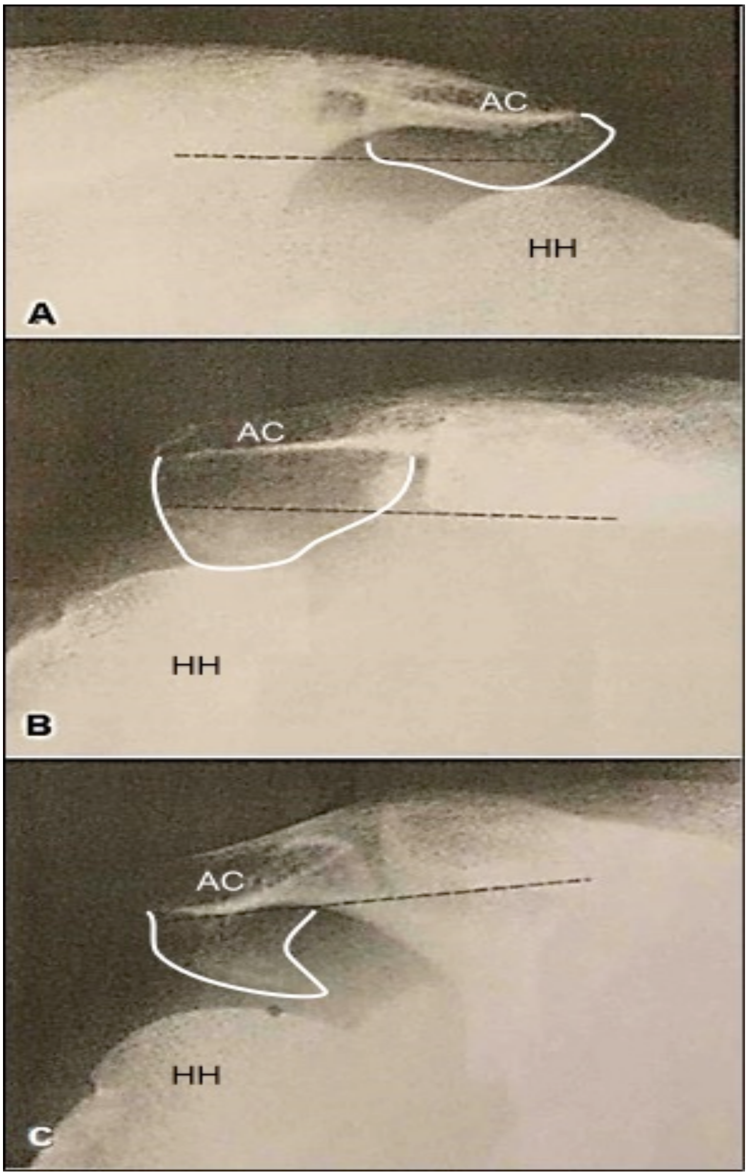


Figure 1.53 Classification of the size of acromial spurs in 30° caudal tilt view: the size of the acromial spur is described as the distance between the tip of the spur and a line extending laterally from the anteroinferior border of the distal clavicle. Based on the length, the spur can be classified into three types: small (< 5mm) (A), medium (5-10 mm) (B), and large (>10 mm) (C): acromion (AC); humeral head (HH), acromion undersurface (outline) (Ono *et al*., 1992).

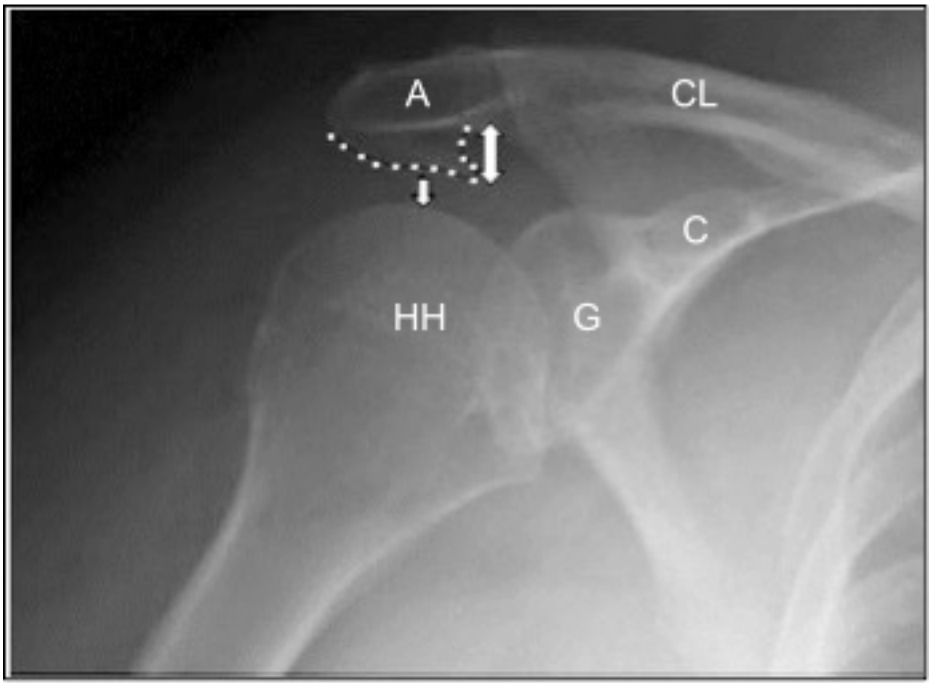


Figure 1.54 Anteroposterior radiograph revealing the size of an acromial spur (outlined): there are two ways to measure the influence of the size of acromial spur in anteroposterior radiographs. First, the length of spur is measured as a line extending between the inferior surface of the acromion superiorly and the distal tip of the spur inferiorly (double arrowhead). Second, the spur-humeral distance (single arrowhead) measured along a line extending between the inferior tip of the spur and the humeral head: acromion (A); clavicle (CL); coracoid (C); glenoid fossa (G); humeral head (HH) (Baumgarten *et al*., 2011).

Ogawa *et al*. (1996) classified the length of an acromial spur at the anterior edge of the acromion into three types: small spur (< 5mm), medium spur (5 – 10 mm) and large spur (> 10 mm). Furthermore, they inspected 144 specimens obtained by anterior acromioplasty and found that large and medium spurs presented in 49% of shoulders with partial or complete bursal side tears. They believed that a small spur develops as a subclinical or physiological subacromial impingement; however increasing size of spurs is caused by clinical impingement represented by rotator cuff pathology. Ogawa *et al*. (2005) stated that the spur growth could be affected by morphological changes on the bursal side of the rotator cuff. In relation to rotator cuff tears small spurs have no significant value compared to medium and large spurs associated with bursal and complete rotator cuff tears. The presentation of small spurs in shoulders without rotator cuff tears or a prolonged duration of symptoms suggests that there are other factors influencing the growth of an acromial spur.

Large acromial spurs are associated with rotator cuff tears. Yoshida and Ogawa (1996) classified the size of acromial spur as in Ogawa *et al*. (1996) and found that shoulders with complete and bursal side tears had larger acromial spurs than shoulders with an intact cuff, bursal side, intratendinous, or articular side tears. Ko *et al*. (2006) identified acromial spurs in 97% of patients with partial tears, with large acromial spurs seen in 11 patients (16.6%). Ko *et al*. (2006) believe that the formation of an acromial spur is influenced by overuse and repeated attrition as they influence degenerative processes. Hamid *et al*. (2012) reported acromial spurs greater than 5 mm in 26 patients (12%), with a significant relationship demonstrated between spurs greater than 5 mm and full thickness tears. Full thickness tears were significantly presented (P = 0.0005) in 88% of shoulders with a large acromial spur compared to 53% in shoulders without a large acromial spur. Furthermore, a significantly larger rotator cuff tear width was present when a larger acromial spur occurred (P = 0.046) (Hamid *et al*., 2012).

1.7.5 CAL and Acromial Spurs

Acromial spur formation usually occurs at the acromial attachment of the CAL, mainly associated with the anterolateral band (Uhthoff *et al*., 1988; Edelson and Luchs, 1995; Fealy *et al*., 2005). Initially, they form at the subacromial attachment of the CAL as an enthesis, with repetitive impingement on the enthesis a spur is formed and extends within the CAL (Tada *et al*., 1990). Shoulders with more prominent anterior acromial edges or spurs have effectively shorter CALs (Zuckerman *et al*., 1992). Furthermore, growth of acromial spurs is usually accompanied with calcification of the CAL that in turn accelerates the rotator cuff lesion (Giordano, 1972; Morimoto *et al*., 1988). However, acromial spurs have been identified as calcification of the acromial attachment of the CAL and not as a portion of the acromion (Ogata and Uhthoff, 1990; Edelson and Taitz 1992).

With respect to morphology, Pieper *et al*. (1997) found no relationship between CAL morphology and acromial spur formation. In contrast, Fealy *et al*. (2005) reported a difference in CAL morphology according to the presence of an acromial spur, noting acromial spurs in 10 of 16 shoulders (62.5%). The CAL had a focal morphology when a spur formed and a diffuse morphology when no spur exists. Therefore, a CAL with a spur has a more acute angle between the anterolateral and posteromedial bands compared to CALs without spurs; 31° and 45° ($P < 0.001$) respectively. Moreover, Fealy *et al*. (2005) reported that CALs with spurs have narrower acromial attachments than CAL without spurs; 5.53 mm and 11.9 mm ($P < 0.001$) respectively. Subsequently, the space between the anterolateral and posteromedial bands at the coracoid attachment site was shorter ($P < 0. 01$) in CALs with spurs (23.9 mm) than in those without spurs (32.2 mm). In addition, both anterolateral and posteromedial CAL bands were shorter and thicker at both their origin and insertion, ($P < 0.01$) when a spur was present. Fealy *et al*. (2005) concluded that an acromial spur associated with a focal CAL was narrower, less divergent, shorter and thicker than a diffuse CAL without a spur. In addition, Fealy *et al*. (2005) suggested that the anterolateral band is a major load-bearing structure due to the preferential location of spurs, while a diffuse CAL plays a role in dampening the tensile forces between the acromion and coracoid processes.

1.7.6 Relation between Spur and Acromial Morphology

1.7.6.1 Acromial morphology and the relation with rotator cuff tears

In 1986 Bigliani *et al*. classified the morphology of the acromion into three types: flat, curved and hooked, with an association between acromion morphology and impingement syndrome. Significantly higher incidence of rotator cuff tears were observed in shoulders with a hooked acromion (69.8%) than those with the flat (3%) and curved (24.2%) types. Bigliani *et al*. (1986) also found that shoulders with full thickness tears had a greater acromial slope angle, the angle between two lines connecting the anterior and posterior ends of the acromion and interconnecting at the midway point on the inferior acromion, than shoulders with intact rotator cuffs. Edelson and Taitz (1992) have described another way to measure the degree of acromial curvature by measuring the maximum height above a straight line drawn between its ends. Flatow *et al*. (1994) found that more subacromial contact with head of humerus in shoulders with hooked acromion than other acromion types. Therefore, the hooked acromion may narrow the subacromial space and increase chance of impingement.

Other studies confirmed the relationship between a hooked acromion and rotator cuff tears (Ogata and Uhthoff, 1990; Epstein *et al*., 1993; Chun and Yoo, 1994; Farley *et al*., 1994; Toivonen *et al*., 1995; Shah *et al*., 2001; Worland *et al*., 2003). In contrast, other studies have found no relationship between rotator cuff tears and acromial type or difference in acromial slope (Balke *et al*., 2013;

Moor *et al*., 2014; Musil *et al*., 2012). Furthermore, outcomes of non-operative management and conservative treatments of patients with subacromial impingement syndrome may be affected by acromial morphology (Morrison *et al*., 1997; Wang *et al*., 2000; TaheriAzam *et al*., 2005). Thus, patients with a hooked acromion, which required surgical intervention to relieve the impingement, showed less successful outcomes. In contrast, other studies have shown no relationship between a hooked acromion and impingement syndrome or rotator cuff tears (Wang and Shapiro, 1997; Hirano *et al*., 2002; Aydin, *et al*., 2011).

1.7.6.2 Formation of Hooked Acromion

The source of a hooked acromion has been debated in the literature, with two contradictory theories put forward to explain the formation. The first theory suggests that a hooked acromion is congenital (Nicholson *et al*., 1996; Sangiampong *et al*., 2007): the second theory proposes that a hooked acromion is an acquired or developmental phenomenon. The second theory is based on three suggestions: tensile forces applied to the acromion by the CAL (Shah *et al*., 2001), the degenerative changes of aging (MacGillivray *et al*., 1998; Speer *et al*., 2001, Vassalou *et al*., 2012; Wang and Shapiro, 1997) and misinterpretation regarding the formation of an acromial spur (Edelson and Taitz, 1992; Epstein *et al*., 1993; Edelson, 1995; Edelson and Luchs, 1995; Getz *et al*., 1996; Prescher, 2000) (Figure 1.55). Finally, a higher incidence of acromial spurs has been reported in shoulders with hooked acromions than in other types (Getz *et al*., 1996; Natsis *et al*., 2007; Ogata and Uhthoff, 1990; Panni *et al*., 1996; Paraskevas *et al*., 2008) (Figure 1.56). In contrast, both Nicholson *et al*. (1996) and Sangiampong *et al*. (2007) reported no relationship between the incidence of acromial spurs and morphology of the acromion. However, previous studies have not investigated the acromial morphology before and after spur formation. Edelson and Taitz (1992) suggested that degenerative changes at the anterior edge of the acromion lead to increase the length of the acromion, which in turn changes the acromial morphology. In addition, spurs form at the anterior edge of the acromion with different size and shape that may change the primary morphology of the acromion. Nevertheless, the affect of these characteristics was also not investigated previously in relation to morphology of acromion.

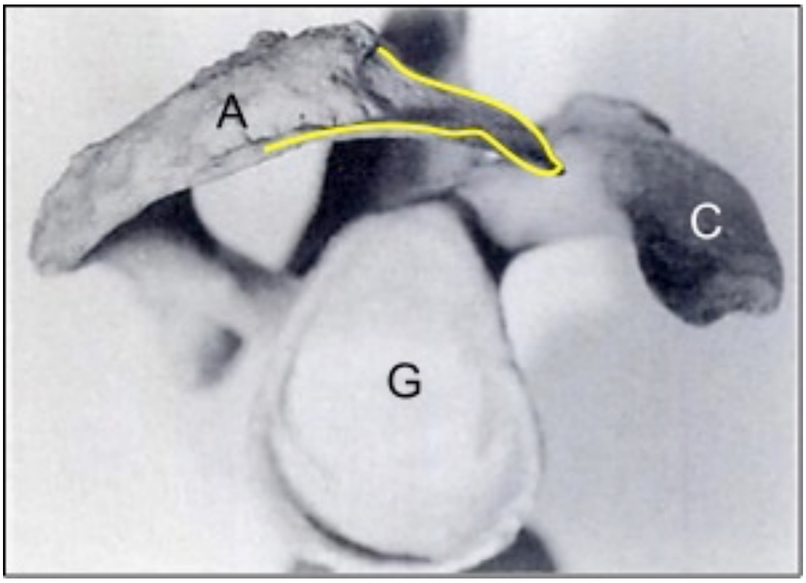


Figure 1.55 Pronounced acromial spur (outline) at the anterior edge of the acromion producing a hooked shape acromion: acromion (A); coracoid (C); glenoid (G) (Edelson, 1995).

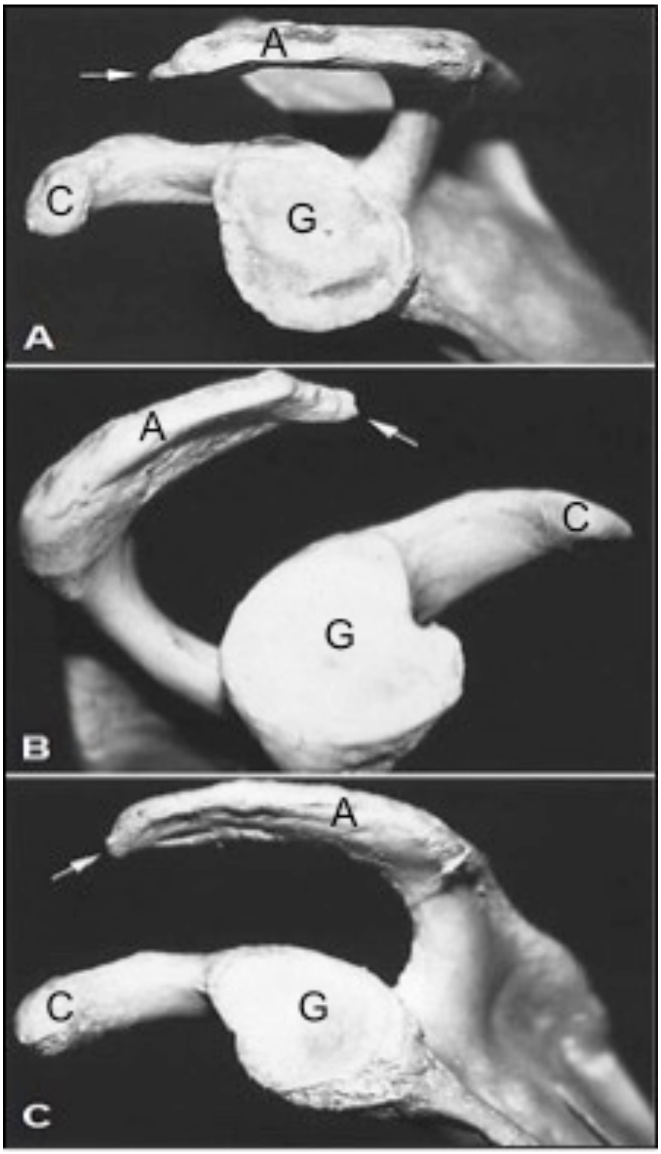


Figure 1.56 Lateral views of the scapula revealing formation of an acromial spur (arrows) according to the morphology of the acromion: flat (A), curved (B), and hooked (C). Acromion (A); coracoid (C); glenoid fossa (G) (Natsis *et al.*, 2007).

1.7.7 The Role of Acromial Spurs in Shoulders with Rotator Cuff Tears

1.7.7.1 Incidence of Cuff Tears in Shoulders with Acromial Spurs

Several studies (Table 1.8) have reported a higher incidence of rotator cuff tears in shoulders with spurs, with the incidence ranging from 43.3% to 86.4% in shoulders with acromial spurs compared to 4.4% to 51% in shoulders without spurs. Gohlke *et al*. (1993) reported acromial spurs in shoulders with rotator cuff tears as follow: 11 had partial tears (20%), 8 had complete tears (15%), 1 had normal intact cuff tendon (2%). Another study identified acromial spurs in 96% of patients with partial tears (Ko *et al*., 2006). Patients with a bursal side partial tear showed more degeneration of the acromion and more prominent acromial spurs than patients with an articular side partial tear. Therefore, direct interaction of rotator cuff tendons with an acromial spur may cause a bursal side partial tear. Furthermore, Hamid *et al*. (2012) found that acromial spurs were significantly associated with full thickness tears, in both symptomatic and asymptomatic shoulders: full thickness tears were present significantly (P = 0.0009) in 78% of shoulders with acromial spurs compared to 51% of shoulders without.

Table 1.8 Incidence of rotator cuff tears in shoulders with acromial spurs.

Study	Sample N	Cuff Tears (%)	Spur (%)	No Spur (%)
Bigliani *et al*. (1986)	140	33 (24)	14 (70)	19 (16)
Tada *et al*. (1990)	74	14 (19)	13 (43.3)	1 (4.4)
Gohlke *et al*. (1993)	54	31 (57.4)	19 (86.4)	12 (38.7)
Hamid *et al*. (2012)	216	123 (57)	38 (78)	85 (51)

1.7.7.2 Severity of Cuff Tear

An association between the severity of rotator cuff tears and the size of acromial spurs has been identified (Ogawa *et al*., 1996; Yoshida and Ogawa, 1996; Ogawa *et al*., 2005; Ko *et al*., 2006; Hamid *et al*., 2012). Both Ozaki *et al*. (1988) and Ogata and Uthoff (1990) showed this association by describing different acromial degenerative changes in shoulders with rotator cuff tears. Regarding the type of rotator cuff tear, shoulders with partial tears showed acromial spurs within the ligament, whereas they were in the subacromial space in all shoulders with complete tears (Ozaki *et al*., 1988; and Ogata and Uthoff, 1990; Gohlke *et al*., 1993). Shoulders with partial articular side tears showed no spurs (Ozaki *et al*., 1988; Gohlke *et al*., 1993). Thus, increasing size of the acromial spur and abrasion of the covering soft tissues are secondary factors leading to mechanical irritation of the rotator cuff. In addition, shoulders with rotator cuff tears have a larger anterior acromial projection than those with an intact rotator cuff. Sakoma *et al*. (2013) suggested that the increased bony coverage (size of the acromion) over the rotator cuff may lead to the development of rotator cuff tears. This was shown previously, in which shoulders with rotator cuff tears presented higher acromial coverage than those with intact rotator cuff tendons (Torrens *et al*., 2007). In contrast, Oh *et al*. (2009) reported no association between spur incidence and the anteroposterior dimension or retraction of rotator cuff tears in MR arthrography and CT radiography. Comparing this to previous studies (Ogawa *et al*., 1996; Yoshida and Ogawa, 1996; Ogawa *et al*., 2005; Ko *et al*., 2006; Hamid *et al*., 2012), Oh *et al*. (2009) consider only the tear size but not the spur size as the previous studies did.

Reformation of Acromion Spurs

Recurrent shoulder impingement and the reformation of an acromial spur after acromioplasty has been reported. Neer (1972 and 1983) advocated subacromial decompression to remove an acromial spur and relieve impingement of the rotator cuff tendons. Since then many surgeons have followed this technique to treat shoulder impingement. However, reformation of an acromial spur has been seen in patients who developed previous shoulder pain (Berg and Ciullo, 1995; Friedman and Morrison, 1995; Anderson and Bowen, 1999). Friedman and Morrison (1995) reported spur reformation in a 63-

year-old patient who underwent subacromial decompression 5 years previously. Both the acromial spur and rotator cuff tear were larger than before (Figure 1.57). In addition, Anderson and Bowen (1999) reported spur reformation in a young volleyball athlete (39 year-old) 2 years after arthroscopic acromioplasty.

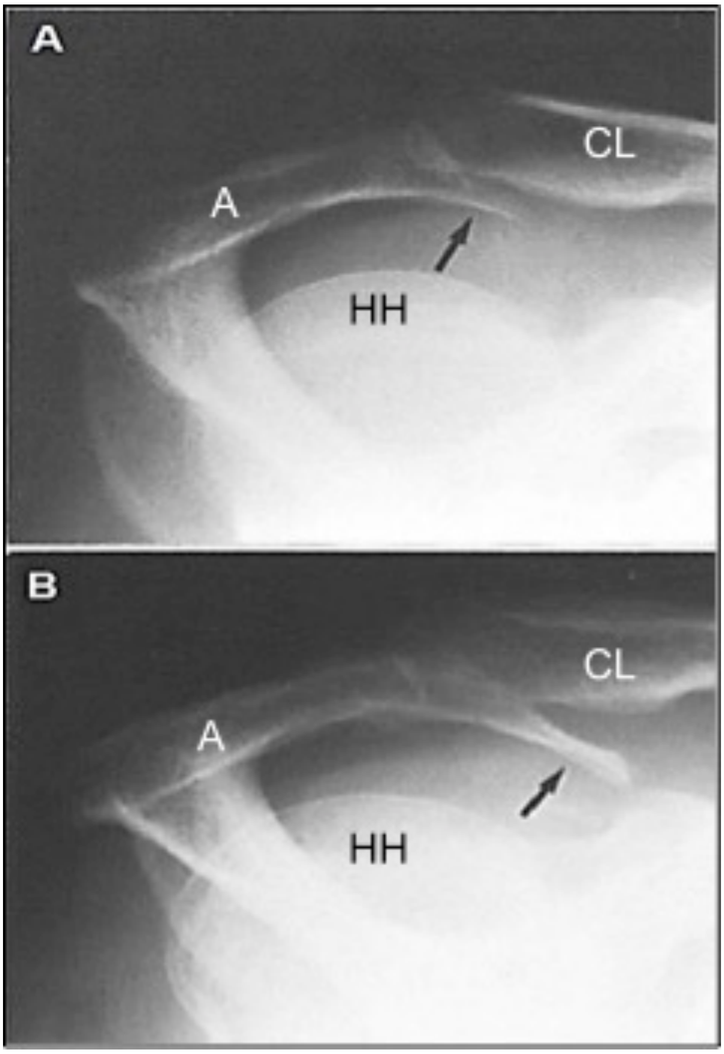


Figure 1.57 Reformation of an acromial spur in a 63 year old patient who underwent subacromial decompression 5 years previously: the superior figure (A) shows the former acromial spur before acromioplasty. The inferior figure (B) shows reformation of the acromial spur after acromioplasty, in which the size of spur and rotator cuff tear are larger than previously: acromion (A); clavicle (CL); humeral head (HH) (Friedman and Morrison, 1995).

In both of the above studies radiographs were taken after the former surgery revealed excellent decompression of the subacromial space of any encroaching bone. Both patients regained full range of motion and good rotator cuff strength during postoperative rehabilitation and a strengthening program that lasted from 3 to 6 months. Friedman and Morrison (1995) doubted that the reformed spur was caused by calcification of the CAL, which was routinely resected during acromioplasty decompression. However, they considered this case a rare condition that did not undergo sufficient radiographic follow-up. In contrast, Anderson and Bowen (1999) cited intrinsic factors, such as shoulder muscle weakness or subtle glenohumeral instability, which led to a reactive change in the acromion. They also suggest that the remaining part of the released CAL contributed to reformation of the acromial spur since it was not completely resected.

However, Berg and Ciullo (1995) suggest that acromial spurs reform as a result of heterotopic ossification. Heterotopic ossification was found in 3.2% of 40 cases, during a retrospective review for recurrent shoulder impingement or acromioclavicular joint pain, after patients had undergone acromioplasty and distal clavicle resection. The heterotopic ossification was significantly disproportionately seen in patients with chronic pulmonary diseases. Shoulder surgery was repeated in 20 patients to relieve the pain; however secondary postoperative heterotopic bone reformed in 4 patients, of which three required a third surgery. It was recommended that patients with hypertrophic pulmonary osteoarthropathy or active spondylitic arthropathy should be treated with prophylaxis to prevent formation of heterotopic ossification after acromioplasty and distal clavicle resection.

1.7.8 Degenerative Changes on the Subacromial Surface

1.7.8.1 Changes in the subacromial surface

In addition to an acromial spur there are several degenerative changes which can develop on the subacromial surface of the acromion, mainly associated with the anterior one third of the surface. These changes include fraying and hypertrophy of the CAL, erosion and eburnation of the subacromial surface, and formation of a subacromial facet: a depressed oval sign of impingement of the head of the humerus against the acromion undersurface (Neer, 1972; Ozaki *et al*., 1988; Edelson and Taitz, 1992; Prescher, 2000; Paraskevas *et al*., 2008). In the severe stage of impingement, Neer (1972) observed eburnation with erosion on the subacromial surface (Figure 1.58). Ozaki *et al*. (1988) demonstrated a regular trabecular pattern without any signs of sclerosis, hypertrophic or cystic changes, except spurs or osteophytes in shoulders with a normal rotator cuff (Figure 1.59: A), while they reported irregular patterns of trabeculae with sclerosis, hypertrophic or cystic changes in the anterior third of the acromion in shoulders with full-thickness tears (Figure 1.59: B). Edelson and Taitz (1992) observed that acromial degenerative changes involved two signs: a traction spur and a rough articular facet on the acromion undersurface (Figure 1.60). Prescher (2000) also reported a grinding facet (Figure 1.61: A) at the inferior surface of the acromion as a result of grinding against the greater tubercle (Figure 1.61: B). In addition, Paraskevas *et al*. (2008) reported degenerative changes on the undersurface of the acromion in relation to a hooked acromion.

Figure 1.58 Degenerative changes on the anterior third of the inferior surface of the acromion: large acromial spur accompanied with excrescences are present in the left figure, whereas erosion and eburnation of the surfaces are present on the right figure (Neer, 1972).

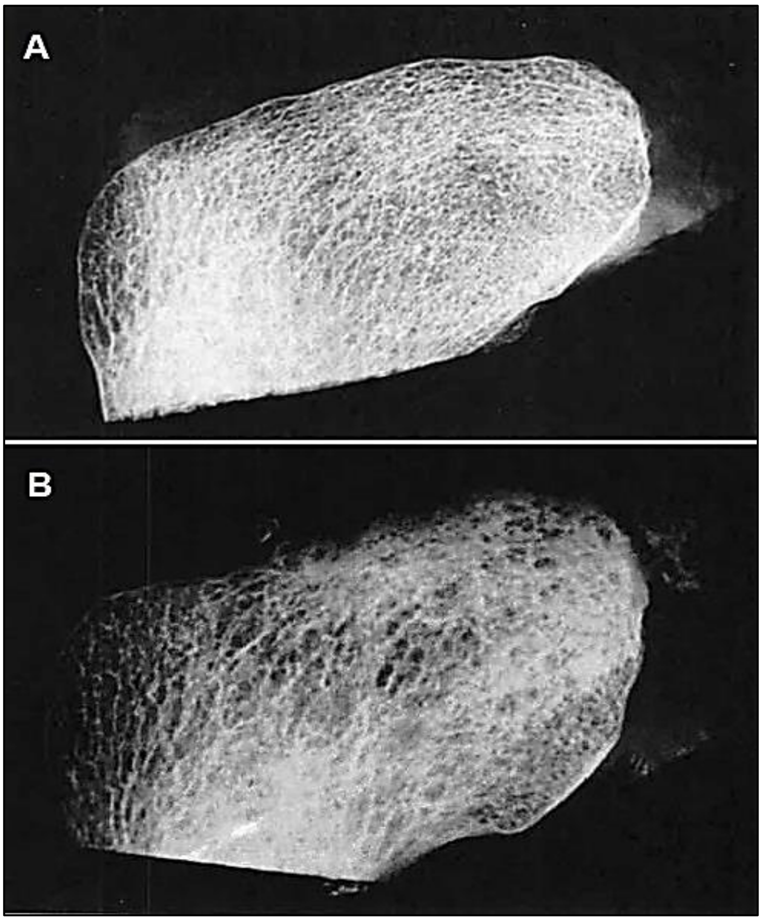


Figure 1.59 Radiographs of the acromion process showing the bone trabecular pattern: shoulders with normal rotator cuff tendons show regular trabecular patterns of the acromion (A), whereas an irregular trabecular pattern is present in shoulders with rotator cuff tears (B) (Ozaki *et al*., 1988).

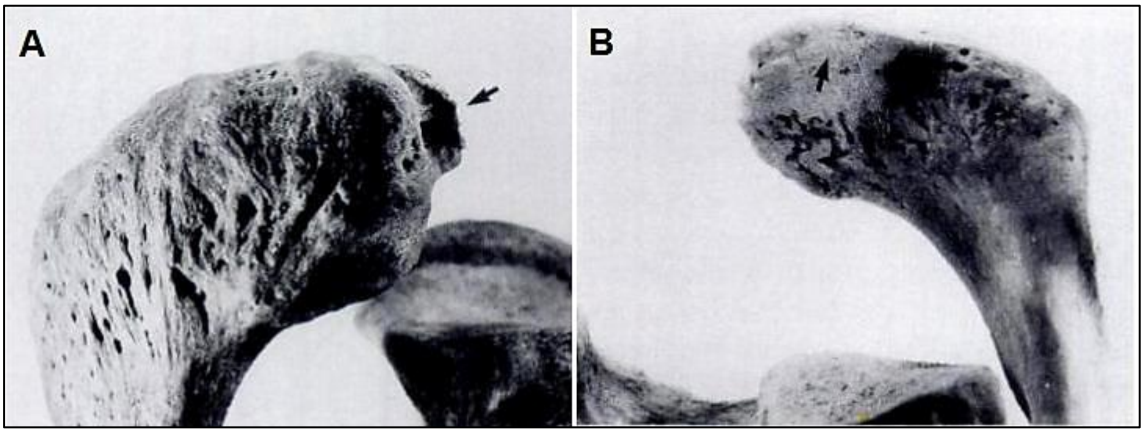


Figure 1.60 Formation of a traction acromial spur (A) and subacromial facet (B) in elderly shoulders (Edelson and Taitz, 1992).

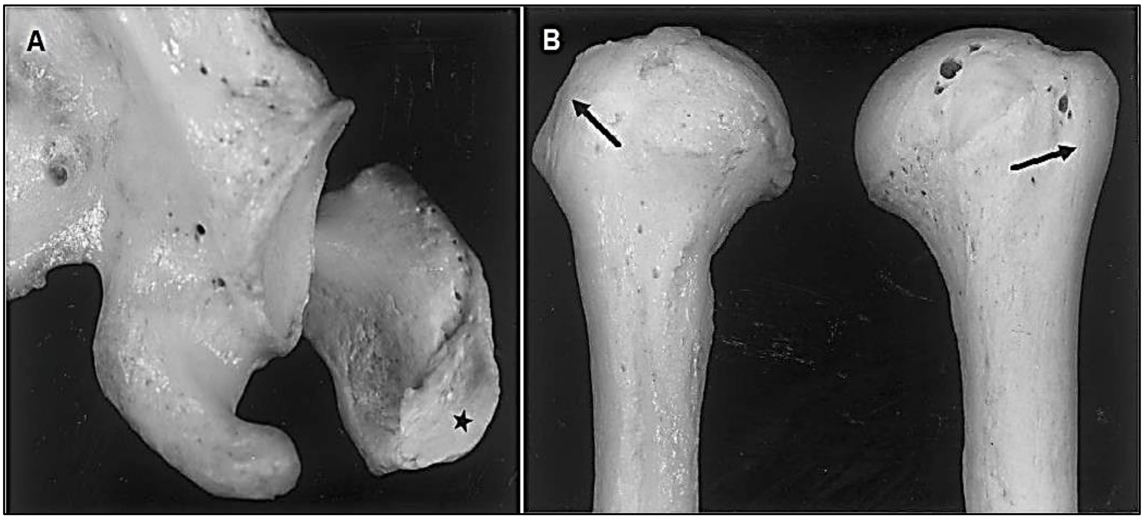


Figure 1.61 Formation of a subacromial or articular facet on the inferior surface of the acromion (A) as a result of grinding against the greater tubercle, which in turn results in near complete attrition of the greater tubercle (B) (Prescher, 2000).

1.7.9 Degeneration of the Acromioclavicular Joint

Degenerative changes seen in shoulders with subacromial impingement syndrome include osteoarthritis and osteophyte formation. Osteoarthritis or degeneration of the acromial articular facet of the acromioclavicular joint in previous studies (Table 1.9) ranged from 6.7% to 95%, with a calculated average incidence of 38%. The incidence of osteophytes or inferior spurs at the lower ridge of the acromioclavicular joint in previous studies ranged from 11% to 58%, with a calculated average of 31.6%. Degenerative changes in the acromial facet were generally greater than the incidence of osteophytes (Hardy *et al.*, 1986; Gohlke *et al.*, 1993; Nicholson *et al.*, 1996), except in one study (Figures 1.62 and 1.63) (Edelson and Taitz, 1992).

Table 1.9. Incidence of osteophytes and degenerative changes of the acromioclavicular joint in previous studies.

Studies	N	Age	ACJ Osteophytes	Degenerative Changes
Cone *et al.* (1984)	103	52		28 (27.2%)
Nasca *et al.* (1984)	60	*		4 (6.7%)
Hardy *et al.* (1986)	36	56 (22-81)	12 (32%)	25 (66%)
Postachani (1989)	18	44 (21-67)	2 (11%)	
Tada *et al.* (1990)	69	76.8 (44-93)	20 (29%)	
Edelson and Taitz (1992)	200	30-70	116 (58%)	76 (38%)
Gohlke *et al.* (1993)	57	75(47-90)	12 (21.1%)	54 (95%)
Farley *et al.* (1994)	45	*	18 (40%)	
Getz *et al.* (1996)	394	20-89	164 (41.6%)	
Nicholson *et al.* (1996)	396	21-70	43 (11%)	128 (32.3%)
Cuomo *et al.* (1998)	123	65.6 (25-95)	13 (17.1%)	
Mahakkanukrauh and Surin (2003)	692	15-100	242 (35%)	
Vassalou *et al.* (2012)	284	18-89		117 (41.2 %)
Total			642 (31.6%)	428 (38%)

- Age: no data found (*)

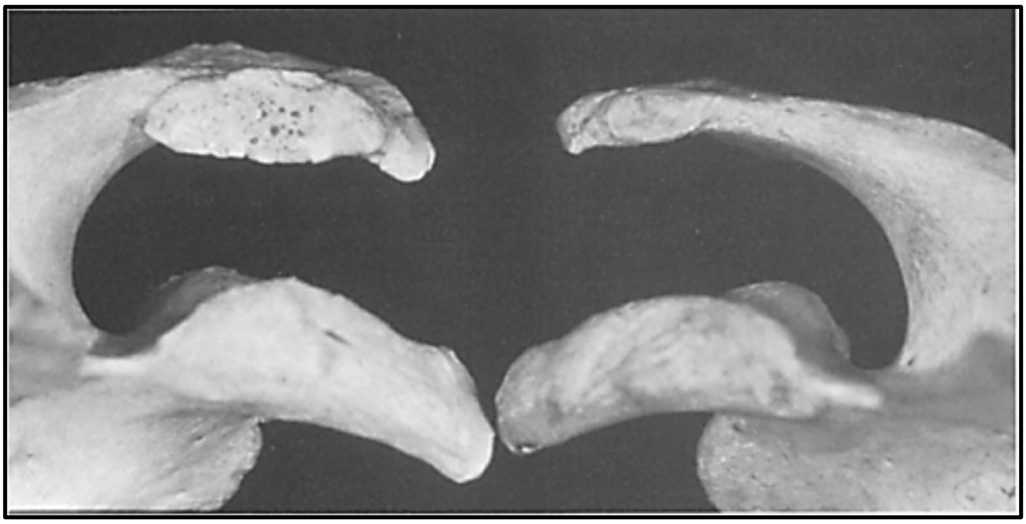


Figure 1.62 Degenerative changes in the acromial facet of the acromioclavicular joint: degeneration of the acromial facet is present in the left scapula compared to the right scapula which shows a normal acromion (Nicholson *et al.*, 1996).

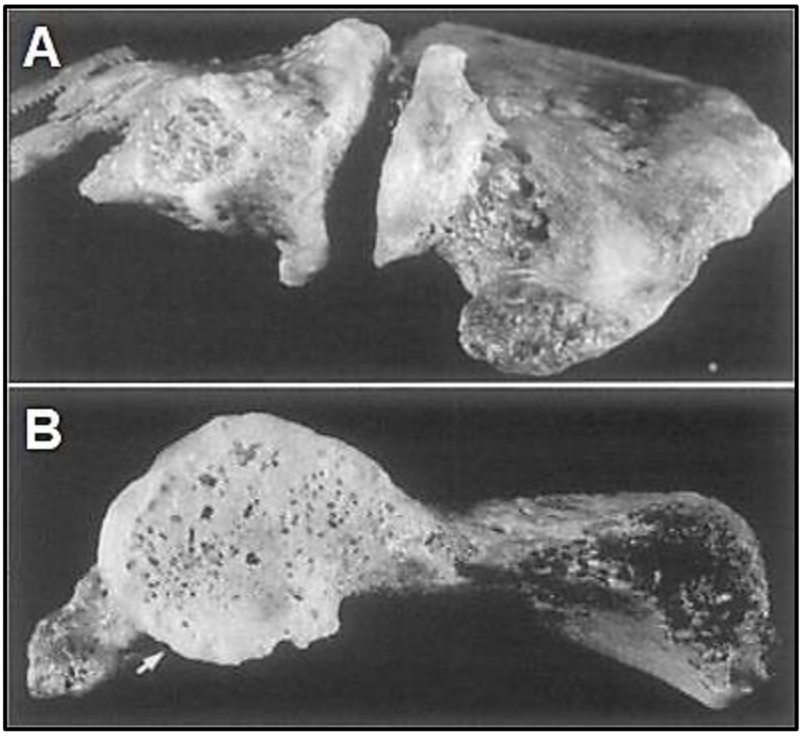


Figure 1.63 Formation of osteophytes at the acromioclavicular joint: the superior figure (A) shows formation of osteophytes on both articular facets of the acromioclavicular joint. Note eburnation of the acromial facet and the size of osteophyte (arrow) in the inferior figure (B) (Cuomo *et al*., 1988).

Shoulders showing acromial spurs have a greater incidence of degenerative changes and osteophyte formation at the acromioclavicular joint (Cone *et al*., 1984; Tada *et al*., 1990; Mahakkanukrauh and Surin, 2003). However, there is no relationship between acromion morphology and osteophyte formation at the lower edge of the acromial facet of the acromioclavicular joint (Getz *et al*., 1996; Pearsall *et al*., 2003). A significant relation between degenerative changes seen in the acromioclavicular joint and both age and rotator cuff tears has been reported (Graves, 1922; Hardy *et al*., 1986; Postacchini, 1989; Gohlke *et al*., 1993; Farley *et al*., 1994; Nicholson *et al*., 1996; Vassalou *et al*., 2012).

1.8 Release of the CAL in Subacromial Decompression to Relieve the Impingement

In 1972 Neer developed open anterior acromioplasty to decompress the subacromial space and relieve impingement on the rotator cuff. It involves rotator cuff repair and resection of each of the anterior edge of the acromion, the undersurface of the anterior aspect of the acromion, any bony abnormality and the coracoacromial ligament. Resection of the CAL is supported by some authors (Ellman and Kay, 1991; Gartsman, 1990), especially if there are no bony abnormalities (Uhthoff *et al*., 1988; Watson, 1985). About 80% to 90% of patients who underwent subacromial decompression showed successful results (Ellman and Kay, 1991; Uhthoff *et al*., 1988). In contrast, other authors prefer preserving the coracoacromial ligament to prevent superior migration of the humeral head (Wiley, 1991; Pollock *et al*., 1992; Levy and Copeland, 2001).

1.8.1 Release of the CAL

Excision of the CAL has been considered as a part of successful subacromial decompression (Neer, 1972; Ellman and Kay, 1991; Okutsu *et al*. 1992; Burns and Whipple, 1993; Delforge *et al*., 2014). Complete or partial resection of the CAL can relieve the symptoms of impingement. Thus, the CAL has a key role in the etiology of impingement syndrome (Watson, 1985). Brandner *et al*. (1989) preferred resection of the CAL for decompression of the subacromial space. They found that the pain decreased in 40% of cases undergoing this surgery, mobility improved in 48% of cases and 67% would agree to the operation again. On the other hand, some authors recommend resection of the CAL only in athletes or young patients to enable them to regain full sporting activity, or in patients who have no acromial spurs and failed conservative treatment

(Jackson, 1976; Hawkins and Kennedy, 1980; Ha’eri and Wiley, 1982; Johansson and Barrington, 1984; Uhthoff *et al*., 1988). Paulos and Franklin (1990) performed arthroscopic resection of the CAL in patients 30 years or younger, with stage I or II impingement and absence of an acromial hook. Their results showed a better improvement in pain at night and impingement sign than those who had arthroscopic acromioplasty. They emphasized that the CAL may play a major role in the etiology of impingement syndrome. However, release of the CAL often leads to complications (Tibone *et al*., 1985; Ellman and Kay, 1991; Lee *et al*., 2001; Hockman *et al*., 2004; Chen *et al*., 2009; Su *et al*., 2009).

1.8.2 Complications of CAL Release

Although releasing the CAL has gained wide acceptance to relieve impingement pain, it is criticised for complications or poor results. The relation between the CAL and deltoid was noted after reports that some detachment of the anterior fibers of deltoid occurred during arthroscopic acromioplasty (Zuckerman *et al*., 1992). Resection of the CAL from the anterior aspect of the acromion is readily achieved since the relationship with the overlying deltoid is not variable. However, the lateral acromial attachment of the CAL is adherent to the undersurface of the deltoid fascia, and cannot be cleanly resected without release of the deltoid attachment (Groh *et al*., 1994; Edelson and Luchs, 1995). Kummer *et al*. (1996) noted that only 25% of the middle deltoid arises from the acromion. Detaching some of the anterior deltoid from the acromion does not appear to have a detrimental effect on the clinical outcome after arthroscopic acromioplasty, however the shoulder is probably weakened in flexion (Ellman and Kay, 1991). Furthermore, resection of the anterior medial part of the CAL from the undersurface of the acromioclavicular joint may cause bleeding (Edelson and Luchs, 1995). Previous studies have also reported a significant increase in anterosuperior glenohumeral translation after CAL release (Lee *et al*., 2001; Hockman *et al*., 2004; Chen *et al*., 2009; Su *et al*., 2009).

1.8.3 Reattachment of the CAL

Reattachment of the CAL after anterior acromioplasty was invented to regain ligament function and avoid shoulder dislocation. A satisfactory outcome has been reported when the CAL is reattached in patients undergoing subacromial decompression. No complaints of anterosuperior humeral head subluxation have been reported (Flatow *et al*., 1994). Fagelman *et al*. (2007) also reported a significant decrease in anterosuperior humeral translation after reattached of the CAL. Reattachment of the medial band to its anatomical attachment site was possible, however the lateral band needed to shift its insertion medially to complete the reattachment.

In a cadaveric study, Shaffer *et al*. (1997) investigated the possibility of release and reattachment of the CAL. In this study two ways of CAL release were compared: anterior acromion and subperiosteal elevation from the subacromial undersurface. The CAL could not be reattached anatomically, to the anterior acromion, when released along the anterior acromion after acromioplasty in any cases. However, medial reattachment (non-anatomic reattachment), to reestablish continuity with the anterior acromion, was undertaken in 79% of specimens (Figure 1.64). On the other hand, the CAL was reattachable in 100% of specimens after subperiosteal release. The anatomic reattachment was successful in 93% of specimens and in non-anatomic reattachment (medialization) in 7% of specimens. Shaffer *et al*. (1997) therefore recommend subperiosteal elevation to preserve and reattach the CAL, even when there is an anterior acromial spur present within the ligament.

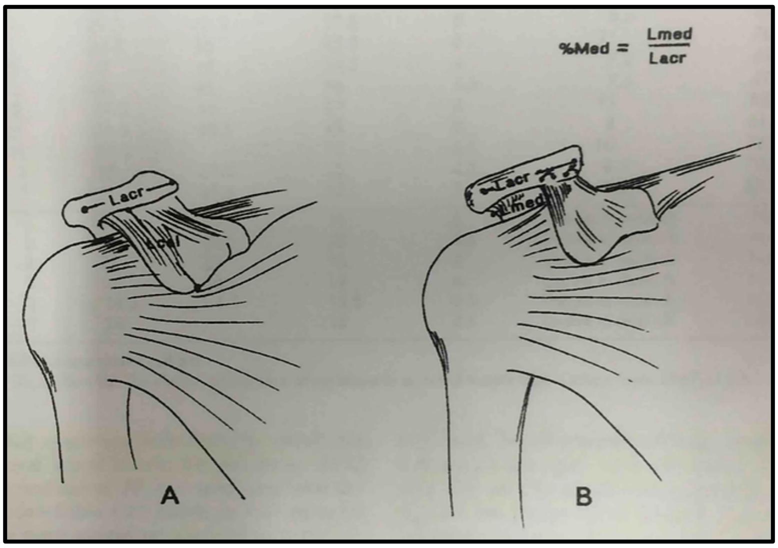


Figure 1.64 Release and reattachment of the CAL: When the CAL cannot be reattached anatomically after release from the anterior acromion after acromioplasty, the reattachment is moved medially (non-anatomic reattachment) to reestablish continuity with the anterior acromion. This was allowed in 79% of specimens. (A) Showing the in-situ measurement of the anterolateral band of the CAL (Lcal) and length of its acromial attachment (Lacr). (B) Showing the medial reattachment (Lmed) of the anterolateral band into the medial side of the anterior edge of the acromion (Shaffer *et al*., 1997).

Shaffer *et al*. (1997) emphasised that anterior acromial release of the CAL resulted in difficulty in reattachment. They assumed this difficulty may be associated with shoulders with more prominent anterior acromial edges or spurs, even when attempted with medialization of the reattachment. Shoulders with prominent edges or spurs have shorter CALs (Zuckerman *et al*., 1992), so anterior acromion release and resection may leave too large a gap that could not be bridged with the remaining CAL. However, this study did not examine whether the normal site for restoration of the CAL attachment restored the normal biomechanics of the coracoacromial arch: it claimed that the medial site attachment of the CAL provided less coverage to prevent anterosuperior humeral displacement (Shaffer *et al.*, 1997).

1.8.4 Regeneration of the CAL after Release

Regeneration or regrowth of the coracoacromial ligament has been reported and claimed to cause recurrent impingement syndrome. Previous studies observed regeneration of the CAL after it had been released during subacromial decompression (Bak *et al*., 2000; Levy and Copeland, 2001; Hansen *et al*., 2004). They found that the CAL has the ability to repair or reform and regain normal strength and elasticity. The new regenerated or reattached ligament is be a factor in recurrent impingement on the rotator cuff tendons or narrowing of the subacromial space. However, the new ligament needs more than 3 years to regain full strength to be able to oppose migration of the humeral head (Shaffer *et al*., 1997).

In one study, the CAL was reviewed in 4% (18 of 418) of shoulders which underwent subacromial decompression because of persistent or relapsing impingement symptoms (Bak *et al*., 2000). The revision took place at a median 21 months (range 4-97 months) after the primary surgery. The CAL was released in 12 shoulders and resected completely in 6 shoulders: it reformed or was reattached in all reviewed shoulders. Histological examination of the reformed CAL showed a predominance of large-diameter collagen fibrils (>100 μm) resembling those of a normal ligament, and small-diameter fibrils indicating a repair process (Figure 1.65). Bak *et al*. (2000) assumed that the reformed or reattached CAL was an extrinsic factor that may cause recurrent impingement or rotator cuff tear, or may be responsible for a reformed acromial spur. Thus, unknown or unexplained causes for recurrent impingement symptoms in previous studies (Hawkins *et al*., 1989; Ogilvie-Harris *et al*., 1990; Stephens *et al*., 1998), may be associated with a reformed or reattached CAL (Bak *et al*, 2000:43).

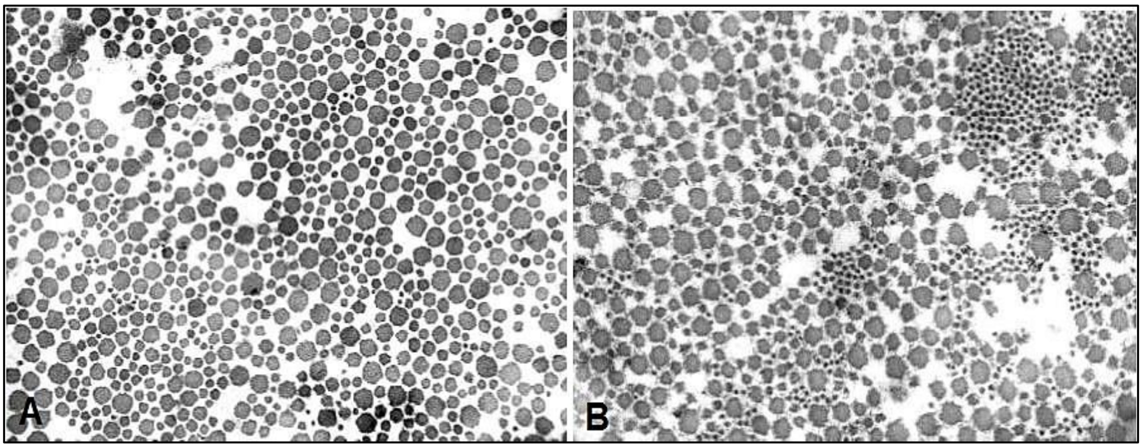


Figure 1.65 Electron micrographs of the CAL: A control primary resected CAL (A) shows large diameter (>100 μm), intermediated-size fibrils, and very few small-diameter fibrils (X35,400). A regenerated CAL (B) shows predominant fibrils of large size diameter (>100 μm) with groups of intermediate-sized and small-diameter fibrils (X 35,400) (Bak *et al*., 2000).

Levy and Copeland (2001) reviewed 10 patients with failed shoulder symptomatic relief after 4 months following acromioplasty and arthroscopic subacromial decompression. They found, in all patients, a regenerated CAL at its acromial attachment after surgical resection. Histologically, the new ligament showed a well-organized architecture consisting of parallel bundles of collagen fibers indistinguishable from a normal ligament (Figure 1.66). They attributed regeneration of the CAL to local stresses, which aligned in the direction of the collagen fibers. CAL regrowth is an argument for resection rather than simple sectioning, to prevent recurrence of impingement, as demonstrated by Levy *et al*. (2001).

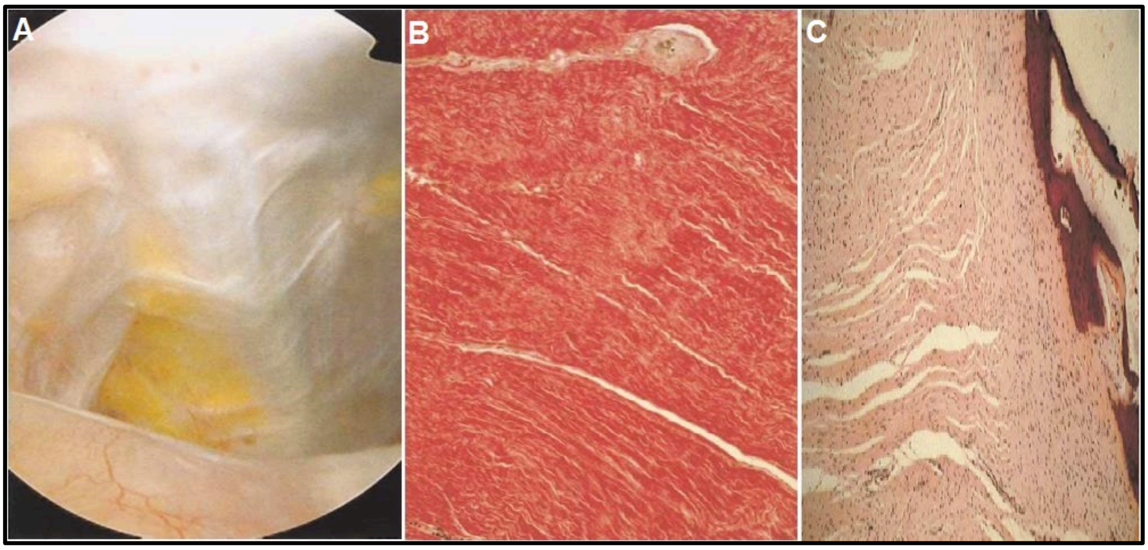


Figure 1.66 Regeneration of the CAL after acromioplasty and arthroscopic subacromial decompression: Arthroscopic view of a regenerated CAL (A) has a shiny appearance identical to that of a normal primary one. The histological appearance of the regenerated ligament, (B) (with Van Gieson stain) and (C) (with hematoxylin-eosin), show well-organized parallel bundles of collagen fibers with no scar or disorganized fibrous tissue (Levy and Copeland, 2001).

Finally, the mechanical properties of a regenerated CAL after subacromial decompression has been evaluated by Hansen *et al*. (2004) in eight patients during revision surgery. They compared the properties to those of seven CALs excised during a series of primary open acromioplasty procedures. They found that the primary CAL had better mechanical properties (failure load, failure stress, and ligamentous modulus) than the regenerated CAL. Moreover, the macroscopic appearance of the primary CAL had a shiny white appearance with clear fiber direction, but the regenerated CAL appeared a red or pinkish color and had a less fibrous texture (Figure 1.67). They summarized that the CAL does have the ability to regenerate quickly after acromioplasty; however, it needs nearly three years to regain its normal strength and elasticity (Hansen *et al*. 2004).

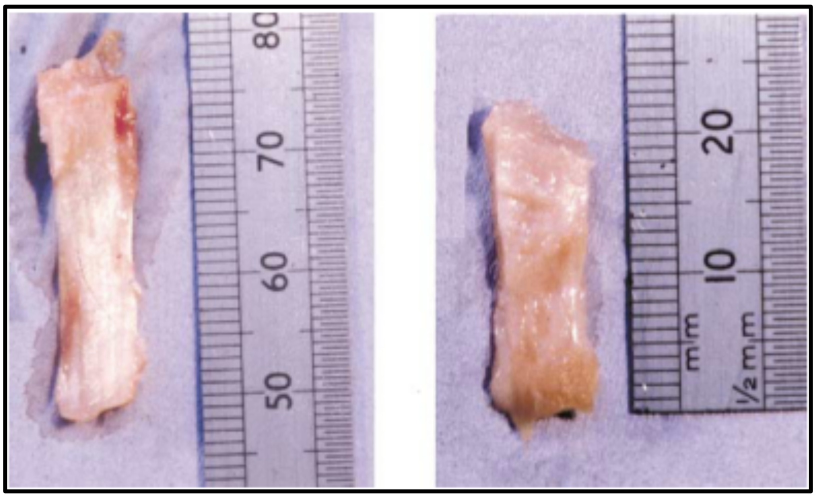


Figure 1.67 Macroscopic appearance of the primary resected CAL (A) and regenerated CAL (B): The primary control CAL has a shiny white appearance with clear fiber direction, whereas the regenerated CAL presents a red or pinkish color and a less fibrous texture (Hansen *et al*., 2004).

1.8.5 New Surgical Techniques to Release or Preserve the CAL

Various surgical techniques have been developed to improve the outcome of subacromial decompression. These techniques were developed either to ensure complete resection or preservation of the CAL. Both Okutsu *et al*. (1992) and Delforge *et al*. (2014) improved the technique to ensure complete release of the CAL without damaging the surrounding structures. They argued that complete resection of the CAL decompresses the subacromial space and impingement of the rotaror cuff. In contrast, other authors (Hunt *et al*. 2000; Torrens *et al*. 2003; Arrigoni *et al*., 2010) have developed new surgical techniques to ensure decompression of the subacromial space and preservation of the CAL. They argued that the CAL works as a final guard that prevents superior humeral dislocation.

Okutsu *et al*. (1992) inspected the release of the CAL in 37 patients (40 shoulders) using the universal subcutaneous endoscope system (USE). In comparison to previous endoscopic operative release described by Ellman

(1987), they developed the surgery under local anesthesia without the need for liquid irrigation or traction of the affected limb. The endoscope and surgical instruments were inserted through the anterior deltoid portal, located between the clavicular (anterior) fibers and acromial (central) fibers of deltoid 3 cm lateral and 5 cm distal to the coracoid process. It is a safe place to insert the instruments without injuring important structures adjacent to the operative site. A popping phenomenon was observed between the CAL and the greater tubercle of the humerus in all affected shoulders: this phenomenon disappeared or decreased after resection of the CAL.

Follow-up results showed that shoulder pain decreased within a week and disappeared within several months of the operation, CAL tenderness also disappeared, while the range of motion of the affected shoulders was significantly improved compared to preoperatively. There were no complications during surgery and there were no hematomas in the subacromial space following surgery: patients could use their upper limbs without any problems. They concluded that using this surgical procedure was useful for the diagnosis of stage-II or stage-III shoulder impingement syndrome, and that CAL resection may relieve the impingement of stage II or stage III.

Delforge *et al*. (2014) evaluated, using ultrasound as a guide, complete resection of the CAL without trauma to the surrounding structures. The study involved 20 cadaveric shoulders after ultrasound location of shoulder structures, with resection performed through a skin incision at the level of the deltopectoral sulcus. A secondary surgical revision found that the CAL was completely resected in 17 (85%) shoulders without rotator cuff or cartilaginous lesions.

However, there were two cases of arterial lesion to the acromial branch of the thoracoacromial artery. Delforge *et al*. (2014) considered that the incomplete resection of the CAL in the remaining three shoulders was due to anatomical variation of the CAL. They concluded that ultrasound was a complement rather than an alternative to surgery.

In contrast, Levy and Copeland (2001) recommend saving the CAL in the subacromial decompression procedure since it is the last restraint preventing superior migration of the humeral head. The importance of preserving the CAL has also been advocated by Wiley (1991) after reporting four rotator cuff deficient patients complaining of superior shoulder instability following subacromial decompression. In addition, Pollock *et al*. (1992) stressed the need to preserve the CAL in cuff deficient patients undergoing shoulder arthroplasty. Bigliani *et al*. (1995 cited in Shaffer *et al*., 1997) tried to avoid the potential complications following CAL release in subacromial decompression through partial and complete resection of the anterolateral band of the CAL: they reported a successful outcome. However, Shaffer *et al*. (1997) found that selective release of the anterolateral band of the CAL was rarely possible because few specimens demonstrated discrete medial and lateral bands at the acromion insertion.

Hunt *et al*. (2000) performed arthroscopic anterior acromioplasty on 10 fresh cadaveric shoulders. They burred away the inferior and anterior acromion by a posterior burr portal technique until adequate decompression was achieved. They found that the subacromial fibers of the CAL were completely divided, whereas the anterior acromial fibers of the CAL and deltoid, the medial fibers of the CAL inserting into the inferior surface of the acromioclavicular joint capsule, and the lateral fibers of the CAL blending with the deltoid fascia remained intact in all cases. Furthermore, they assumed that the medial fibers of the CAL inserting to the inferior surface of the acromioclavicular joint capsule could be damaged by arthroscopic resection of the medial end of the clavicle to treat symptomatic acromioclavicular joint osteoarthritis.

Torrens *et al*. (2003) described a modified surgical technique of open anterior acromioplasty performed through an intra-acromial osteotomy that increased the subacromial space and preserved the insertion of the CAL on the undersurface of the acromion. They compared the new technique with classical acromioplasty in 20 patients (mean age 55.85 years) undergoing open anterior acromioplasty and 22 patients (mean age 63.8 years) undergoing a modified open anterior acromioplasty. In the modified technique, the anterior part of the acromion that extended beyond the anterior border of the clavicle and the most anterior part of the CAL inserting in this acromion portion were vertically excised. Then, a subtraction intra-acromial osteotomy was carried out through a divided cross section of the acromion into three equal parts: upper, middle and lower. The middle part is removed through two osteotomy cuts and closed with non-absorbable sutures passed through pre-drilled acromial holes (Figure 1.68).

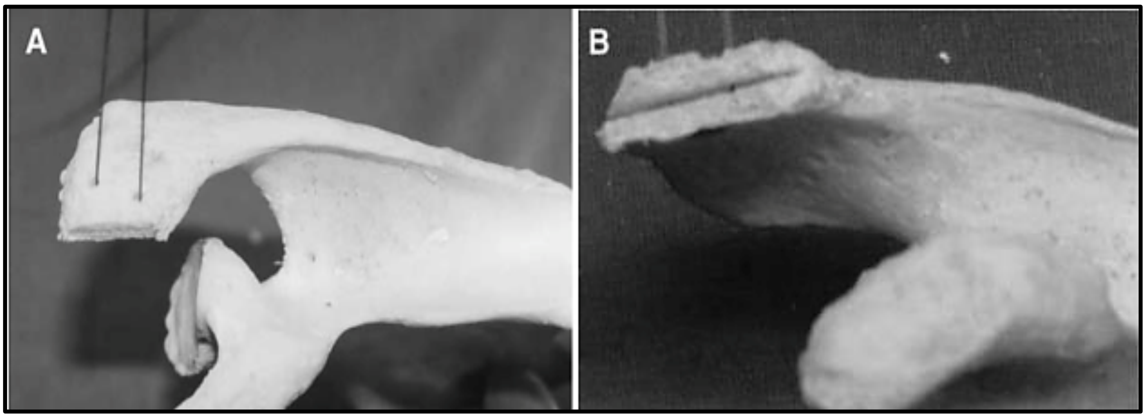


Figure 1.68 Preservation of the CAL in open anterior acromioplasty: A subtraction intra-acromial osteotomy was carried out dividing the cross section of the acromion into three equal parts: upper, middle and lower. The middle part is removed through two osteotomy cuts and closed with non-absorbable sutures passed through pre-drilled acromial holes (Torrens *et al*., 2003).

This technique saved the posterior two thirds of the CAL as well as the undersurface of the middle and posterior acromion, and increased the subacromial space. Follow-up at a mean of 18 months showed that the mean constant score was improved in both groups from 46.69 to 74 in the first group, and from 53.3 to 80 in the second group. Therefore, they found no difference in shoulder function between the two groups. Torrens *et al*. (2003) found that the new modified technique increased the subacromial space, preserved the anatomy of the subacromial arch and provided functional results as good as those obtained with classical open acromioplasty.

Recently, a new technique of subacromial decompression has been devised by Arrigoni *et al*. (2010) to preserve the CAL. The study involved four patients with rotator cuff tears and a hook shaped acromion. The inferior fibers of the CAL were reattached after acromioplasty and reduced the profile of the acromion from a hooked shape to a straight shape (Figure 1.69). Follow-up results revealed a recovery of full range of motion and good strength in all patients.

However, the biomechanical and clinical effects of the resutured ligament was not examined.

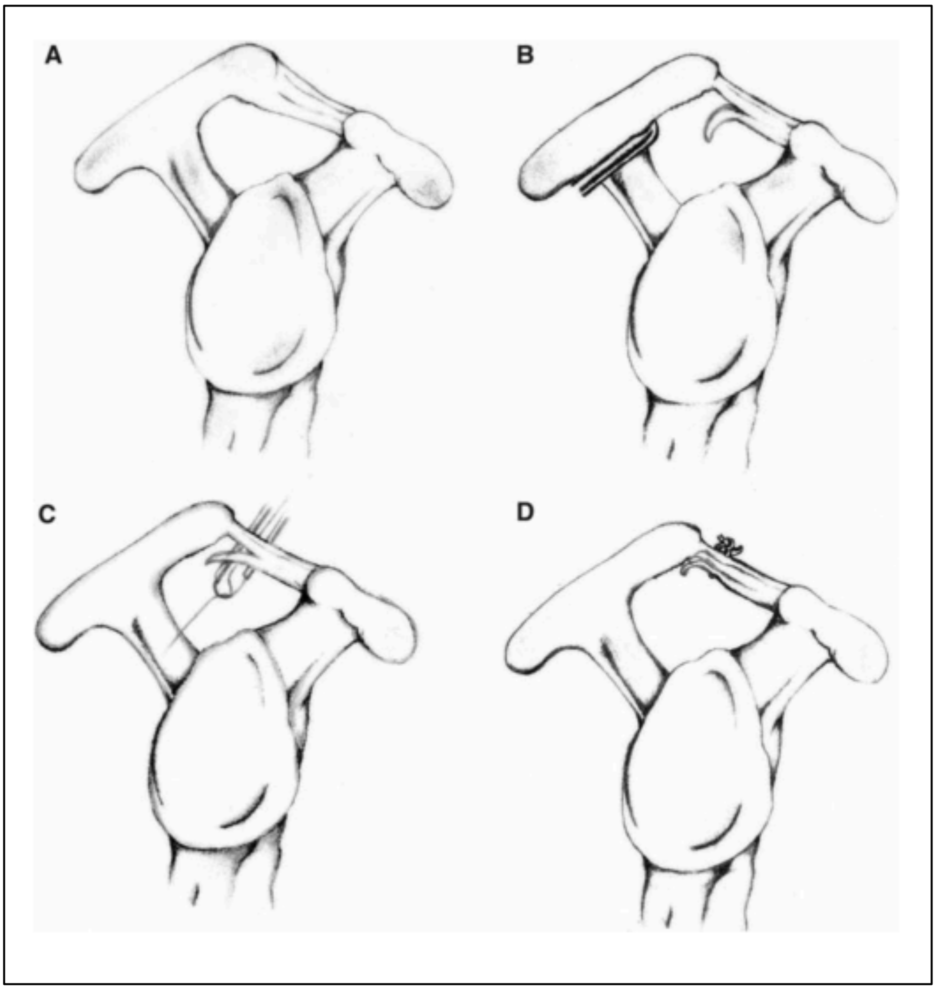


Figure 1.69 The CARE technique to preserve the CAL during arthroscopic acromioplasty: Detachment of the most inferior fibers of the CAL at the subacromial insertion (B) to reduce the profile of the acromion from hooked shape to a straight shape. Then needles and absorbable sutures reattach the inferior fibers of the CAL (C and D) (Arrigoni *et al.*, 2010).

1.9 Summary

In summary, the literature review highlighted the anatomical variations of the CAL, its biomechanical role as well as the degenerative changes of the CAL in shoulders with subacromial impingement syndrome and rotator cuff tears. However, there is gap in the literature concerning the association between these variations and the rotator cuff tears and how the anatomy of the ligament changes regarding these variations from that given in the anatomy atlases and text books.

1.10 Thesis Aim and Objectives

The aim of this study was

- First: to evaluate the anatomical variations of the CAL in a population of formalin embalmed cadavers.
- Second: in relation to the anatomical variations of the CAL, investigate the following:
    1. The attachment sites of the CAL
    2. The incidence of rotator cuff tears.
    3. The incidence of bony spurs.
    4. The size of the subacromial insertion of the CAL.
    5. Attrition lesions at the undersurface of acromion
    6. The size and morphology of acromial spurs.
    7. The morphology of the acromion

A knowledge and understanding of these variations and degenerative changes will help in:

- Predicting the occurrence of rotator cuff tears
- Improving diagnosis and treatment of shoulder impingement syndrome.
- Proper resection or reattachment of the ligament.
- Understanding of shoulder biomechanics.
- Preventing misinterpretation of any abnormalities.

2 Material and Methods

2.1 Dissection and Specimen Preparation

A total of 234 shoulders from 117 formalin embalmed European Caucasian cadavers (donated to the Centre for Anatomy and Human Identification (CAHID) at the University of Dundee under the Human Tissue (Scotland Act 2006) were dissected. The shoulders examined did not show any bony marks caused by previous trauma, traumatic lesions to the CAL or rotator cuff, or have an orthoprosthesis. Fourteen shoulders were excluded due to damage to the CAL. In addition, 63 shoulders showed damage to the rotator cuff tendon or had an orthoprosthesis. Consequently, 220 shoulders, 206 bilateral and 14 unilateral (5 right shoulders and 9 left shoulders), with undamaged CAL, and 155 shoulders with intact rotator cuff tendons were included in the study. The median age at death was 82 years (range 53 to 102 years): there were 110 male and 110 female shoulders.

Shoulders were dissected through an anterosuperior incision to remove the skin. Deltoid was completely detached from its proximal attachment to the clavicle and scapula and its distal attachment to the shaft of the humerus. The clavicle was also detached at the acromioclavicular joint, which included sectioning of the coracoclavicular ligaments to gain a better view of the acromial attachment of the CAL and coracoacromial arch. Blunt dissection was then used to remove the subacromial bursa to clarify the CAL and rotator cuff tendons. Ethanol was added to remove any fatty remnants from the surfaces of the CAL and rotator cuff tendons. This will help in inspecting the morphology of the CAL and identifying the band number. When present a diaphanous membrane between the CAL bands was also dissected. A high beam light was used in some cases to identify the morphology and band number of the CAL.

Categorizing specimens in this study into a young and an old population was not possible, since the youngest age was 53 years; therefore the age of specimens was classified based on decades. Thus, specimens were classified into 60th (17 scapulae) or less, 70th (68 scapulae), 80th (84 scapulae), and 90th or more (51 scapulae) groups. This study investigated the association between age and the morphology of the CAL, rotator cuff tears and acromial spurs. These factors were also evaluated in relation to sex and side, i.e. male and female incidence, right and left sides, and bilateral and unilateral incidence.

2.2 First Stage

The first stage of this study investigated the anatomical variation of the CAL in relation to rotator cuff tears and acromial spur formation. These variations involve the morphology and attachments of the ligament. Moreover, parameters of the CAL were assessed for any significant changes in relation to rotator cuff tears or the formation of acromial spurs. Identifying these relationships may help to understand the role of the CAL in subacromial impingement syndrome. In turn, this may assist surgeons in deciding whether to resect or save the CAL. In addition, identifying the CAL attachment sites may help in the proper resection of the CAL to avoid damage to the surrounding structures or regeneration of the CAL (Zuckerman *et al*., 1992; Groh *et al*., 1994; Edelson and Luchs, 1995; Bak *et al*., 2000; Levy and Copeland, 2001; Hansen *et al*., 2004).

The first stage involved two investigations: gross inspection and parametric assessment. Gross inspection enabled the morphological classification of the CAL and rotator cuff tears based on previous studies. Moreover, it checked the CAL attachment sites and for the formation of acromial spurs at the anterior edge and inferior surface of the acromion. Parametric assessment evaluated changes in CAL parameters according to the incidence of rotator cuff tears and acromial spurs. In addition, parametric assessment evaluated the CAL parameters according to each morphological type of the CAL, sex, side and age.

2.2.1 Gross Inspection

2.2.1.1 Morphological Classification of the CAL

In gross inspection, the CAL was carefully examined in 220 scapulae from above and categorized as described by Kesmezacar *et al*. (2008). Morphologically, the CAL was categorized into five types: broad-band (B), quadrangular band (Q), Y-shaped ligament (Y), V-shaped ligament (V) and multiple-banded ligament (M). With regard to the number of the bands the CAL was also classified into one band, two bands and three bands or more forms. The relation between the morphology of the CAL and each of rotator cuff tears and acromial spurs was inspected. In addition, this study investigated the division of the CAL into two or multiple bands to identify the etiology of variation in the shape of the CAL.

2.2.1.2 Attachment of the CAL

The attachment of the CAL was inspected in 220 scapulae at both the acromial and coracoid sites. First, at the acromial side the CAL attachment was examined to determine whether it involved the medial aspect of the acromion or not. If the attachment exceeded the anteromedial corner of the acromion, the CAL was considered to have a medial attachment. If the attachment was restricted to the anterior edge of the acromion, it was considered to have an anterior or lateral attachment (Figure 2.1). In addition, shoulders with a medial acromial attachment were also examined to determine if the CAL was involved in the acromioclavicular joint. Therefore, the acromial attachment of the CAL was classified into anterior attachment, medial attachment and acromioclavicular joint involvement.

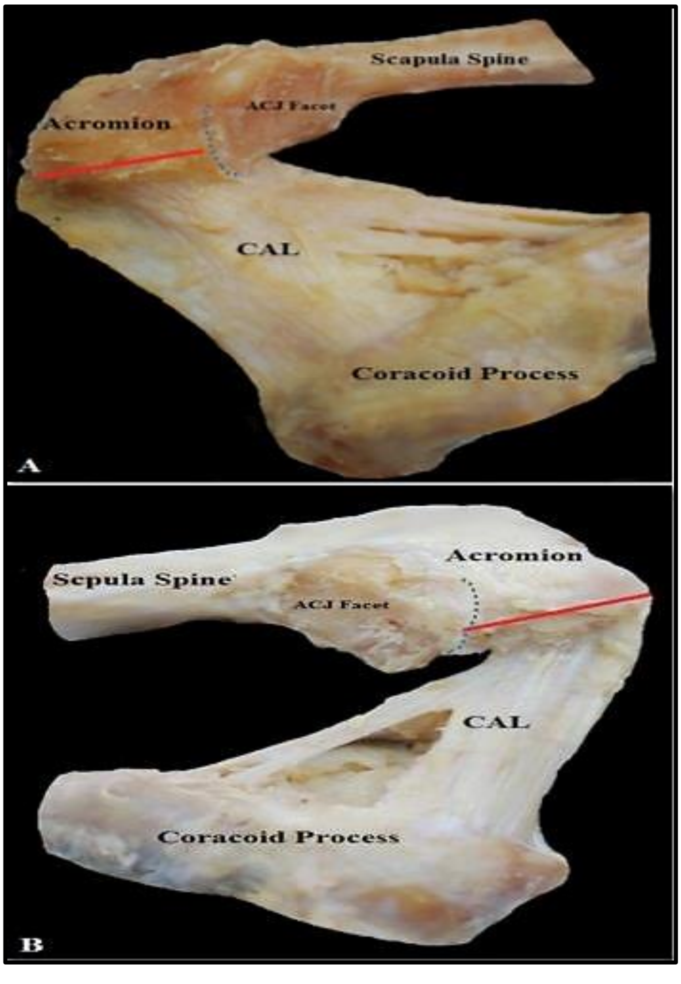


Figure 2.1 Acromial attachment of the CAL: the attachment of the CAL was classified as a medial acromial attachment if it extended to the medial aspect of acromion beyond the dotted blue line (A). Figure (A) shows the CAL attachment extending to the acromioclavicular joint. The lateral or anterior acromial attachment of the CAL was restricted to the anterior edge of the acromion (B): acromial facet of the acromioclavicular joint (ACJ Facet); coracoacromial ligament (CAL). The red lines represent the anterior edge of acromion.

Second, the coracoid attachment of the CAL was classified into lateral and medial attachments. Based on the medial end of the coracoid process, where the conoid ligament inserts, if the CAL was restricted lateral to this point it was considered to have a lateral coracoid attachment. On the other hand, if the ligament extended medially beyond this point toward the root of the coracoid or further, it was considered to have a medial coracoid attachment (Figure 2.2). However, at the anterolateral corner of the CAL, checks were undertaken to determine if there were fiber connections with the conjoined attachment of coracobrachialis and short head of biceps: CAL falx (Figure 2.3). Therefore, the coracoid attachment of the CAL was classified into: lateral attachment, medial attachment and CAL falx.

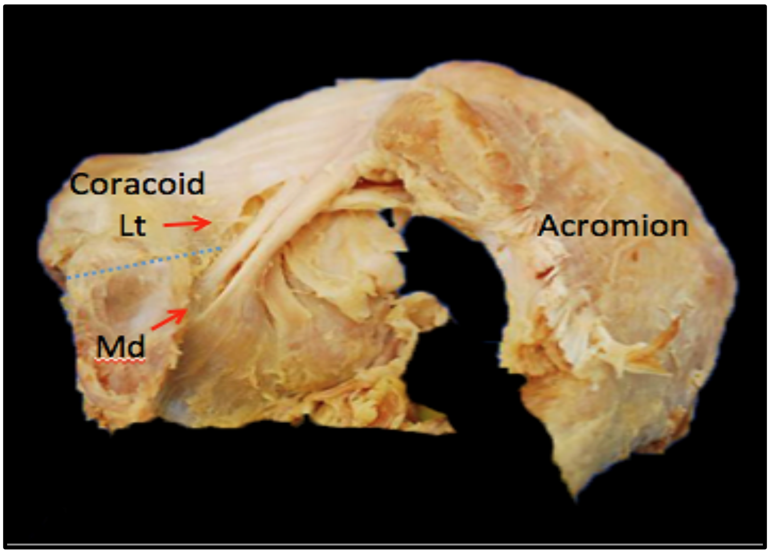


Figure 2.2 Medial view of the coracoacromial arch showing the coracoid attachment of the CAL: ligaments with attachment ends at or before the medial end of the coracoid (conoid ligament: blue dotted line) were classified as having a lateral coracoid attachment. Ligaments with attachment beyond this point extending to the coracoid root or further were classified as having a medial coracoid attachment: lateral coracoid attachment (Lt); medial coracoid attachment (Md).

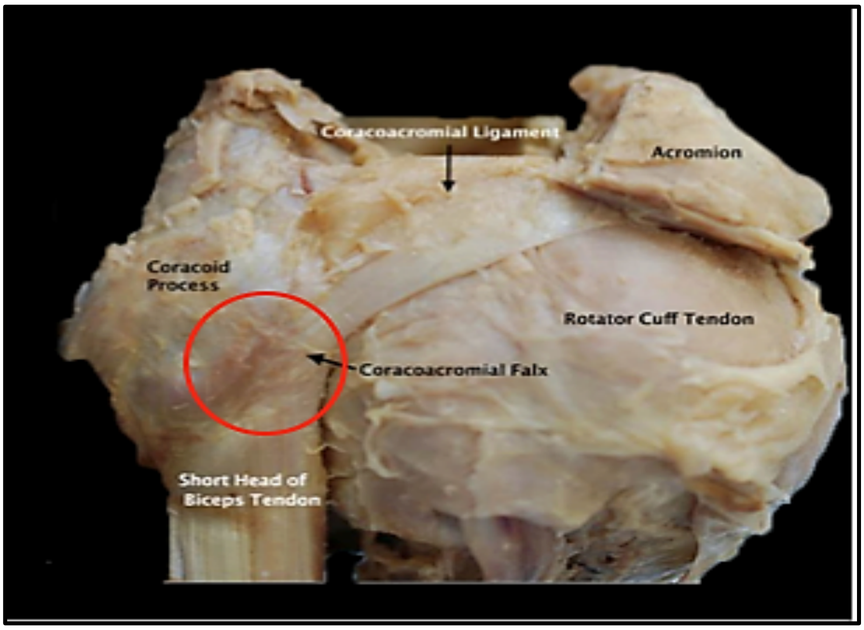


Figure 2.3 Lateral view of the left shoulder showing the CAL falx: the CAL falx is a lateral extension of the CAL. This figure shows connection of the CAL with the conjoined tendon of coracobrachialis and the short head of biceps.

This classification aimed to determine the effect of medial extension of the CAL attachments in relation to rotator cuff tears. In this study, the size and incidence of ligament attachment involving the acromioclavicular joint were assessed in relation to rotator cuff tears and degenerative changes in the acromioclavicular joint. In addition, the size and incidence of the CAL falx were assessed in relation to rotator cuff tears. The incidence of these attachments were compared to the morphological types of the CAL. Finally, a coronal section of 20 specimens was carried out at both the acromion and coracoid processes to determine the mode of attachment of the CAL.

2.2.1.3 Rotator Cuff Tears

The rotator cuff tendons were evaluated in 155 shoulders with respect to rotator cuff tears. Rotator cuff tears were classified morphologically, as described by Snyder (2003), and the arthroscopic classification of rotator cuff lesions according to the Southern California Orthopedic Institute (SCOI), into: normal, bursal surface tear and complete tear. The bursal partial tear has bursal-side fraying fibers, fissures or a bursal-side tear. The complete, or full-thickness, tear was limited to the supraspinatus tendon (Figure 2.4). A complete cuff tear penetrates the whole thickness of the rotator cuff tendon to reveal the head of the humerus. Larger complete tears involving more than one tendon or completely disconnects the tendon of the muscle are described as massive tears. Specimens with articular partial tears and intratendinous tears were excluded since the etiology of these tears has not been shown to be a result of bursal degenerative changes (Ozaki *et al*., 1988; Ogata and Uhthoff, 1990; Ogawa, 1996; Ko *et al*., 2006).

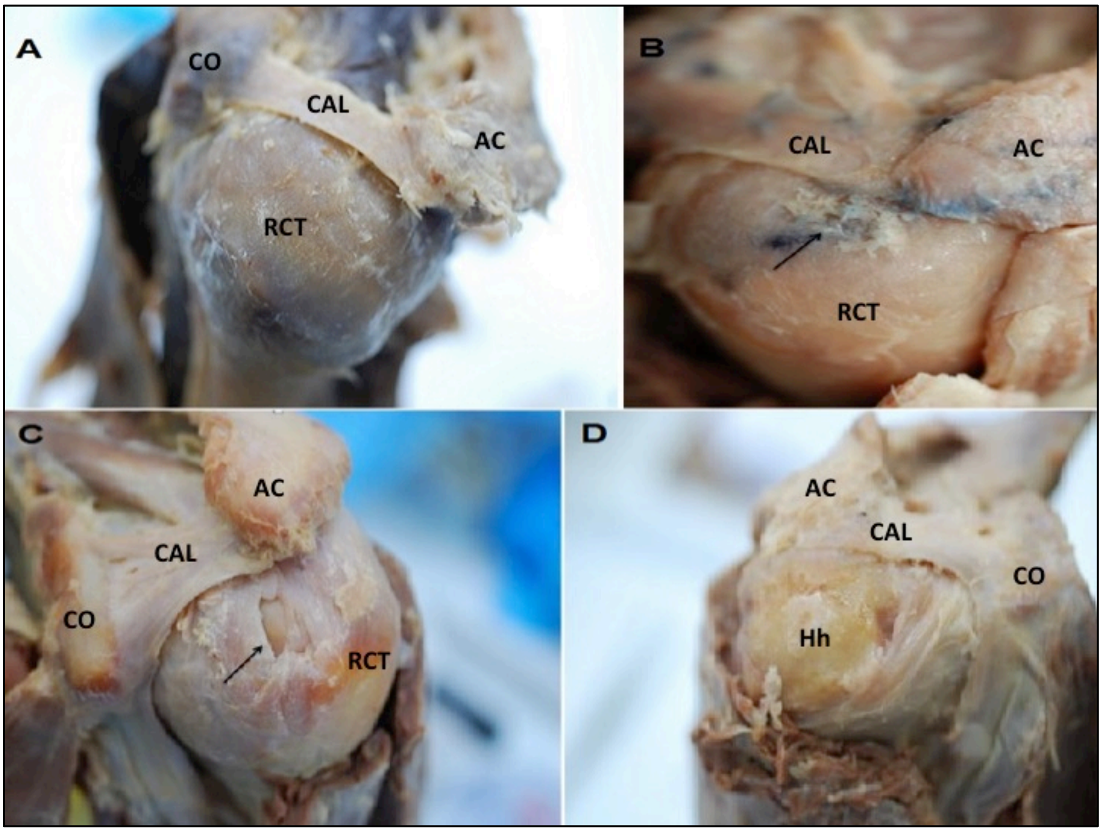


Figure 2.4 Lateral views of shoulders showing rotator cuff: (A) normal rotator cuff tendon, (B) partial bursal rotator cuff tear (arrow), (C) complete rotator cuff tear (arrow), and (D) massive rotator cuff tear: acromion (AC); coracoid (CO); coracoacromial ligament (CAL); rotator cuff tendon (RCT); humeral head (Hh).

2.2.1.4 Acromial Spur

This study investigated the formation of acromial spurs at the anterior end of the acromion in 220 scapulae. In the first stage, two examiners palpated the formation of an acromial spur at the tip and undersurface of the acromion. Moreover, blunt dissection was used in some cases to confirm formation of the spur. The relation between spur formation and rotator cuff tears and morphology of the CAL were evaluated. More investigations were carried out in the second stage regarding acromial spurs.

2.2.2 Parametric Assessment

Eight direct measurements of the CAL dimensions were taken using callipers and a goniometer (Table 2.1). These measurements included: attachments width, lateral and medial lengths (Figure 2.5), attachments and middle thickness (Figure 2.6), division distance, division angle, and space width (Figure 2.7). In addition, the length of the anterior edge of the acromion, the length of the coracoid process between the coracoid base, at the level of the conoid ligament, and the lateral tip of the coracoid were also measured. Attachment ratios of the CAL to the acromion and coracoid were also calculated for robustness comparisons. These parameters were correlated with several factors: rotator cuff tears, acromial spur formation, age, sex and side. They were also used to compare the different morphological types of CAL.

Table 2.1 Description of the CAL taken parameters used callipers and goniometer.

CAL Parameters	Measurement Description
Acromial Width	Extends from the anterolateral corner of the acromion into the anteromedial corner of the acromion. Any lateral or medial extension of the ligament beyond these two corners was considered.
Coracoid Width	Extends from the lateral tip of the coracoid process and medially to the root of the coracoid or anterior wall of the supraspinatus fossa. This involved the whole width of the ligament attachment including spaces. The width and thickness of the lateral and medial bands were also measured in ligaments consisting of more than one band.
Lateral Length	Extends from the anterior margin of the acromion to its insertion on the posterior aspect of the coracoid.
Medial Length	Extends from the anteromedial aspect of the acromion to its insertion at the base of the coracoid process.
Thickness	Superior-inferior length (thickness) of the ligament was measured at both attachment sites, acromion and coracoid, as well as in the middle of the lateral band.
Division Distance	The distance between the anterior edge of the acromion to the division point, where the ligament divided into anterolateral and posteromedial bands.
Division Angle	The angle between the anterolateral band and the first posteromedial band at the coracoid attachment.
Space Width	The width of the first space was defined as the distance between the coracoid attachments of the anterolateral and posteromedial bands.

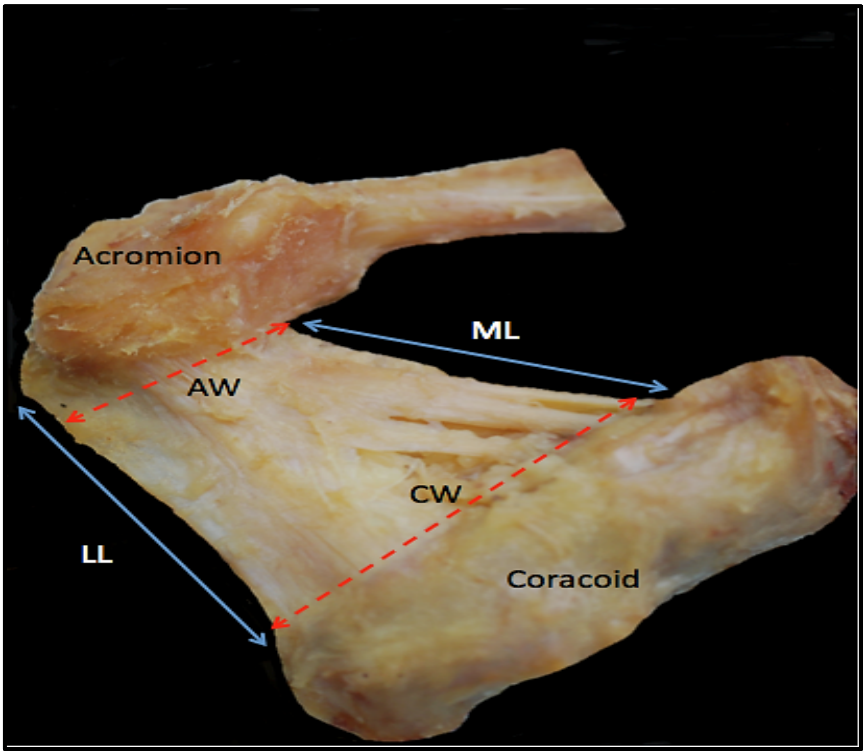


Figure 2.5 Superior view of the coracoacromial arch showing measurement of the width and length of the CAL: acromial width (AW): extending from the anterolateral corner of the acromion into the anteromedial corner of the acromion including any medial or lateral extension beyond these points, coracoid width (CW): extending from the lateral tip of the coracoid process and as far as the ligament extends medially involved spaces between the ligament bands, lateral length (LL): extending from the anterolateral corner of the acromion to its insertion on the lateral tip of posterior aspect of the coracoid process, and medial length (ML): extending from the anteromedial corner of the acromion to its insertion on the posterior aspect of the coracoid as the ligament extends medially.

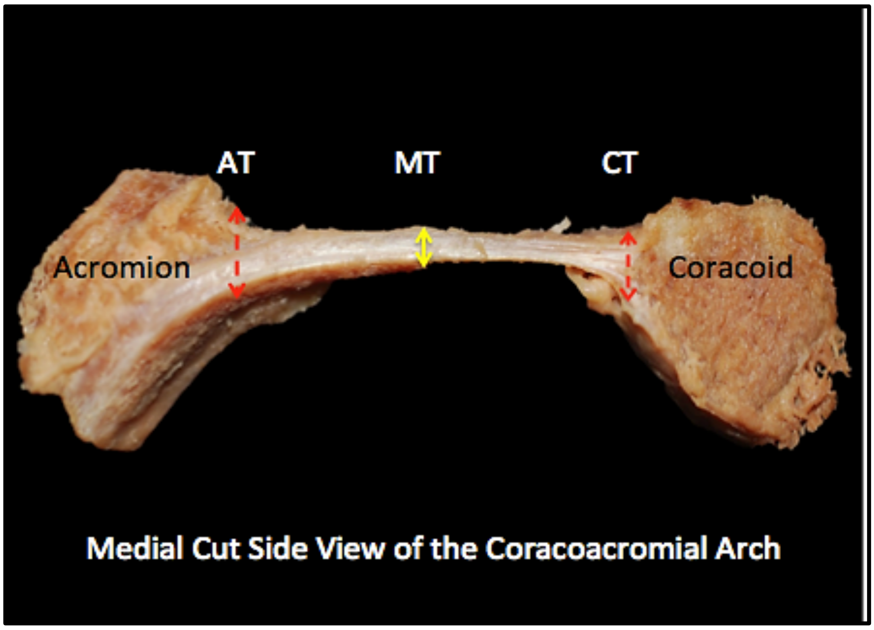


Figure 2.6 Medial cut view of the coracoacromial arch showing measurement of thickness (superior inferior length) of the CAL at: the acromial attachment (AT), middle of the ligament (MT), and at the coracoid attachment end (CT).

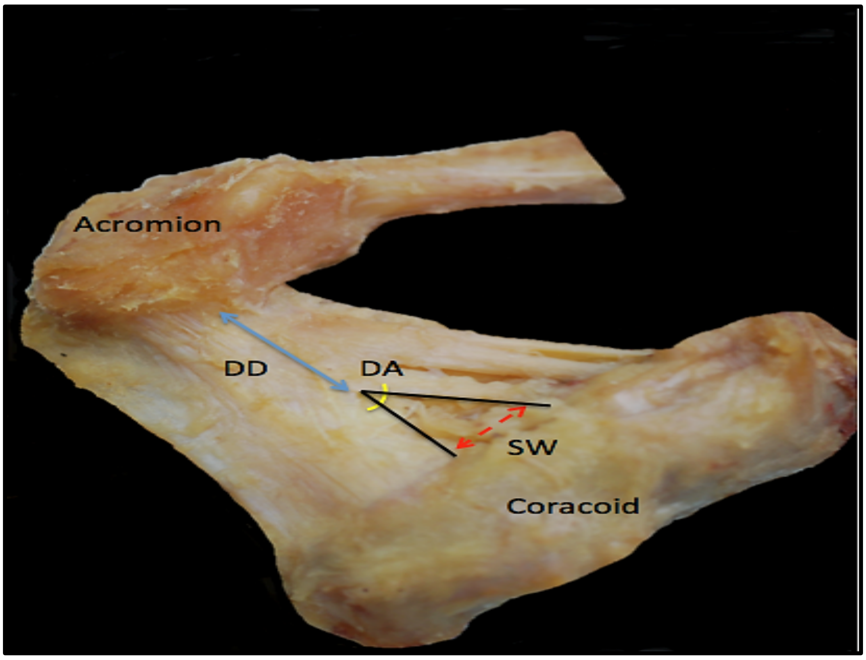


Figure 2.7 Superior view of the coracoacromial arch showing measurement to the division of the CAL: division distance (DD), division angle (DA), and space width (SW).

2.3 Second Stage

In the second stage of the study 60 scapulae were randomly selected from the first stage to investigate subacromial degeneration in relation to subacromial impingement syndrome and rotator cuff tears. This involved the subacromial insertion of the CAL, the subacromial surface, and subacromial spur morphology and size. The average age of specimens was 82 years (range 62 to 101 years), consisting of 20 female and 10 male cadavers. This stage aimed to evaluate the correlation between subacromial spurs and both CAL and rotator cuff tears with regard to morphology and size. Furthermore, the study aimed to inspect degenerative changes at both the subacromial surface and insertion of the CAL as a result of subacromial attrition and rotator cuff tears. The study also evaluated the effect of acromial spurs on the morphology of the acromion by measuring acromial curvature.

2.3.1 Subacromial Insertion of the CAL

First, to study the subacromial insertion of the CAL, the head of the humerus and rotator cuff tendons were detached from the scapulae to enable a better view of the subacromial surface. The parameters of subacromial insertion of the CAL including the lateral and medial lengths were taken using callipers (Figure 2.8). Degenerative changes at the insertion of the CAL were recorded and documented with photographs to correlate with rotator cuff tears and acromial spurs. The maximum anterior-posterior and lateral-medial dimensions of the attrition signs were measured using callipers (Figure 2.9). Furthermore, the location and severity of these changes were recorded.

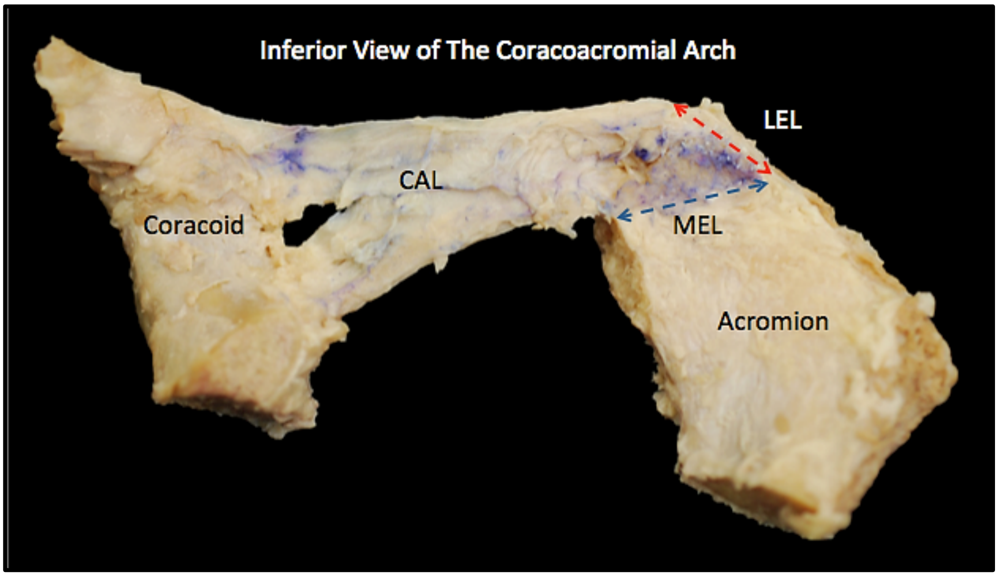


Figure 2.8 Inferior view of the coracoacromial arch showing the subacromial insertion of the CAL: lateral or base extension length of the CAL (LEL), and medial extension length of the CAL (MEL).

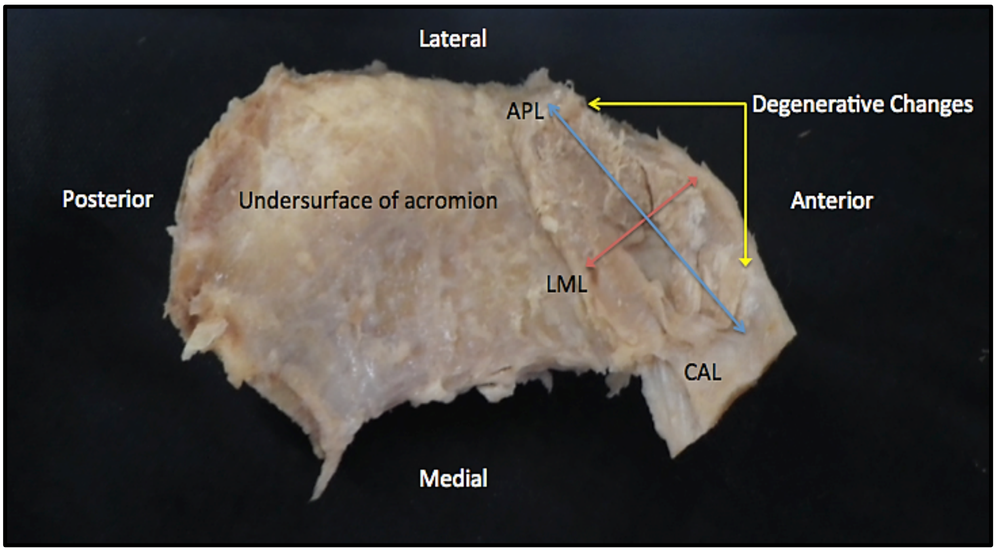


Figure 2.9 Inferior view of the undersurface of the acromion showing degenerative changes (attrition lesions) at the subacromial insertion of the CAL: anterior-posterior length (APL), lateral-medial length (LML).

The purpose of these measurements was to investigate the effect of the size of the CAL subacromial insertion on the incidence of rotator cuff tears and size of subacromial spurs. This also aimed to evaluate the relationship between rotator cuff tears and the formation of acromial spurs by comparing the severity of attrition and the size of the acromial spur superiorly and the type of rotator cuff tear inferiorly.

2.3.2 Subacromial Spur

The 60 shoulders, scapulae and heads of humerus, were macerated in warm water (35°C) to remove the soft tissue and washed in ethanol to remove any fat remnants. Then, specimens were left to dry in air for two days. Several parameters of subacromial spurs were of interest: maximum anterior-posterior (length) and medial-lateral (width) dimensions of the subacromial spurs were measured using callipers (Figure 2.10). Anterior extension of acromial spurs away from the subacromial surface were recorded and measured. These included the width, length and thickness of the extended spur (Figure 2.11). In addition, photographs with a scale background were taken to determine the circumference of subacromial spur using Image-J 1.47v software (Figure 2.12) and to determine the morphology of subacromial spurs. Moreover, superior-inferior thickness of the acromion was measured at the middle of the anterior edge of the acromion.

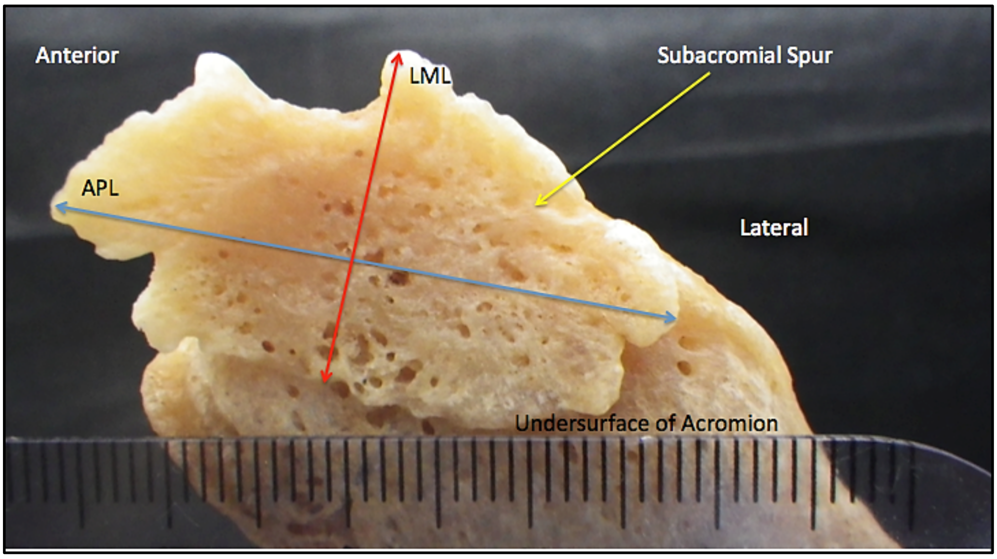


Figure 2.10 Inferior view of the undersurface of the acromion showing measurement of dimensions of the subacromial spur: anterior-posterior length (APL), lateral-medial length (LML).

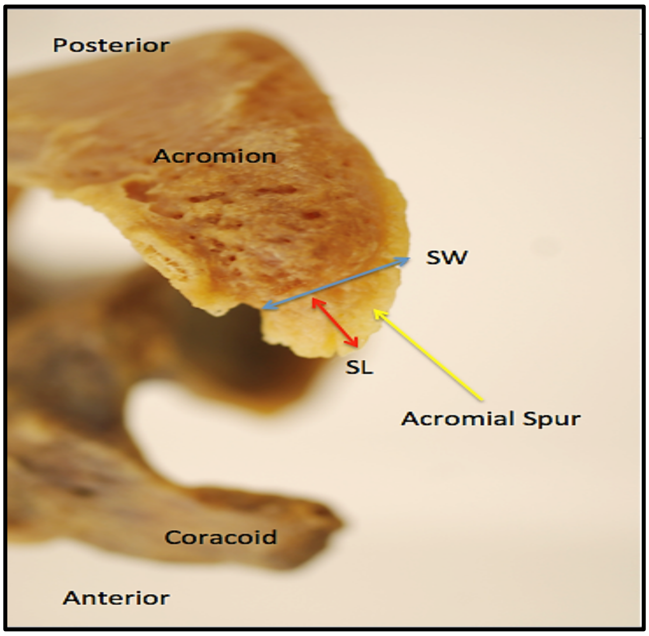
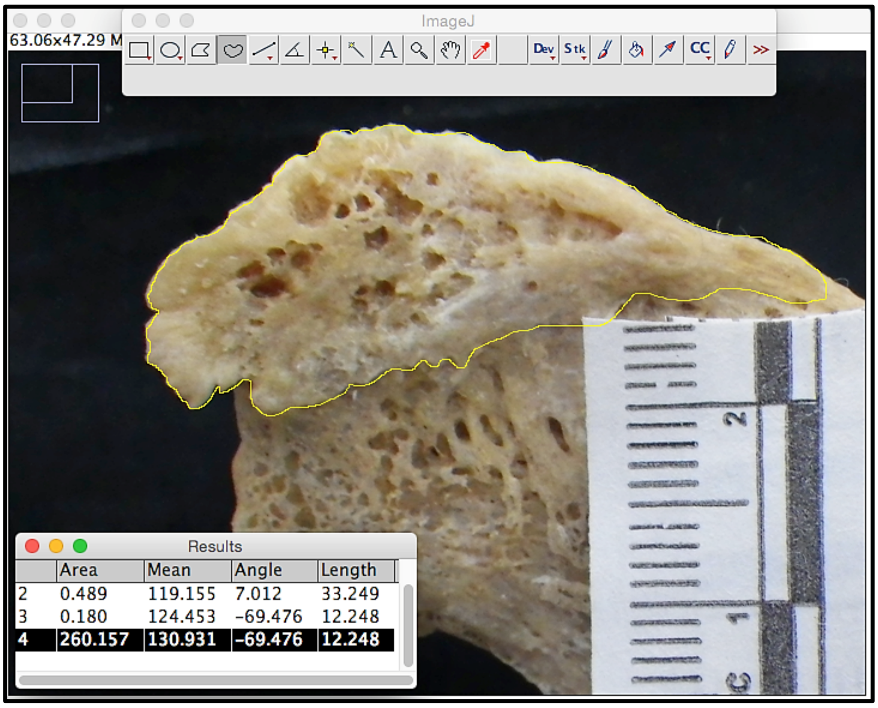


Figure 2.11 Superior view of the acromion showing measurement of the anterior extension of an acromial spur: spur width (SW): lateral-medial length of spur parallel to the anterior edge of acromion, spur length (SL): anterior-posterior length spur extended from the anterior edge of acromion and as far as the spur extends anteriorly.



	Area	Mean	Angle	Length
2	0.489	119.155	7.012	33.249
3	0.180	124.453	-69.476	12.248
4	260.157	130.931	-69.476	12.248

Figure 2.12 Inferior surface of the acromion showing measurement of the circumference of the subacromial spur using Image-J software.

These measurements were compared and correlated with the attrition signs at the insertion of the CAL and the types of rotator cuff tear. In addition, these measurements were correlated with the age of specimens, the morphology and size of the CAL and acromion size. Therefore, this part of the study aimed to clarify the role of subacromial spurs in the etiology of rotator cuff tears. Furthermore, it aimed to understand how a subacromial spur starts and which factors control its formation and size. Thus, understanding these relationships may contribute in planning for better treatment of subacromial impingement and rotator cuff tears.

2.3.3 Subacromial Surface

The subacromial surfaces of 60 scapulae were examined for any subacromial facet formation or degenerative changes as a result of impingement with subacromial soft tissues or attrition against the greater tubercle. As described by Graves (1922), a subacromial facet can be classified into elevated or sunken facets, and degenerative changes into smooth, eburnated or rough surfaces. These changes were compared to the attrition signs, subacromial spurs, types of rotator cuff tears, as well as to changes in the head of humerus. The purpose of this investigation was to determine the range of impingement effects on the subacromial surface and how these changes were reflected on the rotator cuff tendon. This may make diagnosis of impingement accessible and more manageable.

2.3.4 Coracoid Spurs and Acromioclavicular Joint Degenerative Changes

The study was also focused on other bony degenerative changes in the coracoacromial arch. These changes included degenerative changes and osteophyte formation at the acromial facet of the acromioclavicular joint and coracoid spurs. These changes were compared to those seen on the subacromial surface, rotator cuff tears and the age of specimens.

The purpose of studying these changes was to highlight such changes in shoulders with subacromial impingement syndrome that may worsen shoulder pain or function. This may help in the management and treatment of subacromial impingement syndrome and prevent recurrent shoulder pain. The length (superior-inferior distance) of osteophytes at the inferior edge of the acromial facet were measured using callipers (Figure 2.13).

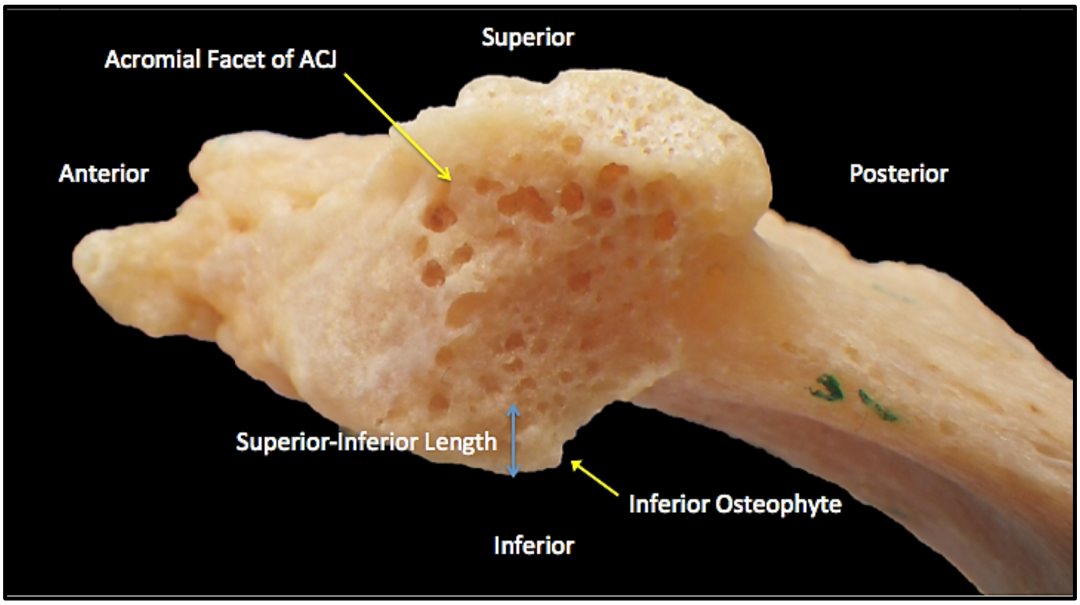


Figure 2.13 Medial view of the acromial facet of the acromioclavicular joint showing measurement of the inferior osteophyte: superior-inferior length extends from the inferior edge of facet as far as the osteophyte extends inferior..

2.3.5 Acromial Curvature

The impact of acromial spur formation on the morphology of the acromion was evaluated by measuring the anterior-posterior curvature of the acromion. Anterior-posterior acromial curvature was measured in two ways: acromial slope angle and the height of acromion curvature. Bigliani *et al.* (1986) described acromial slope angle as the angle between two lines connecting the anterior and posterior ends of the acromion and interconnecting at the midway point on the inferior acromion. Edelson and Taitz (1992) described the height of acromion curvature as the maximum height above a straight line drawn between the acromion ends. The current study measured acromial curvature by taking a print of the anterior-posterior aspect of the acromion using a stamp print (Figure 2.14). Acromial slope angle and curvature height were measured manually using a goniometer taking into consideration the length of the acromial spur at the anterior edge of the acromion. In addition, acromial curvature was compared to rotator cuff tears and attrition lesions on the CAL.

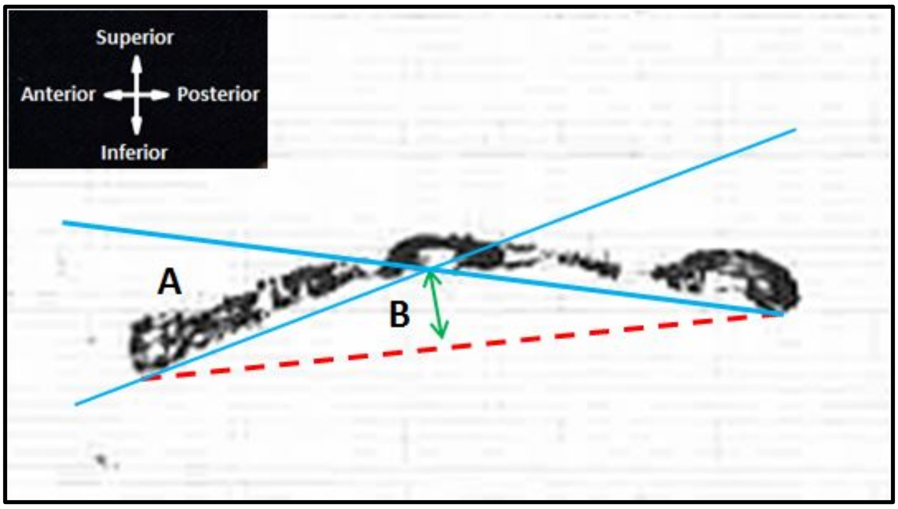


Figure 2.14 Print of the anterior-posterior aspect of the acromion taken to measure the lateral acromial curvature: acromial slope angle (A): the angle between the two crossed blue lines, and acromial curvature height (B): the green line extends between the inferior edge of acromion and straight line drawn between the anterior and posterior acromion edges.

2.4 Tools and Statistical Analysis

Digital calipers were used to measure the dimensions of the CAL, acromion and coracoid: measurements were taken to 0.01mm. The calipers were calibrated and compared with the measurements taken using two other calipers, as well as with a ruler. A goniometer was used to measure the deviation angles of the CAL, acromion and coracoid, the angle between CAL bands and acromion slope angle. Each measurement was taken three times and then averaged. Digital photographs were taken as a permanent record. The sex, age and cadaver number were recorded for each specimen.

In addition, the reliability and repeatability of the measurements taken were assessed at the beginning of the study for each stage before full data collection. The reliability measurements were taken three times at different times a day. Repeatability test carried out by two observers in addition to the main observer. The results of both tests did not show any statistically significant difference between the measurements taken (Tables 2.2 and 3). The data were collected and analyzed using IBM SPSS statistical 21.0 software with $P < 0.050$ considered as being statistically significant. The statistical analysis was carried out after consultation with three statistical experts in the University of Dundee. The collected data showed normal distribution and equal variance.

Table 2.2 **Description of the CAL taken parameters used callipers and goniometer.**

Measurements	1st Observer	2nd Observer	3rd Observer	P Value
CAL acromial width (mm)	15.46 ± 3.1	15.39 ± 2.8	15.40 ± 3.0	0.998
CAL middle thickness (mm)	1.02 ± 0.3	1.03 ± 0.1	1.13 ± 0.3	0.562
Lateral band length (mm)	31.80 ± 5.9	31.48 ± 5.5	32.11 ± 5.4	0.968
Division angle (˚)	40.60 ± 5.7	41.00 ± 5.6	40.70 ± 5.3	0.986
Acromial slope (˚)	37.69 ± 7.4	41.47 ± 5.6	38.96 ± 4.1	0.139
Acromial curvature height (mm)	6.48 ± 1.4	7.25 ± 2.3	7.08 ± 2.0	0.454

Table 2.3 Results of the repeatability test.

Measurements	1st Reading	2nd Reading	3rd Reading	P Value
CAL acromial width (mm)	14.61 ± 4.0	14.05 ± 3.2	14.25 ± 4.4	0.979
CAL middle thickness (mm)	1.29 ± 0.4	1.29 ± 0.3	1.16 ± 0.3	0.824
Lateral band length (mm)	31.34 ± 5.9	29.70 ± 6.3	30.06 ± 3.2	0.903
Division angle (˚)	44.25 ± 5.2	37.25 ± 9.6	43.50 ± 10.2	0.484
Acromial slope (˚)	31.83 ± 4.3	31.00 ± 4.6	35.00 ± 4.0	0.271
Acromial curvature height (mm)	5.09 ± 0.7	4.91 ± 1.1	5.35 ± 0.7	0.687

Statistic tests were used in the current study either to find relationships or differences between the collected data. Tests used to find a relationship include: Chi-square test to determine the association between two nominal data sets considering subgroup classes, and to find the difference in incidence, Pearson correlation to find the correlation between two continuous readings, and Spearman correlation to find the correlation between two nominal data sets. The current study used the Cohen (1988) scale to describe the strength of the relationship: $0.1 < r < 0.3$ is a small or low relationship, $0.3 < r < 0.5$ is a medium or moderate relationship, and $r > 0.5$ is a large or strong relationship. Tests were used to find a difference include: independent samples T-Test to find the difference in continuous data between two groups considering one factor, one-way ANOVA to find the difference in continuous data between more than two groups considering one factor, two and three-way ANOVA to find the difference in continuous data considering more than one factor.

3 Results

3.1 First Stage Results

3.1.1 General Descriptive

In general, the superior view of the CAL showed a trapezoid shaped ligament, with the shorter base attached to the acromion and longer base attached to the coracoid process. However, the inferior view of the CAL showed a triangular shaped ligament, in which the insertion of the CAL beneath the acromion formed the apex of the triangle. A pilot study of 20 shoulders showed that the CAL attached mainly to the anterolateral part of the inferior aspect and to the anterior edge of the acromion. It extended obliquely being directed anteromedially to insert into the posterior aspect of the coracoid process.

A coronal section of 20 specimens showed that the ligament fibres of the CAL divide superiorly and inferiorly at both sites of attachment (Figure 3.1). At the acromial insertion, the superior fibres of the CAL were observed attaching into the anterior edge of the acromion and overlapping with fibres of deltoid. The inferior fibres extended beneath the acromion with a mean length of 20.61 ± 6.6 mm covering 46% of the total length of the acromion. At the coracoid attachment the superior fibres spread over the posterior surface of the medial end of the coracoid process. The inferior fibres overlapped with the common origin of coracobrachialis, the short head of biceps and the coracohumeral ligament.

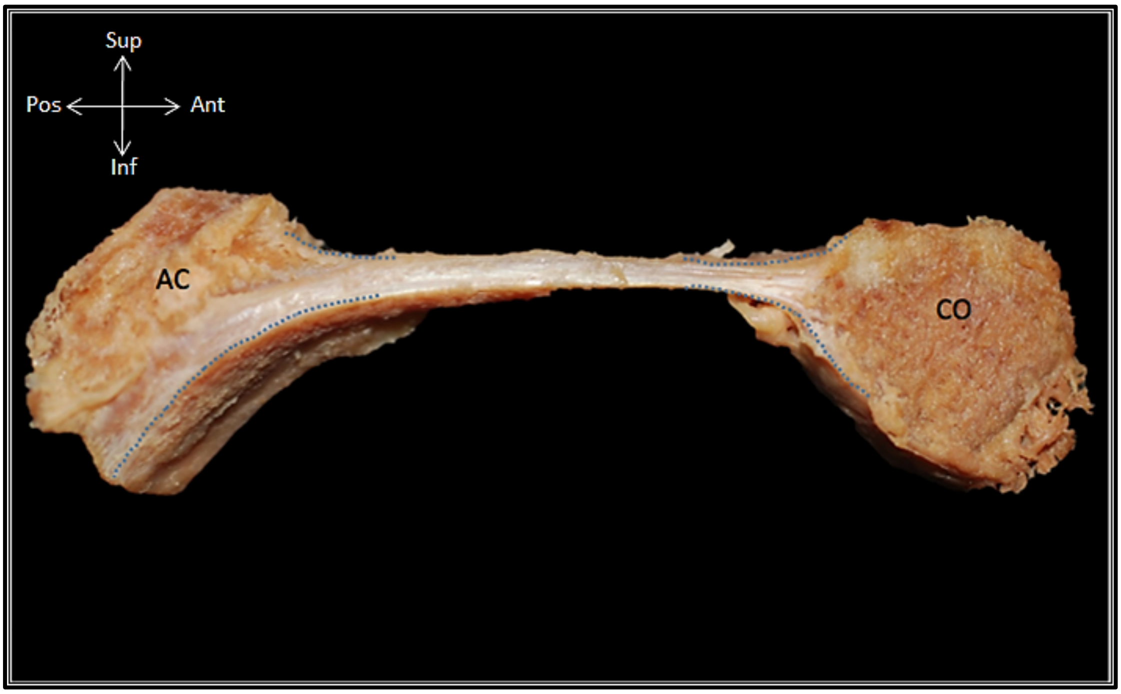


Figure 3.1 Coronal section of the acromion and coracoid processes showing attachment of the CAL (shown by the dotted lines) at both acromial (AC) and coracoid (CO) ends: at the acromial attachment some fibers of the CAL attach to the anterior edge of the acromion, while other fibers extend posteriorly to attach to the inferior surface of the acromion. At the coracoid side the fibers attach to the posterior edge of the coracoid process with some fibers spreading over the superior surface of the medial end, some fibers overlapping the common origin of coracobrachialis, the short head of biceps and the coracohumeral ligament at the lateral end of the coracoid.

The width of the CAL at the coracoid attachment was significantly wider, being double the width at the acromial attachment: 31.58 ± 4.0 mm compared to 15.96 ± 8.0 mm ($P < 0.001$) (Table 3.1). However, the CAL had a significantly greater attachment ratio to the acromion (93%) than to the coracoid process (74%) ($P< 0.001$). In addition, the CAL had a significantly longer lateral than medial length: 37.80 ± 5.4 mm to 32.98 ± 4.6 mm ($P< 0.001$). The thickness of the CAL varied, with the acromial side being significantly thicker than the coracoid and midpoint thickness ($P < 0.001$) (Table 3.2). The thickness of the CAL at the middle of the lateral band (1.07 ± 0.3 mm) was significantly thinner than at the bony attachments. Comparing the lateral and medial bands (Table

3.3), the lateral band was significantly wider and thicker than the medial band ($P < 0.001$).

Table 3.1 Paired samples T-test comparison of CAL width and length at both attachments.

CAL Parameters	N	Mean (mm)	Std. Dev.	P value
Acromial Width	220	15.96	4.0	<0.001
Coracoid Width	220	31.58	8.0	
Lateral Length	220	37.80	5.4	<0.001
Medial Length	220	32.98	4.6	

Table 3.2 Paired samples T-test comparison of CAL thickness at both acromial and coracoid attachments, together with the midpoint thickness of the lateral band.

CAL Parameters	N	Mean (mm)	Std. Dev.	P value
Acromial Thickness	220	2.05	0.6	<0.001
Coracoid Thickness	220	1.29	0.3	
Acromial Thickness	220	2.05	0.6	<0.001
Middle Thickness	220	1.07	0.2	
Coracoid Thickness	220	1.29	0.3	<0.001
Middle Thickness	220	1.07	0.2	

Table 3.3 Paired samples T-test comparison of the width and thickness of the lateral and medial bands in Y shaped or two band ligaments.

CAL Parameters	N	Mean (mm)	Std. Dev.	P value
Lateral Band Width	84	14.05	3.41	<0.001
Medial Band Width	84	7.23	3.37	
Lateral Band Thickness	84	1.34	0.3	<0.001
Medial Band Thickness	84	0.86	0.36	

Pearson correlations showed several significant relationships between CAL parameters and the length of the adjacent bony processes. A strong positive correlation was found between the acromial and coracoid CAL attachment widths: $R = 0.629$, $r^2 = 40\%$, $P < 0.001$ (Figure 3.2). Both attachment widths of the CAL were positively associated with the length of the anterior edge of the acromion (R = 0.257, r^2 =6.6%, P < 0.001) and coracoid process (R = 0.310, r^2 = 9.6%, P < 0.001). In addition, a small positive correlation was present between the acromial width and thickness of the CAL: R = 0.258, r^2 = 7%, P < 0.001. The lateral band width at the coracoid site of two band ligaments was found to be moderately positively correlated with the coracoid width of the CAL: R = 0.448, r^2 = 20%, P < 0.001.

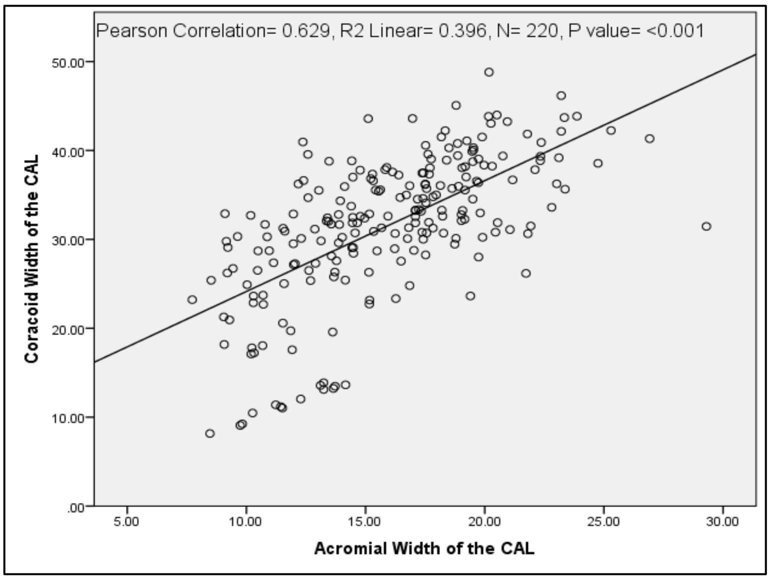


Figure 3.2 Scatter plot displaying a linear correlation between the acromial and coracoid widths of the CAL.

3.1.2 CAL Morphology and Descriptive Parameters

The following shapes of the CAL were observed: broad band ligament in 14 (6%) specimens, quadrangular band ligament in 21 (10%), Y-shaped ligament in 84 (38%) and multiple-banded ligament in 101 (46%). In general, the coracoid attachment width was greater than the acromial attachment width for all CAL configurations (P < 0.001), except for the broad band ligament which had equal attachment widths. The lateral side length was also longer than the medial side length in all ligament shapes (P < 0.001). The distribution of the

CAL according to the number of bands observed was as follows: one band in 35 (16%), two bands in 84 (38%) and three or more bands in 101 (46%). The number of bands in the group with three or more bands was as follows: 72 (71%) specimens with three bands, 25 (25%) specimens with 4 bands, three (3%) specimens with 5 bands and one (1%) specimen with 6 bands.

3.1.2.1 CAL Shapes

3.1.2.1.1 Broad Band Ligament

The broad band ligament was the least frequently observed type in this study, being found in 14 (6%) of the 220 specimens investigated (Table 3.4). It consisted of a single band ligament which usually extended between the lateral ends of the acromion and coracoid processes with parallel lateral and medial margins (Figure 3.3). A lateral extension along the lateral border of the acromion was observed in 6 specimens (43%) with a broad band ligament. Both acromial and coracoid mean widths of the broad band ligament had similar length: 11.84 ± 1.8 mm and 11.68 ± 1.9 mm ($P = 0.135$). The acromial attachment ratio was 68% of anterior acromion length, while the coracoid attachment ratio was 26% of coracoid process length. The mean length of lateral side of the broad band was 40.94 ± 3.7 mm.

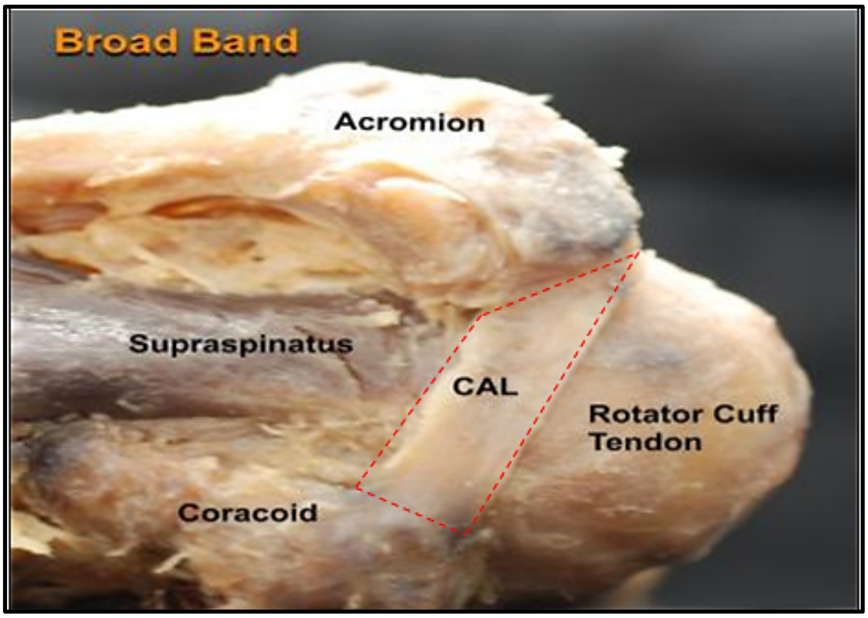


Figure 3.3 Broad band ligament (outlined): consisting of a single band ligament and characterized by almost equal attachment widths.

3.1.2.1.2 Quadrangular Band Ligament

The quadrangular band ligament was the second least commonly observed in this study, being found in 21 (10%) of 220 specimens (Table 3.4). It consisted of a single band ligament that usually attached to the lateral side of the anterior edge of the acromion with a mean width of 13.47 ± 3.9 mm (Figure 3.4). A lateral extension along the lateral edge of the acromion was noted in three specimens (14%) with this type of CAL. A medial extension to the medial border of the acromion was also noted in six specimens (29%) with quadrangular band ligaments. The coracoid attachment mean width of the quadrangular band ligament was 23.41 ± 5.2 mm, being significantly wider than the acromial attachment mean width of 13.47 ± 3.9 mm ($P < 0.001$). However, the acromial attachment ratio was 77%, while the coracoid attachment ratio was 55%. A change in width of the ligament was noted medially, in which the medial side of the ligament widened as it approached the coracoid. The lateral side of the ligament remained straight between its attachments without any change. The mean length of the ligament according to the lateral side length was 39.51 ± 6.9 mm.

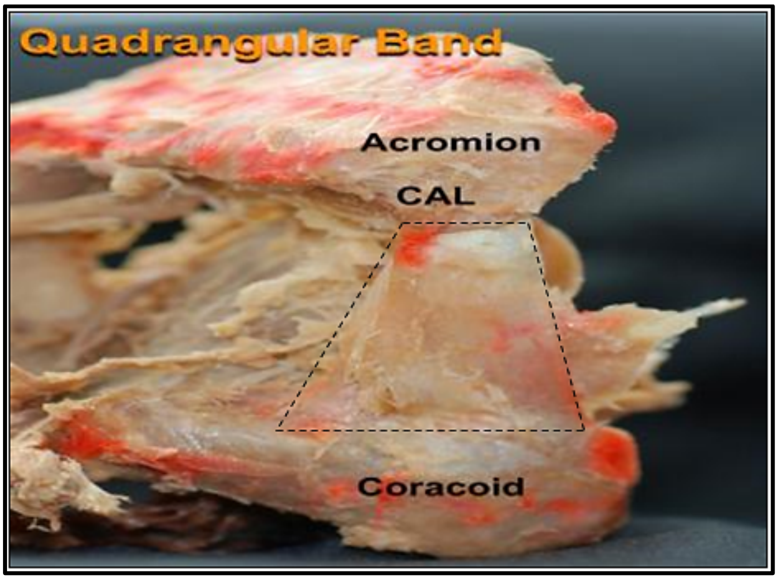


Figure 3.4 Quadrangular band ligament (outlined): consisting of a single band ligament and characterized by a wider coracoid than acromial attachment.

3.1.2.1.3 Y-Shaped Ligament

The Y-shaped ligament was found in 84 (38%) of 220 specimens (Table 3.4). It consisted of two bands at the coracoid side, which originated as a single band at the acromial side (Figure 3.5). It mainly attached to the anterior edge of the acromion with a lateral extension to the lateral edge of the acromion in one case (1%), while in more specimens (57%, n = 48) it extended to the medial border of the acromion. The acromial mean width of the CAL was 15.35 ± 3.6 mm, which formed 89% of the acromial anterior edge. The coracoid attachment mean width was 32.37 ± 5.6 mm, which formed 77% of the coracoid length. The mean width of the lateral band (14.05 ± 3.4 mm) was double that of the medial band (7.23 ± 3.4 mm) ($P < 0.001$). The mean distance between the anterior acromial edge and division of the ligament into lateral and medial bands was 11.39 ± 5.8 mm (range 2.34 to 27.8 mm). It was never observed to start as two bands at the acromial side. The mean distance and angle between the two bands were 11.41 ± 4.7 mm and 35.83 ± 10.0º, respectively. The mean length of the lateral band of the Y-shaped ligament was 37.08 ± 5.0 mm.

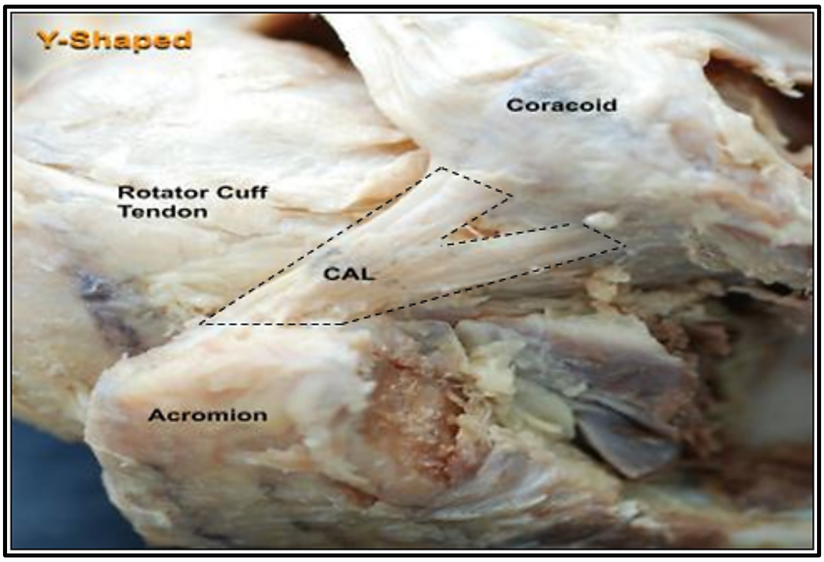


Figure 3.5 Y-shaped ligament (outlined): it always originated as a single band ligament at the acromion and ended in two bands at the coracoid process.

3.1.2.1.4 Multiple-Banded Ligament

The multiple-banded ligament was the most commonly distributed type observed in this study, being found in 101 (46%) of 220 specimens ($P < 0.001$) (Table 3.4). It originated at the acromion as one band and inserted into the coracoid as three or more bands (Figure 3.6). It mainly attached to the anterior edge of the acromion, in the majority of specimens (77%) it extended to the medial border of the acromion and only in two cases (2%) it extended to the lateral border. The mean width of acromial attachment was 17.56 ± 3.9 mm with a higher attachment ratio to the acromion anterior edge: 103%. At the coracoid side the multiple-banded ligament extended from the tip of the coracoid laterally to the medial end and root of the coracoid. In ten shoulders (10%) the most medial fibers attached to the roof of the glenoid fossa just medially to the superior glenoid tubercle, which was hidden beneath supraspinatus (Figure

3.7). The mean width of the coracoid attachment was 35.38 ± 4.9 mm, forming 82% of the coracoid length. The mean lateral length was 37.60 ± 5.4 mm. Comparing the lateral and medial bands, the lateral band was wider and thicker than the medial band. The mean division distance was 14.91 ± 5.1 mm, while the mean distance and angle between the lateral band and the first medial band were 8.30 ± 3.9 mm and 33.43 ± 9.7^0, respectively.

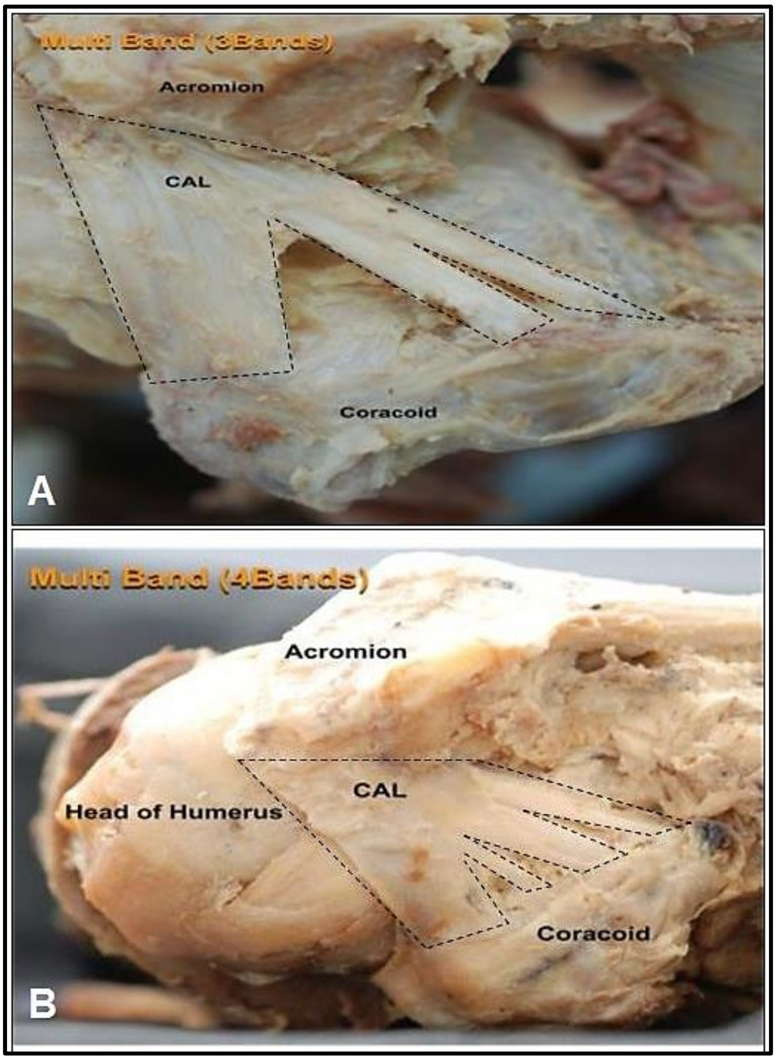


Figure 3.6 Multiple-banded ligament (outlined): it consists of three or more bands. It originated as one band at the acromion and ended as multi bands at the coracoid attachment. Figure (A) shows a multiple banded ligament with three bands, while figure (B) shows a multiple banded ligament with 4 bands.

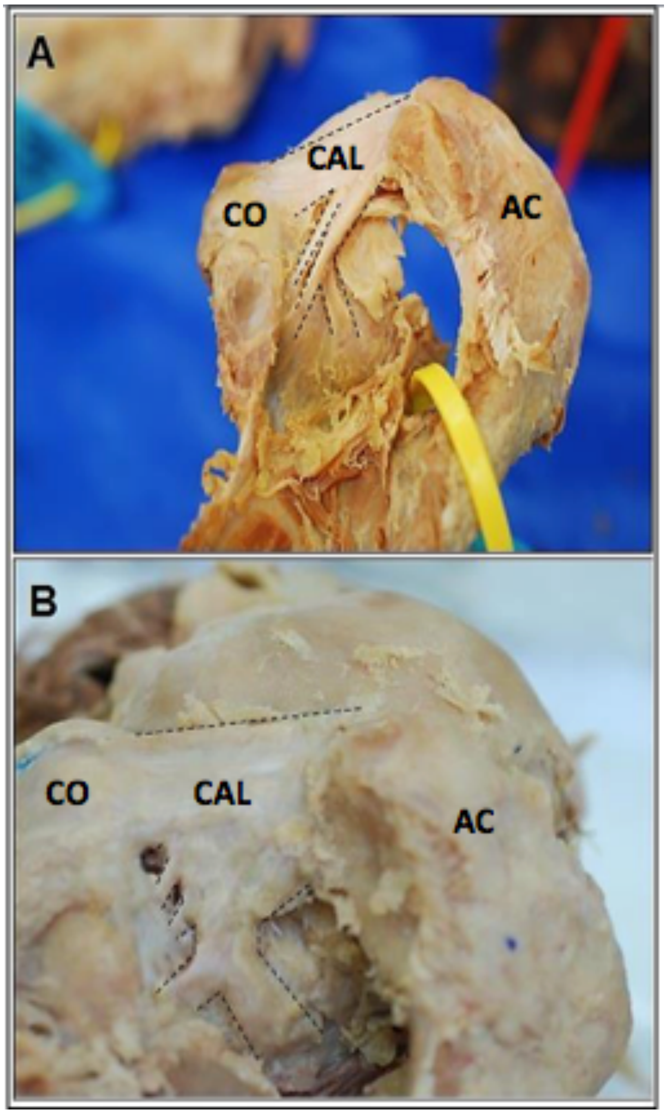


Figure 3.7 Superior views of the right shoulder: shows two cases of the coracoid insertion of the most medial band of a multiple banded ligament into the roof of the glenoid tubercle: acromion (AC); coracoid (CO); coracoacromial ligament (CAL).

Table 3.4 Display of the CAL parameters according to the ligament shapes.

CAL Parameters	B N= 14 (6%)	Q N= 21 (10%)	Y N = 84 (38%)	M N = 101 (46%)
Acromial attachment	11.84 ± 1.8	13.47 ± 3.9	15.35 ± 3.6	17.56 ± 3.9
Coracoid attachment	11.68 ± 1.9	23.41 ± 5.2	32.37 ± 5.6	35.38 ± 4.9
Lateral length	40.94 ± 3.7	39.51 ± 6.9	37.08 ± 5.0	37.60 ± 5.4

CAL shapes: broad band (B); quadrangular band (Q); Y-shaped ligament (Y); multiple banded ligament (M).

3.1.2.2 Division of the CAL into Bands

In Y-shaped forms of the ligament the lateral band was usually found superiorly or overlapped the lateral side of the medial band. However in three cases (4%) of shoulders with Y-shaped ligaments, the medial band crossed over the lateral band and attached to the anterior edge of the acromion (Figure 3.8). In multiple-banded ligaments, the ligament either divided into two bands that then subdivided to multiple bands or it divided directly into multiple bands (Figure 3.6). In addition, the medial bands of the multiple-banded ligament usually attached close to each other at the coracoid side having a branching rather than a dividing style, especially in those bands that extended to the root of the coracoid and anterior surface of the supraspinatus fossa. Generally, the length between the two bands was positively associated with the angle between the two bands: R = 0.610, r^2 = 37%, $P < 0.001$. On the other hand, the length was negatively associated with the division length: R = - 0.322, r^2 = 10%, $P < 0.001$.

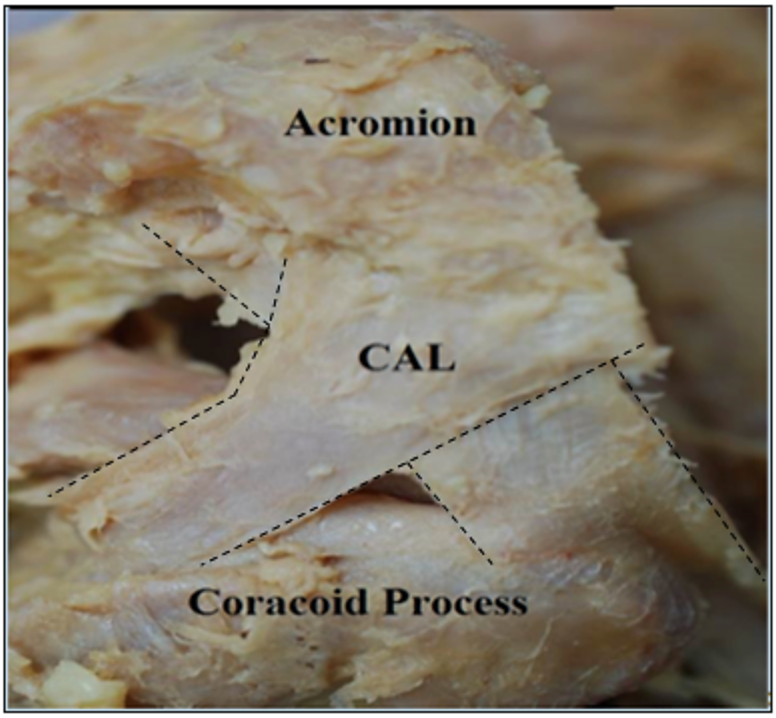


Figure 3.8 Y-shaped ligament with crossed ligament bands

3.1.2.3 Test of Association

The CALs presented the same shape and number of bands in 184 (89%) of 206 bilateral shoulders ($P < 0.001$). However, only 22 (11%) shoulders presented with different shapes and band numbers. Both Y-shaped and multiple-banded ligaments were more common in this study than the other two ligament shapes ($P < 0.001$). This was also true according to band number of the CAL, as well as being related to several factors including: sex, side and age (Table 3.5). The only exception was found in the age ≤ 69 years, in which there was no significant relationship according to ligament shape ($P = 0.233$).

Table 3.5 Pearson Chi-squared test to evaluate association between CAL band number and factors such as side, sex and age decade groups.

Factors	Classes	N	CAL Band Number			Association	
			1 Band (n= 35)	2 Bands (n= 84)	3 Bands (n= 101)	P Value	Rate
Side	Right	103	15 (50.0%)	38 (49.4%)	50 (50.5%)	1.000	0.011
	Left	103	15 (50.0%)	39 (50.6%)	49 (49.5%)		
Sex	Male	110	16 (45.7%)	36 (42.9%)	58 (57.4%)	0.123	0.138
	Female	110	19 (54.3%)	48 (57.1%)	43 (42.6%)		
Age Levels	<69 Years	17	5 (14.3%)	3 (3.6%)	9 (8.9%)	0.025	0.174
	70th	68	12 (34.3%)	26 (31.0%)	30 (29.7%)		
	80th	84	6 (17.1%)	33 (39.3%)	45 (44.6%)*		
	>90 years	51	12 (34.3%)	22 (26.2%)	17 (16.8%)		

- Side: only bilateral shoulders were considered.
- Significant association (*).
- Age according to sex: male = 80 years; female = 84 years

However, no significant association was detected between CAL shape or band number and factors such as side, sex and age ($P > 0.05$), except within the 80th decade age group. The multiple-banded ligament, or ligament with three or more bands, was significantly associated with the 80th decade age group ($P = 0.025$). However, this relationship was very small (Cramer's $V = 0.174$) and was not observed in the 90th decade group nor after combining the 90th and 80th specimens into a single group.

A moderate positive correlation was found between CAL band number and the acromial attachment width: R = 0.429, r^2 = 18%, P < 0.001. Another strong positive correlation was observed between the band number and the coracoid attachment width: R = 0.547, r^2 = 30%, P < 0.001. However, there was no association between band number and the lateral length of the CAL: R = -0.090, P = 0.184.

3.1.2.4 Analysis of Variance

A one-way ANOVA comparison of CAL parameters according to the band number of the CAL showed several significant differences. First, very high significant differences were found between the number of bands according to both acromial and coracoid widths (P < 0.001). Three band ligaments had wider attachments to both the acromion and coracoid processes than did the one and two band ligaments (Table 3.6). Two band ligaments were also wider than one band ligaments at both attachment sites. Similar differences were also noted in relation to the attachment ratios at both attachment ends (P < 0.001). However, the lateral length of the one band ligaments was longer than that of the two and three band forms (P < 0.05). All ligament types had almost the same medial length.

Table 3.6 One way ANOVA comparison of CAL parameters according to the number of bands present.

CAL Parameters	CAL bands	N	Mean (mm)	Comparison P Value
Acromial Width	1 2 3	35 84 101	12.82 ± 3.3 15.35 ± 3.6 17.56 ± 3.9	1 < 2 < 3 P < 0.001
Coracoid Width	1 2 3	35 84 101	18.72 ± 7.2 32.37 ± 5.6 35.38 ± 4.9	1 < 2 < 3 P < 0.001
Lateral Length	1 2 3	35 84 101	40.08 ± 5.8 37.08 ± 5.0 37.6 ± 5.4	1 > 2 & 3 P < 0.05
Medial Length	1 2 3	35 84 101	31.74 ± 4.7 33.13 ± 4.8 33.28 ± 4.4	1 = 2 = 3 P > 0.05

- CAL band numbers: one band (1), two bands (2), and three or more bands (3).

Regarding thickness, the three band ligaments were significantly thicker (P = 0.021) at the acromial side than one band ligaments: 2.17 ± 0.7 mm compared to 1.84 ± 0.5 mm, respectively. In addition, very high significant differences were noted between the two and three band forms with regards to the space and division length between the lateral and medial bands (P < 0.001). The space between the lateral and medial bands was greater in two band ligaments than in three band ligaments: 11.42 ± 4.7 mm compared to 8.30 ± 4.0 mm, respectively. The length of the CAL before dividing into lateral and medial bands from the anterior acromial edge in three band ligaments was longer than in two band ligaments: 14.91 ± 5.1 mm compared to 11.39 ± 5.8 mm, respectively. However, the angle between the lateral and first medial band showed no significant difference between two (34.90 ± 8.0°) and three band ligaments (33.43 ± 9.7°) (P = 0.275).

With respect to side, one-way ANOVA did not show any significant differences in any CAL parameters between right and left shoulders (P > 0.05). However, significant differences were observed between the CAL parameters of male and female specimens (Table 3.7), with male shoulders having larger CALs than female shoulders (P < 0.001). These differences can be explained by both the acromial and coracoid widths and lateral and medial lengths. In addition, male shoulders had thicker (P = 0.047) acromial attachments than female shoulders: 2.14 ± 0.6 mm and 1.97 ± 0.6 mm, respectively. Moreover, male shoulders had a wider space between the lateral and medial bands and a greater division length than female shoulders: 10.41 ± 5.1 mm and 14.27 ± 5.9 mm compared to 8.99 ± 4.0 mm and 12.33 ± 5.4 mm, respectively. Finally, comparing the parameters of the CAL according to the age of the specimens did not show any significant differences between age levels (P > 0.05). Only one difference was found between the 70th and 80th decade specimens regarding the width of the space between the lateral and medial bands (P = 0.035): 10.79 ± 5.5 mm and 8.62 ± 3.7 mm, respectively.

Table 3.7 Independent samples T-test comparison of CAL parameters according to sex.

CAL Parameters	Sex	N	Mean (mm)	P Value
Acromial Width	F	110	15.01 ± 4.0	< 0.001
	M	110	16.92 ± 3.9	
Coracoid Width	F	110	28.64 ± 7.3	< 0.001
	M	110	34.52 ± 7.6	
Lateral Length	F	110	35.21 ± 3.8	< 0.001
	M	110	40.38 ± 5.5	
Medial Length	F	110	31.32 ± 3.9	< 0.001
	M	110	34.63 ± 4.7	

- Sex: Female (F), Male (M).

3.1.3 CAL Attachment Sites

3.1.3.1 Acromial Attachment

The acromial attachment ratio of the CAL ranged from 0.41 to 2.03 of the anterior length of the acromion, with a mean of 0.93 ± 0.2. As a result, the CAL extended beyond the anteromedial corner of the acromion in 132 of 220 specimens (60%) and involved the ACJ in 109 specimens (49.5%). The mean width of the CAL involving the ACJ was 5.75 ± 2.4 mm. This formed 34% of the total width of the CAL at the acromial attachment and 33% of the length of the ACJ acromial facet. The CAL was restricted to the anterior edge of the acromion in 88 of 220 specimens (40%). Ligaments with a medial extension at the acromion side were called medial acromion attachment, while ligaments restricted to the anterior edge of acromion were called anterior or lateral acromion attachment.

In this study there were more CALs with medial than anterior acromial attachments ($P = 0.004$). There was no association between the acromial attachment and side, sex and age ($P > 0.05$) (Table 3.8). However, there was a moderate significant relationship between CAL band number and the CAL acromial attachment ($P < 0.001$). CALs with one band were found predominantly attached to the anterior edge of the acromion. On the other hand, CAL with three or more bands were found to have a significant attachment extending beyond the anteromedial corner of the acromion (Figure 3.9).

Table 3.8 Pearson Chi-squared test to evaluate association between the acromial attachment sites and factors such as side, sex, age decade groups and CAL band number.

Factors	Levels	N	Acromial Attachment		Association	
			Anterior (88)	Medial (132)	P Value	Rate
Side	Right	103	42 (52.5%)	61 (48.4%)	0.668	0.040
	Left	103	38 (47.5%)	65 (51.6%)		
Sex	Male	110	46 (52.3%)	64 (48.5%)	0.680	0.037
	Female	110	42 (47.7%)	68 (51.5%)		
Age Levels	≤ 69 Years	17	8 (9.1%)	9 (6.8%)	0.241	0.139
	70th	68	25 (28.4%)	43 (32.6%)		
	80th	84	29 (33.0%)	55 (41.7%)		
	≥ 90 years	51	26 (29.5%)	25 (18.9%)		
CAL Bands Number	1 Band	35	29 (33.0%)*	6 (4.5%)	<0.001	0.424
	2 Bands	84	36 (40.9%)	48 (36.4%)		
	3 Bands	101	23 (26.1%)	78 (59.1%)*		

- Side: only bilateral shoulders were considered.
- Significant association (*).

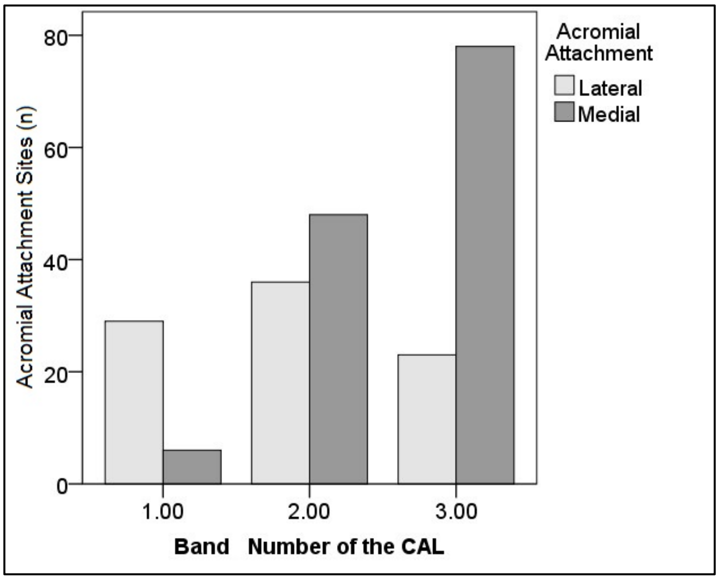


Figure 3.9 Association of the acromial attachment sites of the CAL to CAL band number.

3.1.3.2 Coracoid Attachment

The coracoid attachment ratio of the CAL ranged from 0.21 to 1.01 of the length of coracoid, with a mean of 0.74 ± 0.2. The lateral band of the CAL was continuous with fibres of the joint tendon of coracobrachialis and short head of the biceps in 65 of 147 specimens (44%) with mean width of 4.68 ± 1.7 mm. Medially, the coracoid attachment extended beyond the root of the coracoid in 164 of 220 specimens (74.5%). The CAL was restricted to the posterior aspect of coracoid in 56 of 220 specimens (25.5%). Ligaments with a medial extension of CAL into the coracoid root were called medial coracoid attachments, while ligaments with a restricted attachment to the posterior coracoid surface were called lateral coracoid attachments.

In this study there were significantly more CALs with medial than lateral coracoid attachments ($P < 0.001$). There was no association between the coracoid attachment and side, sex or age ($P > 0.05$) (Table 3.9). However, there was a strong association between the coracoid attachment site and the number of CAL bands ($P < 0.001$). One band ligaments were significantly attached to the lateral side of the coracoid, while both two and three band ligaments were significantly attached to medial side of the coracoid (Figure 3.10).

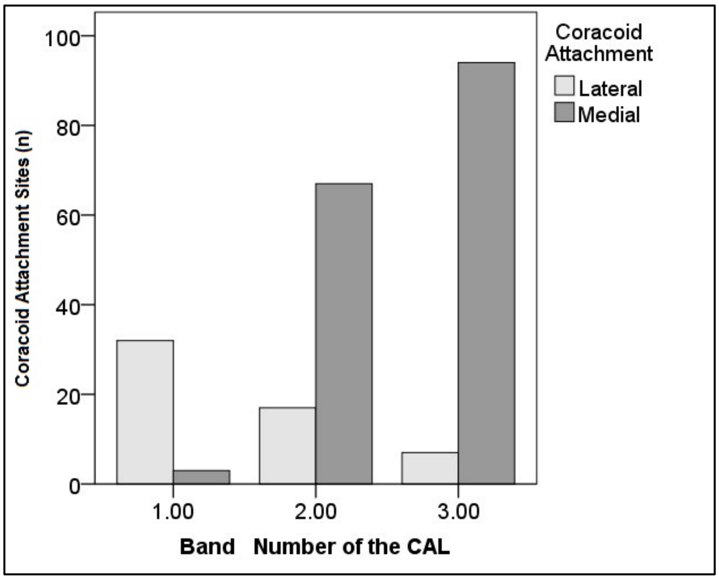


Figure 3.10 Association of the coracoid attachment site of the CAL with CAL band number.

Table 3.9 Pearson Chi-squared test to evaluate association between the coracoid attachment sites of the CAL and factors such as side, sex, age decade groups and CAL band number.

Factors	Levels	N	Coracoid Attachment		Association	
			Lateral (56)	Medial (164)	P Value	Rate
Side	Right	103	24 (48.0%)	79 (50.6%)	0.871	0.023
	Left	103	26 (52.0%)	77 (49.4%)		
Sex	Male	110	28 (50.0%)	82 (50.0%)	1.000	0.000
	Female	110	28 (50.0%)	82 (50.0%)		
Age Levels	≤ 69 Years	17	7 (12.5%)	10 (6.1%)	0.310	0.303
	70th	68	19 (33.9%)	49 (29.9%)		
	80th	84	17 (30.4%)	67 (40.9%)		
	≥ 90 years	51	13 (23.2%)	38 (23.2%)		
CAL Bands Number	1 Band	35	32 (57.1%)*	3 (1.8%)	<0.001	0.673
	2 Bands	84	17 (30.4%)	67 (40.9%)*		
	3 Bands	101	7 (12.5%)	94 (57.3%)*		

- Side: only bilateral shoulders were considered.
- Significant association (*).

3.1.3.3 Acromial-Coracoid Attachment Sites

Combining both acromion and coracoid attachment sites produced four groups:

anterior acromial-lateral coracoid (41), medial acromial-lateral coracoid (15), anterior acromial-medial coracoid (47) and medial acromial-medial coracoid (117). The CAL band number examined against this combination, with the results showing a significant relationship between this combination and the CAL bands (P < 0.001) (Table 3.10). The one band ligament was significantly attached laterally at both the acromial and coracoid sites, while three or more band ligaments were significantly attached medially at both acromial and coracoid sites (Figure 3.11)

Table 3.10 Pearson Chi-squared test to evaluate the association between the acromial-coracoid attachment sites to CAL band number.

CAL Band Number	N	Acromion-Coracoid Attachment				Association	
		LL (41)	**ML (15)**	**LM (47)**	**MM (117)**	P Value	Rate
1 Band	35	28 (68.3%)*	4 (26.7%)	1 (2.1%)	2 (1.7%)	<0.001	0.519
2 Bands	84	12 (29.3%)	5 (33.3%)	24 (51.1%)	43 (36.8%)		
3 Bands	101	1 (2.4%)	6 (40.0%)	22 (46.8%)	72 (61.5%)*		

- Acromion-Coracoid attachment sites of CAL: laterally at both attachment ends (LL), medially at acromial and laterally at coracoid (ML), laterally at acromion and medially at coracoid (LM) and medially at both attachment ends (MM).
- Significant association (*).

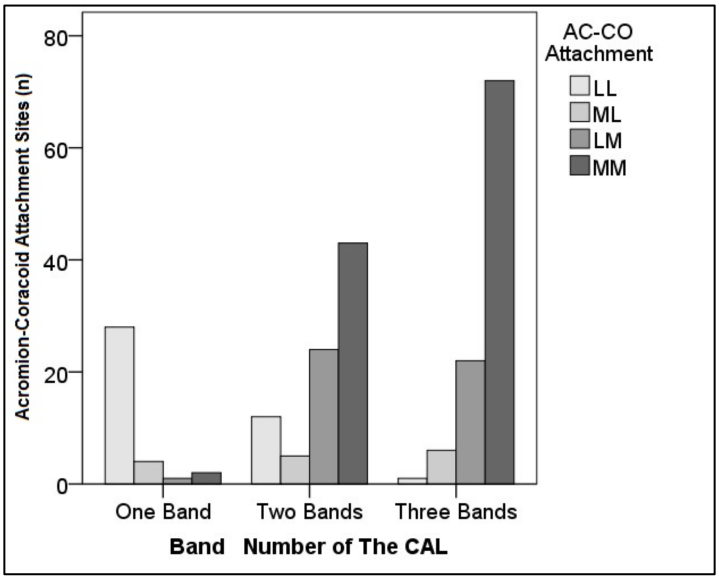


Figure 3.11 Association of the acromial-coracoid attachment sites of the CAL to the CAL band number.

Comparing the attachment widths and ratios of the CAL based on the acromial and coracoid attachment sites, showed that the medially attached ligaments had very high significantly wider attachments than the laterally attached ligaments ($P < 0.001$) (Table 3.11). The medial acromial attached ligaments were also significantly thicker ($P = 0.001$) than the lateral acromial attached ligaments at the acromial side: 2.17 ± 0.7 mm compared to 1.88 ± 0.5 mm, respectively. A similar situation was observed according to the coracoid attachment sites, medial coracoid attached ligaments had thicker acromial attachment ($P = 0.048$) than lateral coracoid attached ligaments: 2.11 ± 0.6 mm compared to 1.91 ± 0.6 mm, respectively. On the other hand, the lateral coracoid attached ligaments had significantly shorter medial side lengths ($P = 0.001$) than the medial coracoid attached ligaments: 31.23 ± 4.4 mm compared to 33.57 ± 4.5 mm, respectively. In addition, the space between the lateral and medial bands at the coracoid attachment site showed a significant difference ($P = 0.030$): 7.82 ± 2.7 mm for the lateral coracoid attachment and 10.00 ± 4.8 mm for the medial coracoid attachment.

Combining attachment groups of the CAL showed that ligaments with lateral acromial-lateral coracoid attachments had significantly shorter acromial and coracoid attachment widths than other attachment groups (P < 0.001) (Table 3.10). The medial acromial-medial coracoid group had a wider acromial attachment width (P < 0.001) than the lateral acromial-medial coracoid group. However, there was no difference (P = 0.283) between the medial acromial-medial coracoid group and the medial acromial-lateral coracoid group regarding acromial attachment width. On the other hand, the medial acromial-medial coracoid group had a wider coracoid attachment width than the lateral acromial-lateral coracoid and medial acromial-lateral coracoid groups (P < 0.001). Moreover, the lateral acromial-medial coracoid group had a wider coracoid attachment than the medial acromial-lateral coracoid group (P < 0.001).

Table 3.11 Independent samples T-test (one way ANOVA for combined acromial-coracoid attachments) comparison of CAL parameters according to the acromial and coracoid attachment sites.

Attachment Sites	CAL Parameters	Levels	N	Mean (mm)	Comparison P Value
Acromial	Acromial Width	Lateral Medial	88 132	13.89 ± 3.31 17.35 ± 3.89	< 0.001
	Coracoid Width	Lateral Medial	88 132	27.54 ± 9.42 34.27 ± 5.48	< 0.001
Coracoid	Acromial Width	Lateral Medial	56 164	13.48 ± 3.48 16.81 ± 3.87	< 0.001
	Coracoid Width	Lateral Medial	56 164	21.94 ± 7.50 34.87 ± 4.93	< 0.001
Combined Acromial-Coracoid	Acromial Width	L-L M-L L-M M-M	41 15 47 117	12.64 ± 2.73 15.79 ± 4.30 14.97 ± 3.42 17.55 ± 3.81	LL < All MM > LM < 0.001
	Coracoid Width	L-L M-L L-M M-M	41 15 47 117	19.75 ± 7.20 27.91 ± 4.59 34.33 ± 4.64 35.09 ± 5.05	LL < All MM > ML LM > ML < 0.001

- Acromion-Coracoid attachment sites of CAL: laterally at both attachment ends (LL), medially at acromial and laterally at coracoid (ML), laterally at acromion and medially at coracoid (LM) and medially at both attachment ends (MM).

With respect to acromial attachment thickness, the medial acromial-medial coracoid group was thicker (P = 0.017) than the lateral acromial-lateral coracoid group: 2.18 ± 0.7 mm compared to 1.83 ± 0.5 mm, respectively. The medial side length of the ligament with a lateral acromial-medial coracoid attachment site (35.19 ± 4.3 mm) was significantly longer than those with a lateral acromial-lateral coracoid (30.61 ± 4.3 mm) and medial acromial-medial coracoid (32.93 ± 4.5 mm) attachment groups: P < 0.001 and P = 0.018, respectively. Moreover, the medial acromial-medial coracoid attachment sites ligament had a longer medial length than the lateral acromial-lateral coracoid attachment sites ligament (P = 0.022). Regarding the space between the lateral and medial bands, the lateral acromial-medial coracoid ligaments had a wider space (P = 0.021) than the lateral acromial-lateral coracoid ligaments: 11.24 ± 4.9 mm compared to 7.09 ± 2.1 mm, respectively.

3.1.4 Formation of an Acromial Spur in CAL

Acromial spurs were detected mostly at the anterior edge of the acromion hidden within the CAL in 95 shoulders (43%) (P = 0.050). Of 104 cadavers, spurs were found bilaterally in 32 cadavers (31%) and unilaterally in 26 cadavers (25%). Shoulders with acromial spurs were significantly older than shoulders without spurs: 84.08 ± 8.06 years compared to 80.84 ± 9.7 years, respectively.

No association of significant incidence were found between acromial spurs and factors such as side, sex, age decade groups and CAL band number (P > 0.050), except a small association with the attachment site of the CAL (P < 0.050) (Table 3.12). Both medial acromial and coracoid attachments of the CAL were significantly associated with the formation of acromial spurs. High significant incidents of acromial spurs found in shoulders presented medial acromial attachment (72%) and medial coracoid attachment (85%) compared to shoulders with lateral acromial (28%) and coracoid (15%) attachments. However, combined acromial and coracoid attachment site groups showed no significant association with acromial spur formation. Furthermore, shoulders with a CAL falx had a small significant relationship with spur incidence ($P < 0.001$, Cramer's V = 0.257). Acromial spurs were found in 41 (63%) shoulders which had a CAL falx.

Shoulders with acromial spurs had a significantly wider and thicker CAL than those without acromial spurs ($P < 0.05$) (Table 3.13). Both acromial (17.03 ±3.8 mm) and coracoid attachments (32.97 ± 7.4 mm) of the CAL in shoulders with acromial spurs were wider than those in shoulders without acromial spurs: 15.15 ± 4.0 mm and 30.52 ± 8.3 mm ($P < 0.001$ and $P = 0.024$), respectively. The lateral and medial lengths of the CAL did not show any difference according to the presence or not of acromial spurs. However, differences in thickness were observed at the acromial site, the middle of the lateral band ligament, and the coracoid site for both the lateral and medial ligament bands ($P < 0.01$) (Table 3.12). Furthermore, shoulders with acromial spurs had a wider space between the lateral and medial ligament bands than shoulders without spurs: 10.59 ± 5.4 mm compared to 8.98 ± 3.6 mm ($P = 0.017$), respectively. The angle between the lateral and medial ligament bands showed no difference ($P = 0.068$) between shoulders with (35.97 ± 11.40˚) and without spurs (33.31 ± 8.3˚).

Table 3.12 Pearson Chi-squared test to evaluate the association between an acromial spur and factors such as side, sex, age decade groups, CAL band number, acromial and coracoid attachment sites.

Factors	Levels	N	Acromial Spur		Association	
			No (125)	Yes (95)	P Value	Rate
Side	Right	103	60 (51.7%)	43 (47.8%)	0.674	0.039
	Left	103	56 (48.3%)	47 (52.2%)		
Sex	Male	110	66 (52.8%)	44 (46.3%)	0.414	0.064
	Female	110	59 (47.2%)	51 (53.7%)		
Age Levels	<69 Years	17	12 (9.6%)	5 (5.3%)	0.100	0.170
	70th	68	43 (34.4%)	25 (26.3%)		
	80th	84	48 (38.4%)	36 (37.9%)		
	>90 years	51	22 (17.6%)	29 (30.5%)		
CAL Bands Number	1 Band	35	24 (19.2%)	11 (11.6%)	0.315	0.103
	2 Bands	84	46 (36.8%)	38 (40.0%)		
	3 Bands	101	55 (44.0%)	46 (48.4%)		
Acromion Attachment	Lateral	88	61 (48.8%)*	27 (28.4%)	0.003	0.206
	Medial	132	64 (51.2%)	68 (71.6%)*		
Coracoid Attachment	Lateral	56	42 (33.6%)*	14 (14.7%)	0.002	0.214
	Medial	164	83 (66.4%)	81 (85.3%)*		
Acromion-Coracoid Attachment	L-L	17	12 (9.6%)	5 (5.3%)	0.100	0.170
	M-L	68	43 (34.4%)	25 (26.3%)		
	L-M	84	48 (38.4%)	36 (37.9%)		
	M-M	51	22 (17.6%)	29 (30.5%)		

- Acromion-Coracoid attachment sites of CAL: laterally at both attachment ends (LL), medially at acromial and laterally at coracoid (ML), laterally at acromion and medially at coracoid (LM) and medially at both attachment ends (MM).
- Side: only bilateral shoulders were considered.
- Significant association (*).

Table 3.13 Independent samples T-test comparison of CAL parameters according to the presence of an acromial spur.

CAL Parameters	Spur	N	Mean (mm)	P Value
Acromial Width	No	125	15.15 ± 4.0	0.001
	Yes	95	17.03 ± 3.8	
Coracoid Width	No	125	30.52 ± 8.3	0.024
	Yes	95	32.97 ± 7.4	
Acromial Thickness	No	125	1.93 ± 0.6	0.001
	Yes	95	2.21 ± 0.7	
Middle Thickness	No	125	1.03 ± 0.2	0.003
	Yes	95	1.13 ± 0.3	
Lateral Band Thickness	No	125	1.23 ± 0.3	0.001
	Yes	95	1.38 ± 0.3	
Medial Band Thickness	No	46	0.76 ± 0.3	0.005
	Yes	38	0.98 ± 0.4	

3.1.5 Rotator Cuff Tears

Rotator cuff tears were observed in 77 of 155 specimens (50%). According to the type of tear the incidence of a rotator cuff tear was detected as follows: 37 specimens with a bursal partial tear, 33 specimens with a complete tear and 7 specimens with massive tears. They were detected more significantly ($P < 0.001$) bilaterally than unilaterally. Of 69 cadavers, bilateral tears were observed in 27 cadavers (39%) while unilateral tears were detected in 7 cadavers (10%). The same incidence of tear type was also found more significantly ($P = 0.020$) in both shoulders when they occurred: 26% (36 of 138 specimens) compared to 13% (18 of 138 specimens), respectively. The incidence of tear type was as follows: 18 (50%) specimens had a partial tear, 16 (44%) specimens had a complete tear and 2 (6%) specimens had a massive tear.

The incidence of rotator cuff tears in relation to various factors are displayed in Table 3.14. With respect to side almost the same incidence of tears was observed on both sides: 35 (51%) of right shoulders and 33 (48%) of left shoulders (P = 0.808). Right shoulders had a higher incidence of complete tears than left shoulders: 21 (60%) compared to 14 (40%), respectively. By comparison, left shoulders had a higher incidence of partial rotator cuff tears than right shoulders: 19 (58%) compared to 14 (42%), respectively. However, these differences were not significant and no association was found between rotator cuff tears and shoulder side (P > 0.05).

In relation to sex there was a greater incidence of rotator cuff tears in females than males: 50 (60%) compared to 27 (38%), respectively (P = 0.012). Concerning tear type, a difference was found in the incidence of partial tears only: 26 (70%) in female shoulders and 11 (30%) in male shoulders, respectively, (P = 0.020). Therefore, there was a small significant association between sex and rotator cuff tears (P = 0.010).

Regarding age, significant incidences of rotator cuff tear were found in specimens older than 90 years (68%) (P = 0.047). Inspecting the association between the rotator cuff tears and the cadavers age groups showed a small association (P = 0.008). Specimens in the 80th and 90 decades or older had a greater than 50% incidence of rotator cuff tears: 54.5% and 67.6%, respectively. Finally, shoulders with rotator cuff tears were an average older than those without: 83.87 years ± 8.6 compared to 79.56 years ± 9.9, respectively (P = 0.004). Concerning tear type there was a significant difference (P = 0.001) between the age of shoulders with complete tears (86.15 years ± 6.7) and those with normal rotator cuff tendons (79.56 years ± 9.9). However, there was no difference (P > 0.05) between the age of shoulders with partial tears (81.41

years ± 9.8) and those with complete tears or normal rotator cuff tendons.

Table 3.14 Pearson Chi-squared test to evaluate the association between rotator cuff tears and factors such as side, sex, age decade groups, CAL bands numbers, acromion and coracoid attachment sites, and spurs.

Factors	Levels	N	Rotator cuff Tendon		Association	
			Normal (n=78)	Tear (n=77)	P Value	Rate
Side	Right	69	34 (48.6%)	35 (51.5%)	0.865	0.029
	Left	69	36 (51.4%)	33 (48.5%)		
Sex	Male	71	44 (56.4%)*	27 (35.1%)	0.010	0.214
	Female	84	34 (43.6%)	50 (64.9%)*		
Age Levels	<69 Years	13	10 (12.8%)*	3 (3.9%)	0.009	0.274
	70th	50	31 (39.7%)*	19 (24.7%)		
	80th	55	25 (32.1%)	30 (39.0%)		
	>90 years	37	12 (15.4%)	25 (32.5%)*		
CAL Bands Number	1 Band	28	20 (25.6%)*	8 (10.4%)	0.042	0.202
	2 Bands	56	27 (34.6%)	29 (37.7)		
	3 Bands	71	31 (39.7%)	40 (51.9%)*		
Acromion Attachment	Lateral	54	36 (46.2%)*	18 (23.4%)	0.004	0.239
	Medial	101	42 (53.8%)	59 (76.6%)*		
Coracoid Attachment	Lateral	42	30 (38.5%)*	12 (15.6%)	0.002	0.257
	Medial	113	48 (61.5%)	65 (84.4%)*		
Acromion-Coracoid Attachment	L-L	28	20 (25.6%)*	8 (10.4%)	0.002	0.313
	M-L	14	10 (12.8%)	4 (5.2%)		
	L-M	26	16 (20.5%)	10 (13.0%)		
	M-M	87	32 (41.0%)	55 (71.4%)*		
Spur	No Spur	85	64 (82.1%)*	21 (27.3%)	<0.001	0.550
	Spur	70	14 (17.9%)	56 (72.7%)*		

- Acromion-Coracoid attachment sites of CAL: laterally at both attachment ends (LL), medially at acromial and laterally at coracoid (ML), laterally at acromion and medially at coracoid (LM) and medially at both attachment ends (MM).
- Side: only bilateral shoulders were considered.
- Significant association (*)

In relation to the CAL, there was a significant association between band number of the CAL and rotator cuff tears (P = 0.042). More than half of the specimens with three or more bands (56.3%) had rotator cuff tears, while around two thirds of specimens with one band ligament (71.4%) had normal rotator cuff tendons. However, this relationship was small: (Cramer's V = 0.202). Both the acromial and coracoid attachments of the CAL had a significant association with rotator cuff tears ($P < 0.01$). Shoulders with a lateral acromial attached CAL had significantly normal rotator cuff tendons, whereas shoulders with a medial acromial attached CAL had significantly more rotator cuff tears. Moreover, shoulders with a lateral coracoid attached CAL had significantly more normal rotator cuff tendons, whereas shoulders with medial coracoid attached CAL had significantly more rotator cuff tears. Combined acromial-coracoid attachments showed a moderate significant association with rotator cuff tears ($P = 0.002$) (Figure 3.12). Shoulders with a lateral acromial and coracoid attached CAL had significantly more normal rotator cuff tendons, while shoulders with medial acromial and coracoid attached CAL had significantly more rotator cuff tears.

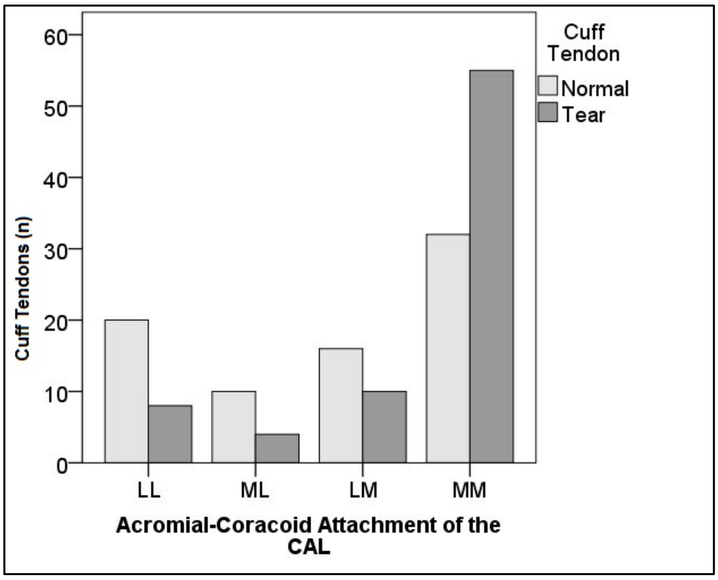


Figure 3.12 Association of a rotator cuff tear with the acromial-coracoid attachment sites.

A strong association was found between acromial spurs and rotator cuff tears ($P < 0.001$). Shoulders without acromial spurs (82.1%) were significantly associated with normal rotator cuff tendons. On other hand, shoulders with acromial spurs (72.7%) were strongly associated with rotator cuff tears (Figure 3.13). Investigating this relationship to the type of rotator cuff tear resulted in a strong relationship between spur incidence and both partial (64.9%) and complete tears (80.0%) (P < 0.001, Cramer’s V = 0.561), (Figure 3.14).

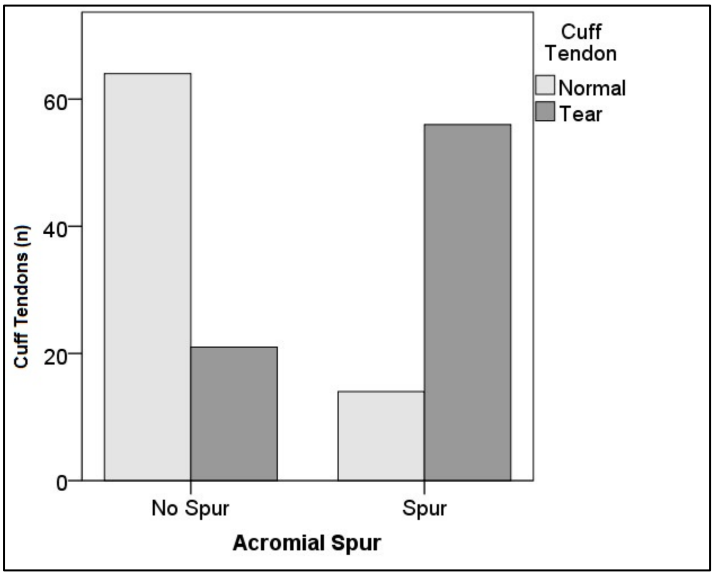


Figure 3.13 Association of rotator cuff tears to acromial spurs.

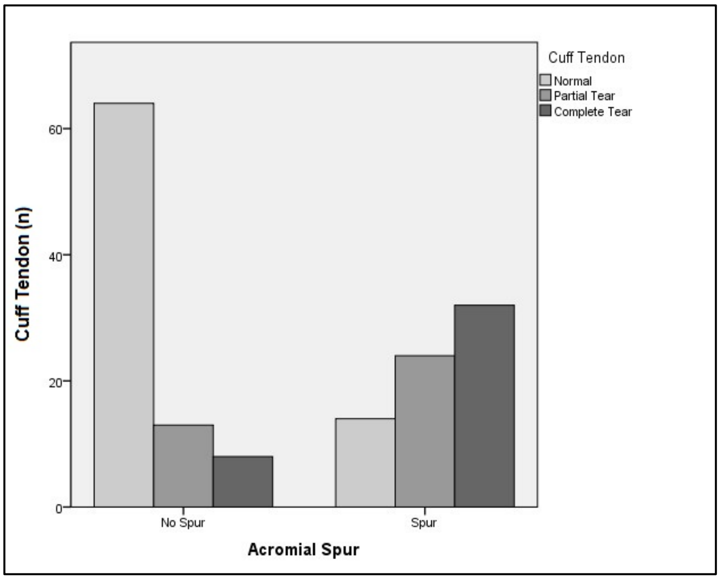


Figure 3.14 Association of rotator cuff tear type to acromial spurs.

According to rotator cuff tears significant differences were observed in relation to acromial and coracoid width and acromial and middle thickness of the CAL ($P < 0.05$) (Table 3.15). The CAL in shoulders with rotator cuff tears had wider acromial and coracoid attachments than those without tears: $P < 0.001$ and $P = 0.012$, respectively. However, the lateral and medial lengths of the CAL were the same in both types of shoulder ($P > 0.05$). The CALs in shoulders with rotator cuff tears were thicker at the acromial side ($P < 0.001$) and middle of the lateral ligament band ($P = 0.024$) than in shoulders without rotator cuff tears. However, the thickness of the lateral and medial ligament bands at the coracoid attachment side were not different in relation to rotator cuff tears: $P = 0.099$ and $P = 0.086$, respectively.

Table 3.15 Independent samples T-test comparison of CAL parameters according to the presence of rotator cuff tears.

CAL Parameters	Cuff Tear	N	Mean (mm)	P Value
Acromial Width	No	78	15.66 ± 4.1	0.001
	Yes	77	17.73 ± 3.7	
Coracoid Width	No	78	29.90 ± 9.4	0.012
	Yes	77	33.27 ± 7.0	
Acromial Thickness	No	78	1.78 ± 0.4	< 0.001
	Yes	77	2.19 ± 0.8	
Middle Thickness	No	78	1.02 ± 0.2	0.024
	Yes	77	1.11 ± 0.3	
Lateral Band Thickness	No	78	1.21 ± 0.3	0.099
	Yes	77	1.29 ± 0.3	
Medial Band Thickness	No	27	0.77 ± 0.3	0.086
	Yes	29	0.93 ± 0.4	

Considering these differences with respect to the type of rotator cuff tear showed no difference in the parameters of the CAL between shoulders with partial bursal tears and those with normal rotator cuff tendons (Table 3.16). Shoulders with complete rotator cuff tears had a wider and thicker CAL at the acromial side than shoulders with partial rotator cuff tears and those with normal rotator cuff tendons (P < 0.050). There was no difference in the thickness of the lateral band of the CAL between shoulders with normal and partial or complete rotator cuff tears (P > 0.050). On the other hand, thickness differences were found at both the middle of the lateral and medial bands between shoulders with complete rotator cuff tears and those with normal rotator cuff tendons (P < 0.050).

Table 3.16 One way ANOVA comparison of CALs according to the type of rotator cuff tears.

CAL Parameters	Cuff Tendon	N	Mean (mm)	Comparison(P Value)
Acromial Width	NL PT CT	78 37 40	15.66 ± 4.1 16.56 ± 3.0 18.81 ± 4.1	CT > NL (< 0.001) CT > PT (0.030)
Coracoid Width	NL PT CT	78 37 40	29.90 ± 9.4 32.78 ± 8.1 33.72 ± 5.8	> 0.050
Acromial Thickness	NL PT CT	78 37 40	1.78 ± 0.4 1.98 ± 0.7 2.38 ± 0.8	CT > NL (<0.001) CT > PT (0.011)
Middle Thickness	NL PT CT	78 37 40	1.02 ± 0.2 1.05 ± 0.2 1.17 ± 0.3	CT > NL (0.007)
Lateral Band Thickness	NL PT CT	78 37 40	1.21 ± 0.3 1.23 ± 0.3 1.35 ± 0.3	> 0.05
Medial Band Thickness	NL PT CT	27 11 18	0.77 ± 0.3 0.78 ± 0.3 1.02 ± 0.4	CT > NL (0.043)

- Cuff tendon: normal (NL), partial tear (PT), complete tear (CT).

Two way ANOVAs comparison of CAL parameters revealed five significant interactions between different factors (Table 3.17). There was a significant interaction between sex and spur for medial length of the CAL (P = 0.009). A significant difference was found in the mean medial length of the CAL between shoulders with and without spurs in male specimens: 36.23 ± 4.2 mm compared to 33.58 ± 4.8 mm in females. In addition, male specimens had a longer medial length of the CAL than female specimens in both shoulders with and without acromial spurs (Table 3.18).

Table 3.17 ANOVA, two-way interactions.

CAL Parameters	Two Ways Interactions	P Value
Medial Length	Sex * Spur	0.009
Medial Length	Acromial Attachment * Spur	0.002
Lateral Length	Coracoid Attachment * Spur	0.036
Middle Thickness	Acromial Attachment * Tear	0.009
Middle Thickness	Acromial Attachment * Tear Types	0.010

Table 3.18 Tow way ANOVA comparison of the mean medial length of the CAL between females and males according to the presence of an acromial spur.

Spur	Sex	N	Mean	P Value
No Spur	Female	59	31.51 ± 3.5	0.007
	Male	66	33.58 ± 4.8	
Spur	Female	51	31.11 ± 4.4	<0.001
	Male	44	36.23 ± 4.2	

Another significant association was found between acromial attachment and a spur for the medial length of the CAL (P = 0.002). With respect to the lateral acromial attachment shoulders with acromial spurs they had a longer medial CAL length than those without acromial spurs: 35.55 ± 5.2 mm compared to 31.96 ± 4.2 mm, respectively. In shoulders with acromial spurs no difference was found in the mean medial length of the CAL between the lateral and medial acromial attachments: 35.55 ± 5.2 mm and 32.66 ± 4.7 mm, respectively. On the other hand, interactions between spurs and the coracoid attachment of the CAL for the lateral length of the CAL was significant for the lateral coracoid attachment between shoulders with spurs (41.81 ± 7.5 mm) and those without (38.07 ± 5.5 mm), (P = 0.024). This significant interaction can be explained by the significant difference in the lateral length of the CAL between the lateral and medial coracoid attachments of the CAL in the spur group: 41.81 ± 7.5 mm compared to 37.32 ± 5.3 mm, respectively.

The middle thickness of the CAL showed a significant interaction between the acromial attachment of the CAL and rotator cuff tears (P = 0.009). In the medial acromial attached group shoulders with rotator cuff tears had a thicker CAL than shoulders with normal rotator cuff tendons: 1.16 ± 0.3 mm compared to 1.01 ± 0.3 mm respectively. This difference was also found in the rotator cuff tear group between the thickness of the lateral and medial acromial attachment ligaments: 0.96 ± 0.2 mm and 1.16 ± 0.3 mm, respectively. Furthermore, this interaction was also significant with the type of rotator cuff tear (P = 0.010). In the medial acromial attachment group shoulders with complete rotator cuff tears had a thicker CAL ligament at the middle of the lateral band than shoulder with normal rotator cuff tendons: 1.23 ± 0.3 mm compared to the 1.01 ± 0.3 mm, respectively. However, there was no difference in thickness between shoulders with a partial tear (1.08 ± 0.2 mm) and either shoulders with normal rotator cuff tendons or complete tears. Furthermore, the significance of this interaction can be explained by the difference in the complete tear group between the medial and lateral acromial attachment ligaments: 1.23 ± 0.3 mm and 0.9 ± 0.2 mm, respectively.

Finally, there was a significant interaction between band number of the CAL, spurs and rotator cuff tears for the acromial width of the CAL (P = 0.005). Simple interaction comparisons for two band ligaments in the no spur group showed that shoulders with rotator cuff tears had wider acromial attachments

(18.89 ± 3.6 mm) than those with normal rotator cuff tendons (14.66 ± 3.2 mm). However, this comparison was not significant in the one and three band ligaments or in the spur group for two band ligaments.

3.2 Second Stage Results

3.2.1 Morphology and Size of the Acromial Spur

Inspecting the 60 specimens showed that acromial spurs had formed in 33 specimens (55%). Small acromial spurs had formed and were restricted to the anterolateral portion of the subacromial surface in 10 specimens (30.3%). Larger spurs were found to extend into or beyond the anterior and lateral edges of acromion (deltoid muscle attachment sites) in 7 specimens (21.2%), while in 16 specimens (48.5%) spurs reached the medial edge of the acromion covering the entire anterior portion of the subacromial surface. Acromial spurs therefore extended along the CAL at the anterior edge of acromion in 23 specimens (38%). With respect to the appearance of the subacromial surface, 34 specimens (56.7%) had a smooth surface, 22 specimens (36.7%) had a rough surface and 4 specimens (6.7%) had a polished or eburnated surface (Figure 3.15). Shoulders with rough and eburnated subacromial surfaces were showed also equivalent changes on the head of humerus. There was a significant positive correlation between the surface appearance and the severity of degenerative changes at the insertion of the CAL ($R = 0.675$, $P < 0.001$). In addition, shoulders with rough and eburnated surfaces were older than shoulders with smooth surfaces ($P = 0.027$): 84.42 ± 8.2 years compared to 79.32 ± 8.9 years, respectively.

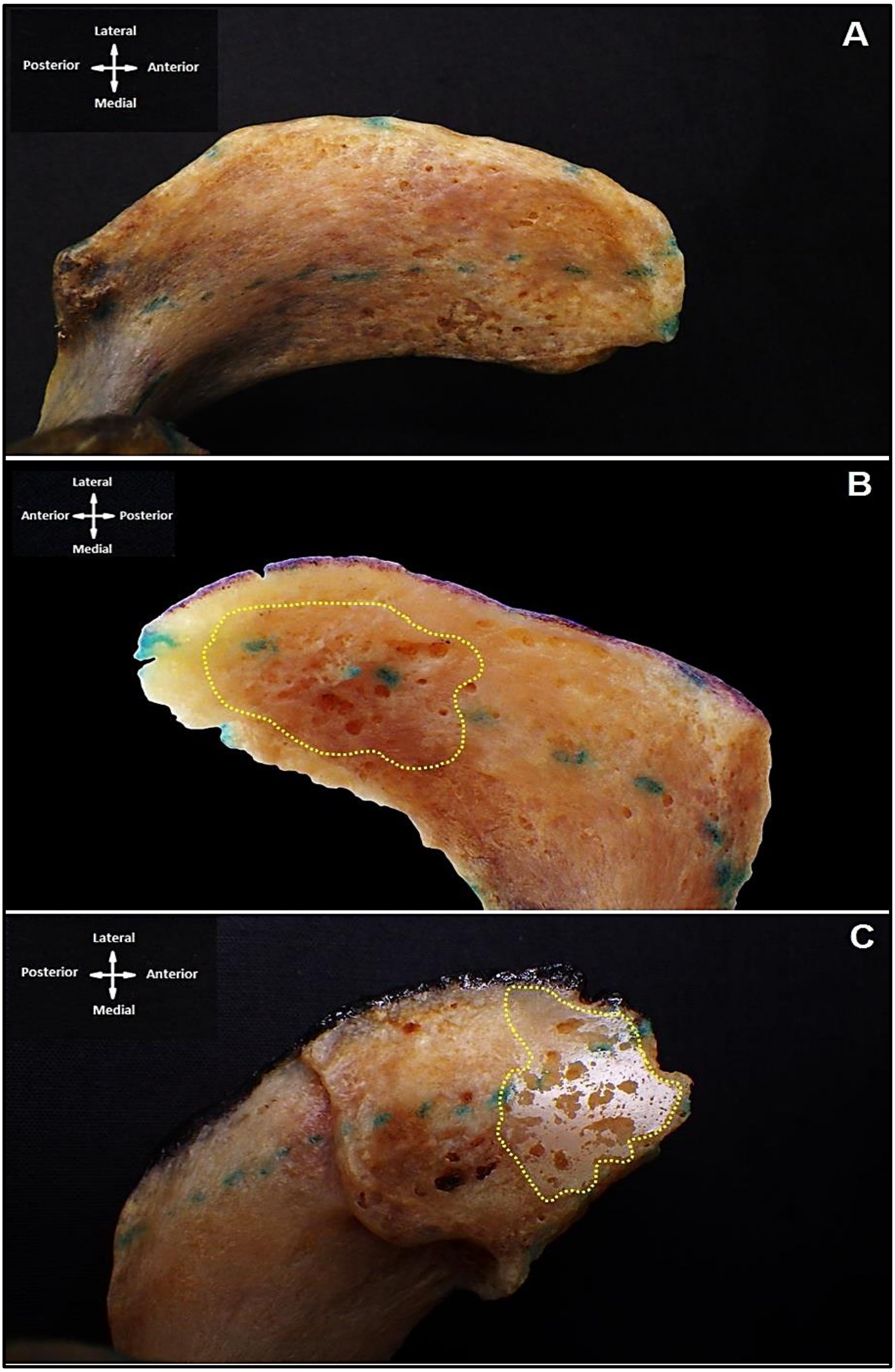


Figure 3.15 Inferior views of the acromion showing the appearance of the subacromial surface: (A) smooth surface, (B) rough (reaction) surface (dashed area), (C) eburnated (polished) surface (dashed area).

The mean length of acromial spurs was 24.11 ± 5.3 mm, while the mean width was 10.67 ± 5.1 mm. The size or circumference of acromial spurs was 19.29 ± 13.22 cm^2 occupying 25.3% of the subacromial surface. Comparing spur parameters did not show any significant correlation with the age of specimens ($P > 0.050$). In addition, there was no difference in the size of acromial spurs according to side (right = 17.89 ± 12.1 cm^2 compared to left = 18.56 ± 9.8 cm^2, P = 0.866) or sex (male = 20.55 ± 12.6 cm^2 compared to female = 16.85 ± 10.0 cm^2, P = 0.359). At the anterior edge of the acromion the mean length of anterior extending spurs was 6.20 ± 2.4 mm, the mean width was 12.57 ± 3.0 mm and the mean thickness 4.09 ± 0.9 mm. A large significant correlation was found between the circumference of acromial spurs and the area of subacromial insertion of the CAL ($R = 0.634$, $r^2 = 0.403$, $P < 0.001$) and between the width of anterior extending spurs and the width of the acromial attachment of the CAL ($R = 0.607$, $r^2 = 0.369$, $P = 0.002$) (Figures 3.16 and 17). Finally, positive significant correlations were found between spur width at the anterior of the acromion and both CAL morphology and band number ($R = 0.668$, $P < 0.001$).

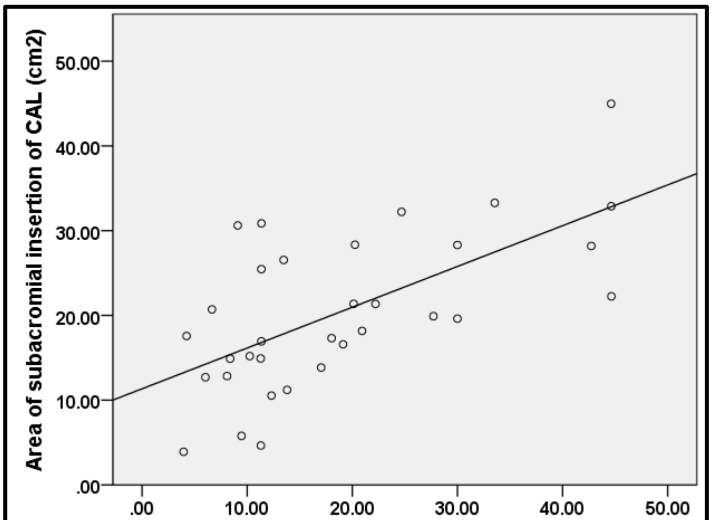


Figure 3.16 Pearson correlation between spur circumference and the area of subacromial insertion of CAL: $R = 0.634$, $r^2 = 0.403$, $P < 0$ 0.001.

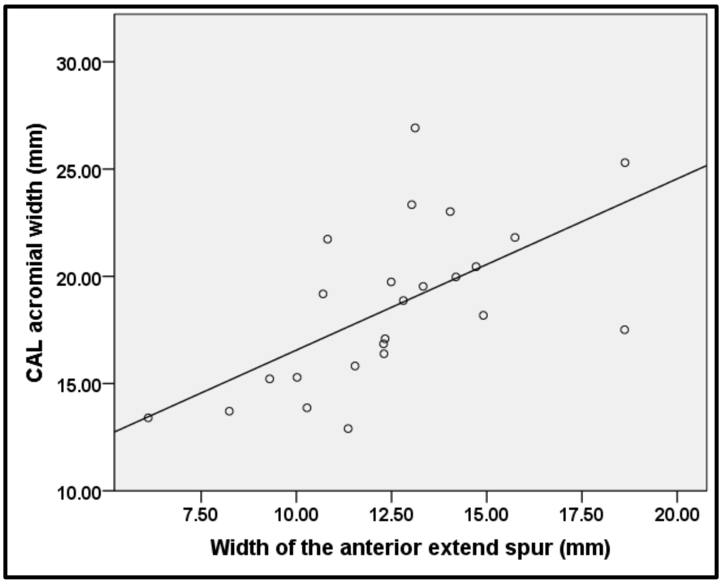


Figure 3.17 Pearson correlation between the width of anterior extending spurs and the acromial width of the CAL: R = 0.607, r^2 = 0.369, P = 0.002.

3.2.1.1 Classification of Acromial Spurs

3.2.1.1.1 Subacromial Spurs

Acromial spurs can be classified into three sizes according to their extensions on the undersurface of acromion: small, medium and large (Figure 3.18). Small spurs were found in 10 specimens (16.7%) being restricted to the subacromial surface and parallel to the deltoid margin. They usually had a round inferior surface characterised by smooth surface, as well as linear shape parallel to the lateral edge of the anterior portion of the acromion. Medium spurs were found in 14 specimens (23.3%) being characterised by extending to the anterior tip of the acromion. Thy had flat inferior surface characterised with traction or straight marks. Large claw acromial spurs were found in 9 specimens (15%) with cup-shaped or facet formation on the inferior surface of the spur. Large spurs were also characterized by claws usually around the formed facet at the undersurface of acromion. Using this classification, statistical analysis showed no difference in the length of spurs, but there was a difference in their width and circumference (Table 3.19). Large spurs were wider than small and medium spurs (P < 0.001 and P = 0.001, respectively), with medium spurs also being wider than small spurs (P < 0.001). Large and medium spurs had larger circumference areas compared to small spurs (P < 0.001 and P = 0.005, respectively), however there was no difference in the circumference area between large and medium spurs (P = 0.212).

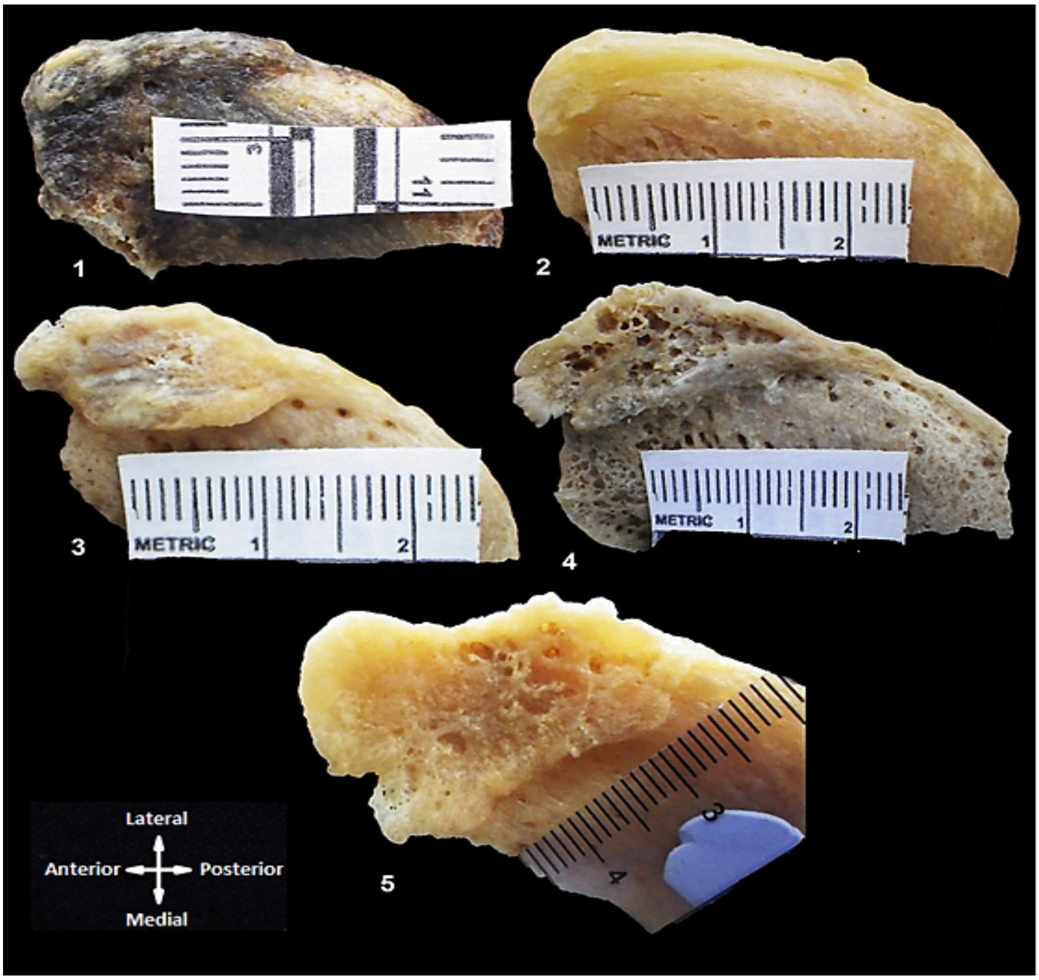


Figure 3.18 Inferior views of the acromion: showing different spurs that can be classified into small spurs (1 & 2), medium spurs (3 & 4), and large spurs (5). Small spurs are found at the lateral side of the anterior portion of the subacromial surface: they have a linear or oval shape extending to the anterior edge of the acromion. Medium spurs are larger than small spurs and are characterised by an anterior extension beyond the tip of the acromion and raised edges over the subacromial surface. Large spurs reach the medial edge of the acromion and are characterised by claws and a facet.

Table 3.19 One way ANOVA comparison of spur parameters according to the morphology of the spur.

Parameters	Spur morphology	N	Mean	Comparisons
Length (mm)	Small	10	21.47 ± 5.0	S = M (P = 0.127) S = L (P = 0.075) M = L (P = 0.455)
	Medium	14	24.59 ± 4.6	
	Large	9	26.29 ± 6.1	
Width (mm)	Small	10	5.17 ± 1.3	S < M (P < 0.001) S < L (P < 0.001) M < L (p = 0.001)
	Medium	14	10.85 ± 3.4	
	Large	9	16.42 ± 3.0	
Circumference (cm^2)	Small	10	8.07 ± 2.7	S < M (P< 0.001) S < L (P= 0.005) M = L (P= 0.212)
	Medium	14	20.32 ± 7.4	
	Large	9	27.75 ± 15.7	

- Spur morphology: small (S), medium (M), and large (L).

Inspecting the relationship between the morphology of acromial spurs and the appearance of the subacromial surface revealed a significant correlation: R = 0.707, r^2 = 0.500, P < 0.001 (Figure 3.19). A significant correlation was also found between the appearance and the spur size: circumference (R = 0.751, P < 0.001) and width (R = 0.771, P < 0.001). However, there was no association between the morphology of acromial spurs and the morphology or band number of the CAL (P = 0.237 and P = 0.367). Furthermore, no association was found between spur morphology and side or sex (P = 0.449 and P = 0.574, respectively). Regarding age, shoulders with large and medium spurs were older than shoulders without spurs (P = 0.003): 87.22 ± 10.2 years and 85.92 ± 7.0 years compared to 77.48 ± 6.6 years, respectively. There was no difference between the age of shoulders with small spurs (81.20 ± 11.0 years) and shoulders without spurs (P = 0.221), nor between the age of shoulders with different spur types (P > 0.050).

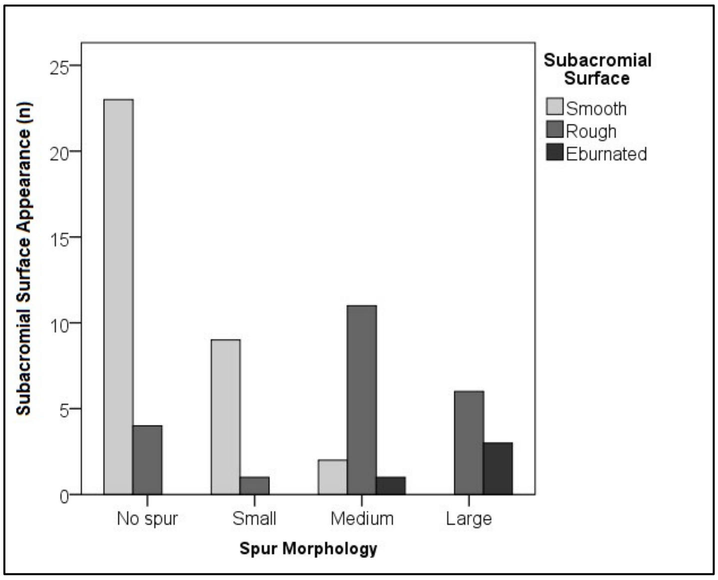


Figure 3.19 Spearman's correlation between the spur morphology and the appearance of the subacromial surface: R = 0.707, $r^2 = 0.500$, $P < 0.001$.

Comparing the size of the subacromial insertion of the CAL and the morphology of acromial spurs there were significant differences between the types of acromial spurs (P < 0.001) (Table 3.20). Shoulders with large spurs had a greater subacromial insertion than shoulders with medium and small spurs, as well as shoulders without acromial spurs. The size of the subacromial insertion of the CAL did not show differences between shoulders with small spurs and either shoulders with medium spurs or shoulders without acromial spurs. However, shoulders with medium spurs had a greater CAL subacromial insertion than shoulders without acromial spurs.

Table 3.20 One way ANOVA comparison of the area of the subacromial insertion of the CAL according to spur morphology.

Spur	Number	Mean (cm^2)	Comparisons (P Value)
No Spur	27	14.69 ± 6.6	N = S (P = 0.879) N < M (P = 0.026) N < L (P < 0.001) S = M (P = 0.094) S < L (P = 0.001) M < L (P = 0.024)
Small	10	14.29 ± 8.2	
Medium	14	19.99 ± 7.6	
Large	9	26.60 ± 5.35	

- Spur morphology: (N) no spur; (S) small spur; (M) medium spur; (L) large spur.

Regarding the acromial width of the CAL, shoulders with larger spurs had a wider acromial attachment than shoulders with small spurs and those without acromial spurs (Table 3.21). However, there was no difference in the acromial width of the CAL between shoulders with large and medium spurs, or between shoulders with medium and small spurs, or between shoulder with medium and small spurs and those without spurs.

Table 3.21 One way ANOVA comparison of the acromial attachment width of the CAL according to spur morphology.

Spur	Number	Mean (mm)	Comparisons (P Value)
No Spur	27	15.40 ± 3.6	N = S (P = 0.923) N = M (P = 0.070) N < L (P = 0.001) S = M (P = 0.171) S < L (P = 0.009) M = L (P = 0.178)
Small	10	15.27 ± 4.2	
Medium	14	17.77 ± 4.3	
Large	9	20.03 ± 2.6	

- Spur morphology: (N) no spur; (S) small spur; (M) medium spur; (L) large spur.

3.2.1.1.2 Anterior Acromial Spurs

Acromial spurs extending beyond the tip of the acromion were observed in 23 specimens (38.3%). The mean length of the extended part was 6.32 ± 2.4 mm, with a width of 12.58 ± 3.0 mm and thickness of 4.08 ± 1.0 mm. The length of anterior acromial spurs formed 25% of the length of the subacromial spur. Gross inspection revealed that anterior acromial spurs usually had a flattened subacromial surface, whereas the superior surface was concave. The anterior edge of spurs usually tapered with a curved or sharp line. The direction of anterior acromial spurs classified into straight (traction) spurs seen in 8 specimens (13.3%) and curved (claw) spurs, seen in 15 specimens (25%) (Figure 3.20). The dimensions of anterior acromion spurs did not show any difference between straight and curved spurs ($P > 0.050$) (Table 3.22).

However, comparing the total length of the spur (i.e. both subacromial and anterior acromial portions) showed that shoulders with anterior curved spurs were longer than those with anterior straight spurs ($P = 0.010$): 27.19 ± 4.2 mm compared to 21.62 ± 5.1 mm, respectively.

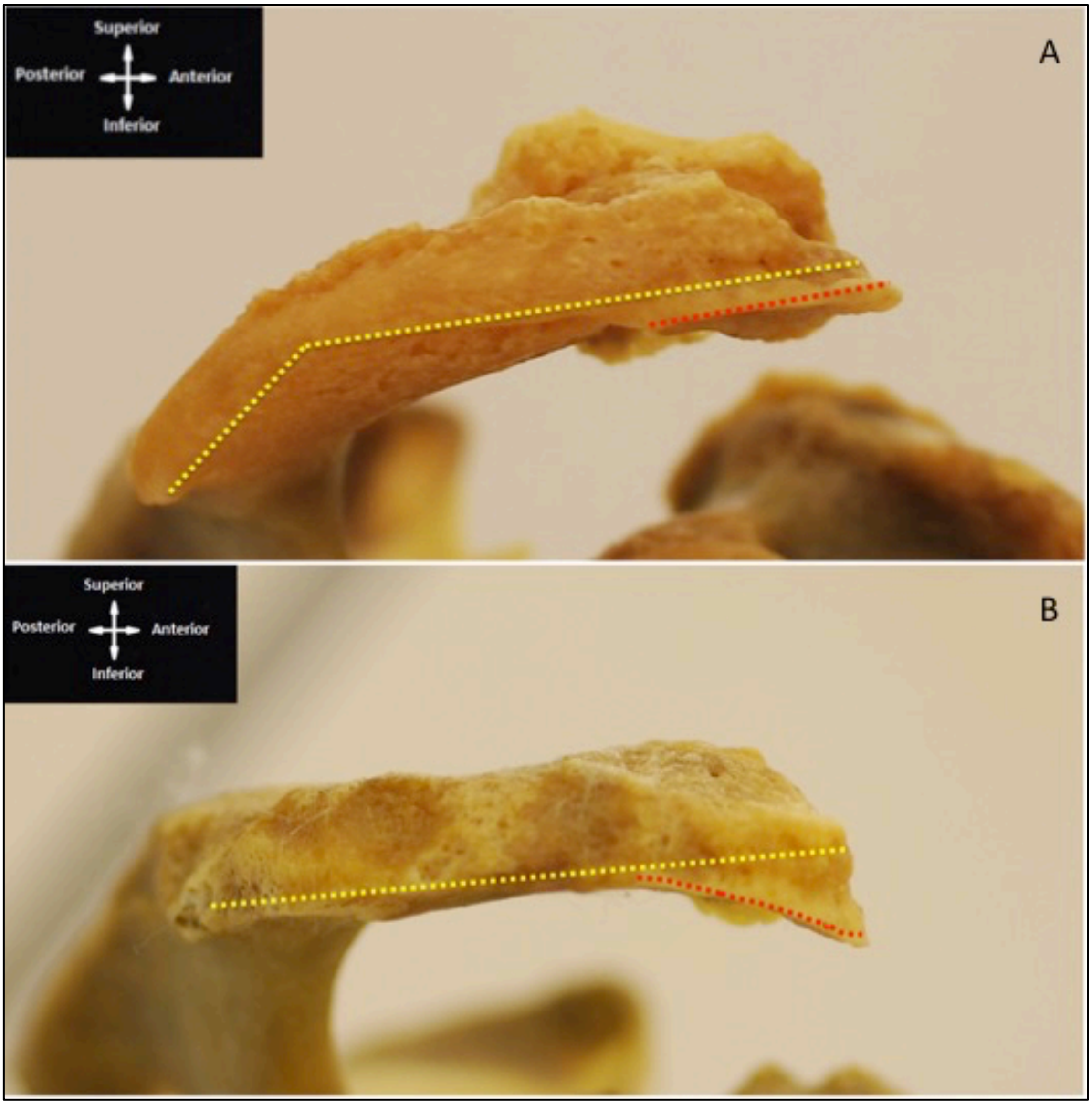


Figure 3.20 Lateral views of the acromion: showing the direction of anterior acromial spurs either straight (A) or curved (B), where the yellow dashed line is parallel to the lateral edge of the acromial and the red dashed line parallel to the lateral edge of the spur.

Table 3.22 Independent samples T-test comparison of anterior acromial spur parameters according to the direction of the spur.

Anterior acromial spur		N	Mean (mm)	P value
Length	Straight	8	5.67 ± 2.1	0.345
	Curved	15	6.66 ± 2.5	
Width	Straight	8	12.83 ± 3.9	0.653
	Curved	15	12.15 ± 1.9	
Thickness	Straight	8	3.63 ± 0.9	0.106
	Curved	15	4.27 ± 0.6	

Statistical analysis showed significant correlations between the appearance of the subacromial surface and the incidence (R = 0.770, r^2 = 0.593, P < 0.001) and direction of anterior acromial spurs (R = 0.727, r^2 = 0.529, P < 0.001) (Figure 3.21). However, the incidence and direction of anterior acromial spurs had no relationship with CAL morphology or band number (P > 0.050). With respect to side, there were 12 right shoulders (40%) with anterior acromial spurs compared to 11 left shoulders (36.7%). There was no association between the direction of anterior acromial spurs and shoulder side (P = 1.000). Moreover, anterior acromial spurs presented in 50% of male specimens compared to 32.5% in female specimens. There was a significant association between the direction of the anterior acromial spurs and sex (P = 0.045, Cramer’s V = 0.342), in which male specimens showed more curved spurs (60%) than female specimens (40%). Regarding age, specimens with anterior acromial spurs were significantly older than those without anterior acromial spurs (P < 0.001): 86.43 ± 8.2 years compared to 78.49 ± 8.0 years, respectively. However, there was no difference between the age of specimens with curved acromial spurs and those with straight acromial spurs (P = 0.895): 86.60 ± 8.4 years compared to 86.13 ± 8.5 years, respectively.

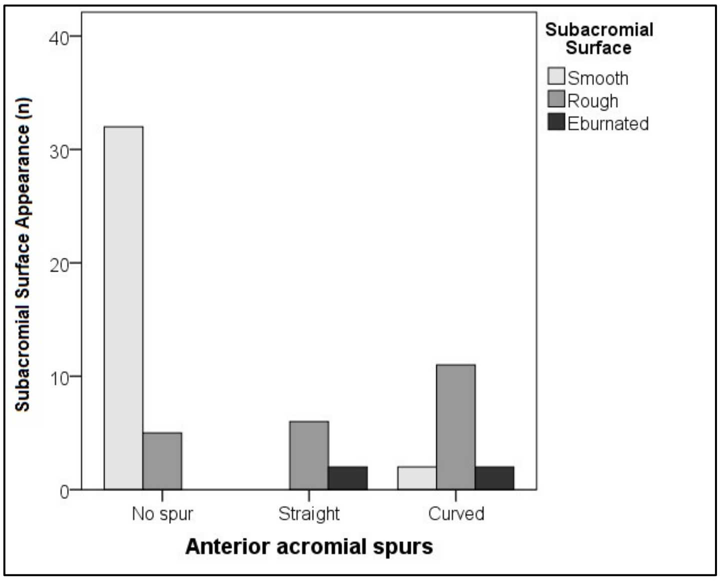


Figure 3.21 Spearman's correlation between the direction of the anterior acromial spurs and the appearance of the subacromial surface: R = 0.727, $r^2 = 0.529$, P < 0.001.

3.2.1.1.3 Subacromial Facet

A subacromial facet is a concave area found on the undersurface of the acromion equivalent to the convexity of the head of humerus. Gross inspection of the subacromial surface showed a subacromial facet in 17 specimens (28.3%). According to Gray (1942), subacromial facets can be classified into elevated and sunken facets (Figure 3.22). The elevated facet (cupping spur) is found on the inferior surface of a subacromial spur with claws surrounding the facet: this was observed in 9 specimens (15%). The sunken facet is also found on the subacromial surface but without claw formation around it: this was observed in 8 specimens (13.3%). Three specimens (37.5%) with sunken facets had acromial spurs, while five specimens (62.5%) had no spur formation.

Subacromial facets were observed in 9 right shoulders (30%) and 8 left shoulders (26.6%). It presented as bilateral incidence in 8 shoulders (88.9%) compared to one shoulder with unilateral incidence (11.1%). In addition, symmetrical type incidences of subacromial facet were observed in 7 specimens (87.5%) compared to one shoulder (12.5%) with asymmetrical types. There was no association between the incidence of a subacromial facet and sex (P = 1.000), in which facets were observed in 6 male shoulders (30%) compared to 11 female shoulders (27.5%). However, shoulders with elevated subacromial facets were older than those with sunken facets: 87.22 ± 10.2 years compared to 75.00 ± 10.8 years, respectively.

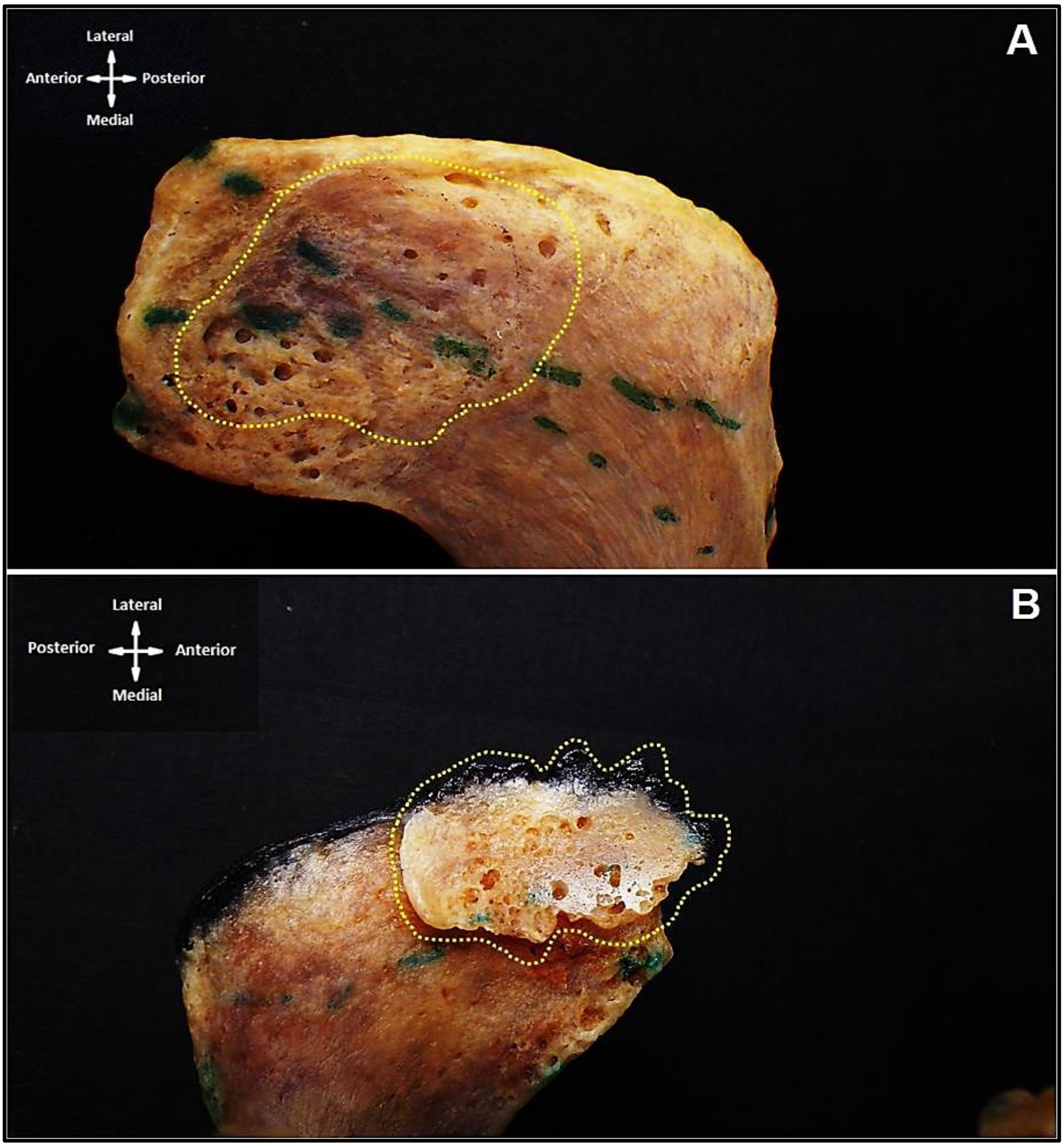


Figure 3.22 Inferior views of the acromion: showing formation of a subacromial facet that can be classified into sunken (flattened) facet (A) and raised (cupped) facet (B).

With respect to the CAL, there was no relationship between the incidence of subacromial facets and the morphology and band number of the CAL (P = 0.247 and P = 0.246, respectively). However, shoulders with subacromial facets had a larger CAL than shoulders without a subacromial facet (Table 3.23). The CAL in shoulders with subacromial facet had a wider acromial attachment and greater subacromial insertion than shoulders without a subacromial facet. Furthermore, shoulders with a subacromial facet showed a greater defect area in the subacromial insertion of the CAL than shoulders with a subacromial facet. Statistical analysis showed a significant association between subacromial facets and the presence of spurs at the anterior edge of the acromion (Cramer's V = 0.317 and P = 0.020) (Figure 3.23). Shoulders with subacromial facets had a significant incidence of anterior acromial spurs than shoulders without a subacromial facet: 64.7% compared to 30.2%, respectively.

Table 3.23 Independent samplets T-test comparison of CAL acromial width, subacromial insertion area, and defect area according to subacromial facet incidence.

CAL	Subacromial facet	N	Mean	P value
Acromial width (mm)	No	43	15.72 ± 4.2	0.005
	Yes	17	18.90 ± 2.7	
Subacromial insertion area (cm^2)	No	43	15.87 ± 7.6	0.004
	Yes	17	22.83 ± 9.2	
Defect area (cm2)	No	29	19.85 ± 16.2	< 0.001
	Yes	12	52.80 ± 23.9	

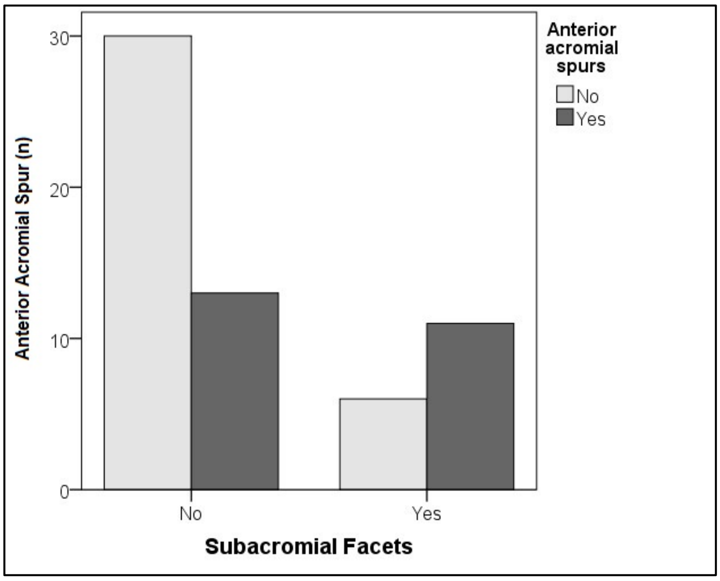


Figure 3.23 Association between subacromial facets and the presence of spurs at the anterior edge of the acromion: Cramer's V = 0.317 and P = 0.020.

3.2.1.2 Relation to Rotator cuff Tears

Comparing subacromial spur length and width in relation to rotator cuff tears showed a significant difference in the width (P < 0.001). Shoulders with cuff tears had wider subacromial spurs than shoulders with normal rotator cuff tendons: 11.51 ± 4.3 mm compared to 6.15 ± 1.2 mm, respectively. The mean length of subacromial spurs was 24.41 ± 5.0 mm in shoulders with rotator cuff tears and 23.42 ± 6.2 mm in shoulders with normal rotator cuff tendons. The circumference of acromial spurs in shoulders with rotator cuff tears was also larger than that in shoulders with normal rotator cuff tendons: 23.73 ± 13.5 cm^2 compared to 9.07 ± 2.8 cm^2. However, according to the type of rotator cuff tear, there was a significant difference in the mean width and circumference of the subacromial spur between complete tears and normal rotator cuff tendons (Table 3.24). Regarding the dimensions of anterior acromial spurs, there was no difference between shoulders with complete tears and those with partial tears (P > 0.050) (Table 3.25). However, there was insufficient incidence of anterior acromial spurs with normal rotator cuff tendons to compare to tear groups.

Table 3.24 One way ANOVA comparison of spur dimensions according to the type of rotator cuff tear.

Spur	Rotator Cuff	Number	Mean	Comparison (P Value)
Length (mm)	N	10	23.42 ± 6.2	N = P (P = 0.442) N = C (P = 0.861) P = C (P = 0.392)
	P	7	25.80 ± 6.0	
	C	16	23.80 ± 4.6	
Width (mm)	N	10	6.15 ± 1.2	N = P (P = 0.062) N < C (P < 0.001) P = C (P = 0.599)
	P	7	10.77 ± 5.3	
	C	16	11.83 ± 3.9	
Circumference (cm^2)	N	10	9.07 ± 2.8	N = P (P = 0.055) N < C (P < 0.001) P = C (P = 0.886)
	P	7	23.10 ± 15.6	
	C	16	24.01 ± 13.1	

- Rotator cuff: normal (N); partial tear (P); complete tear (C).

Table 3.25 Comparison of anterior acromial spur dimensions according to the type of rotator cuff tears.

Anterior acromial spur	Cuff Tendon	N	Mean (mm)	P value
Length	Normal	2	7.86 ± 4.7	0.630
	Partial tear	6	6.35 ± 2.9	
	Complete tear	15	6.10 ± 1.9	
Width	Normal	2	13.86 ± 1.5	0.747
	Partial tear	6	12.98 ± 3.4	
	Complete tear	15	12.25 ± 3.1	
Thickness	Normal	2	4.56 ± 0.3	0.701
	Partial tear	6	4.20 ± 1.3	
	Complete tear	15	3.98 ± 0.9	

Inspecting the relationship between rotator cuff tears and spur classifications showed several significant results (Table 3.26). First, positive correlations were found between rotator cuff tears and the appearance of the subacromial surface, the spur site and spur shape. Similar significant correlations were found in relation to the type of rotator cuff tear, but were larger with spur site and spur shape classifications (Figure 3.24). Regarding subacromial facets, there was no correlation between rotator cuff tears and subacromial facet incidence or shape. However, correlations were found between the anterior acromial spur (both incidence and shape) and rotator cuff tears (both incidence and type) (Figure 3.25).

Table 3.26 Spearman's correlation between spur classifications and rotator cuff tears.

Classification	Rotator cuff tear			Types of rotator cuff tear		
	R	**R^2**	**P value**	**R**	**R^2**	**P value**
Subacromial surface	0.375	0.141	0.004	0.496	0.246	< 0.001
Spur site	0.444	0.197	0.001	0.538	0.289	< 0.001
Spur shape	0.438	0.192	0.001	0.531	0.282	< 0.001
Facet	0.048	0.002	0.779	0.065	0.004	0.655
Facet shape	0.083	0.007	0.575	0.107	0.011	0.039
Anterior spur	0.575	0.331	< 0.001	0.657	0.432	< 0.001
Anterior spur shape	0.543	0.295	< 0.001	0.618	0.382	< 0.001

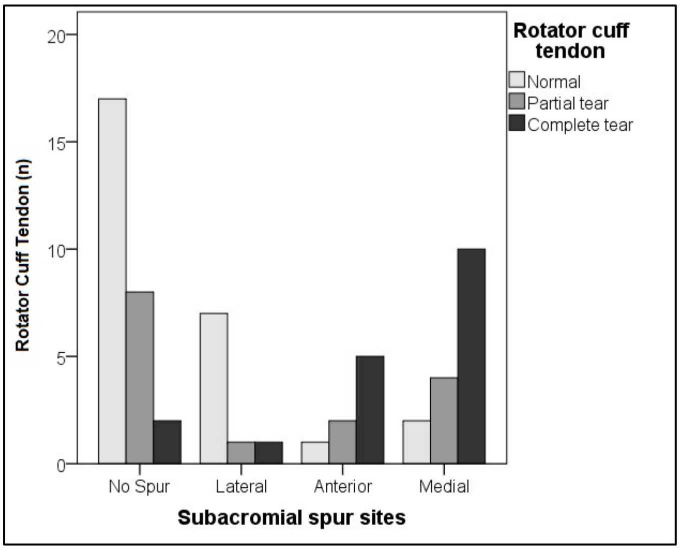


Figure 3.24 Spearman's correlation between the extension site of the subacromial spur and the type of rotator cuff tear.

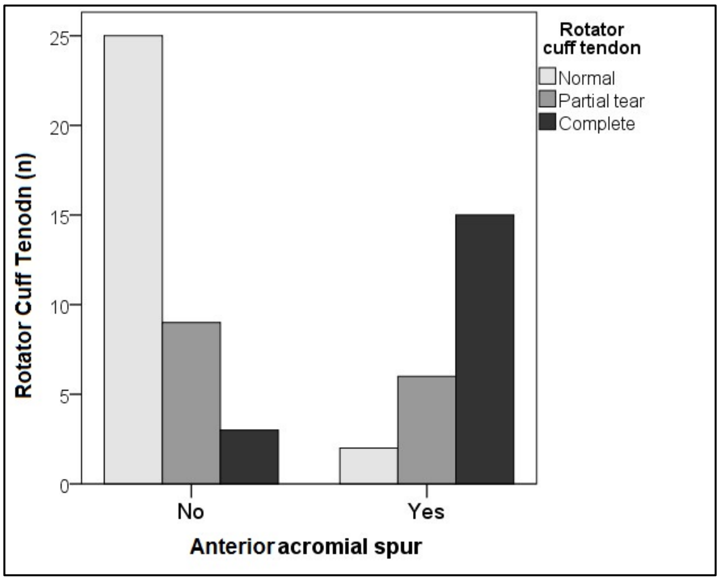


Figure 3.25 Spearman's correlation between anterior acromial spurs and the type of rotator cuff tear.

3.2.1.3 Acromion Dimensions to Spur Formation

The mean length of the anterior edge of the acromion was 18.26 ± 2.7 mm and of lateral edge 44.83 ± 5.9 mm. Acromion thickness at the anterolateral edge was 6.32 ± 1.0 mm. Comparing acromion dimensions according to acromial spurs showed a significant difference in both the anterior length and thickness, but not in lateral length (Table 3.27). Shoulders with acromial spurs were significantly had wider ($P = 0.020$) and thicker ($P < 0.001$) acromions than those without acromial spurs. Considering anterior acromial spurs, acromions with spurs were significantly longer than those without spurs ($P < 0.001$): 53.08 ± 7.0 mm compared to 43.56 ± 4.0 mm, respectively. However, comparing acromion dimensions according to morphology of subacromial spurs showed that acromion with large subacromial spurs had a longer acromion than shoulders with small subacromial spurs ($P = 0.005$): 48.97 ± 5.3 mm compared to 42.02 ± 4.8 mm, respectively. According to spur formation at the anterior edge of the acromion, acromions with anterior spurs were longer ($P = 0.025$) and thicker ($P = 0.003$) than shoulders without anterior acromial spurs: 46.96 ± 5.7 mm compared to 43.76 ± 4.9 mm, and 6.76 ± 0.9 mm compared to 6.07 ± 0.8 mm, respectively. However, there was no difference between acromion dimensions according to the appearance of the subacromial surface and the formation of subacromial facets (P > 0.050).

Table 3.27 Independent samples T-test comparison of acromion dimensions according to spur incidence.

Acromion	Spur	N	Mean (mm)	P value
Anterior edge length	No	27	17.36 ± 2.9	0.020
	Yes	33	18.91 ± 2.1	
Lateral edge length	No	27	44.69 ± 5.0	0.657
	Yes	33	45.33 ± 5.8	
Thickness	No	27	5.82 ± 0.7	< 0.001
	Yes	33	6.77 ± 0.8	

3.2.1.4 Coracoid-acromion space to spur formation

The mean length of the space between the anterior edge of the acromion and the posterior aspect of the coracoid (coracoacromial space) was 35.54 ± 6.6 mm. Both shoulder sides had similar lengths: 35.76 ± 6.4 mm on the right and 35.33 ± 7.0 mm on the left. Male shoulders had a significantly longer coracoacromial space than female shoulders (P = 0.005): 38.85 ± 7.3 mm compared to 33.89 ± 5.6 mm, respectively. With respect to anterior acromial spur formation, shoulders with spurs had a significantly shorter coracoacromial space (P < 0.001) than shoulders without spurs, being 30.91 ± 5.9 mm compared to 38.42 ± 5.3 mm, respectively. In addition, shoulders with rotator cuff tears had a significantly shorter coracoacromial space than shoulders with normal rotator cuff tendons (P = 0.004): 33.35 ± 6.4 mm compared to 38.22 ±

5.9 mm, respectively. However, there was no difference (P = 0.968) in the length of the coracoacromial space between shoulders with complete rotator cuff tears (33.31 ± 6.9 mm) and those with partial rotator cuff tears (33.40 ± 6.0 mm).

3.2.1.5 Acromion anterior-posterior curvature to spur formation

The anterior-posterior curvature of the acromion had a height of 5.26 ± 1.6 mm and slope angle of 26.41 ± 5.7º. Both shoulder sides had similar heights and slope angles (P > 0.050): 5.07 ± 1.2 mm and 25.93 ± 4.4º in right shoulders compared to 5.24 ± 1.5 mm and 26.60 ± 5.2º in left shoulders, respectively. According to gender, there was a significant difference in acromion height between males and females (P = 0.015), but not in the acromion slope angle (P = 0.090). Male shoulders (5.97 ± 1.8 mm) had a higher acromion curvature than female shoulders (4.84 ± 1.1 mm). The acromion slope angle was 28.03 ± 6.5º in males and 25.50 ± 4.7º in females.

With respect to anterior acromial spur formation, shoulders with acromial spurs had a greater acromial curvature than shoulders without spurs. Acromion height in shoulders with anterior acromial spurs was 6.35 ± 1.5 mm, which was greater than that in shoulders without spurs (4.51 ± 0.9 mm) (P < 0.001). Shoulders with anterior acromial spurs had greater acromial slope angles than shoulders without anterior acromial spur formation (P = 0.001): 29.28 ± 6.3º compared to 24.63 ± 4.4º, respectively. Comparing the primary (original) acromial curvature and that after considering spurs length at the anterior edge of acromion showed significant differences (P < 0.001): acromion slope = 29.13 ± 6.4º compared to 23.27 ± 6.3º, and acromial height = 6.40 ± 1.7 mm compared to 4.25 ± 1.5 mm, respectively. However, comparing the acromial original curvature in shoulders with acromial spurs to that in shoulders without acromial spurs showed no difference ($P > 0.050$): acromion slope = 23.27 ± 6.3º compared to 24.63 ± 4.4º, acromial height = 4.51 ± 0.9 mm compared to 4.45 ± 1.0 mm, respectively. Furthermore, there were significant differences in acromial curvature based on the direction of anterior acromial spurs (Table 3.28). Curved anterior acromial spurs showed a significantly greater acromial curvature height and slope than straight anterior acromial spurs. The length of the anterior acromial spur also showed a significant correlation with curvature of the acromion (Figure 3.26). With respect to the appearance of the subacromial surface, shoulders with a degenerative appearance (rough and eburnated surfaces) had higher acromial curvature than shoulders with smooth surfaces ($P = 0.007$): 5.95 ± 2.0 mm compared to 4.73 ± 1.0 mm, respectively. However, the acromial slope did not show any difference between the two groups ($P = 0.104$).

Table 3.28 Independent samples T-test comparison of acromial curvature according to the direction of anterior acromial spurs.

Acromial curvature	Spur	N	Mean (mm)	P value
Height (mm)	Straight	8	5.35 ± 1.3	0.018
	Curved	15	6.88 ± 1.4	
Slope (degree)	Straight	8	24.04 ± 2.7	0.001
	Curved	15	31.80 ± 5.3	

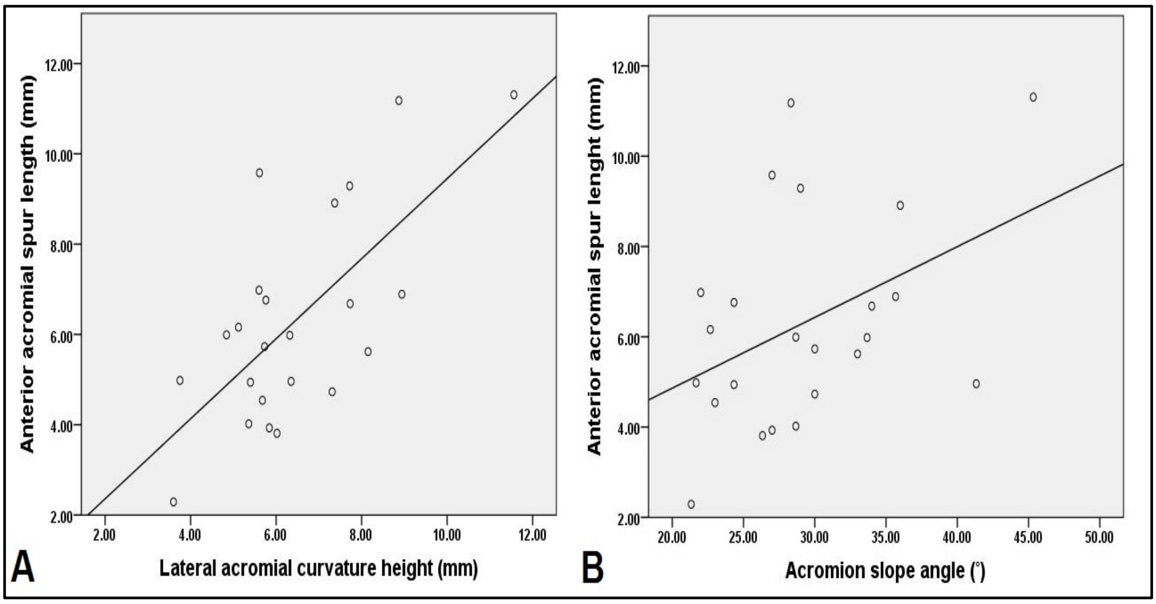
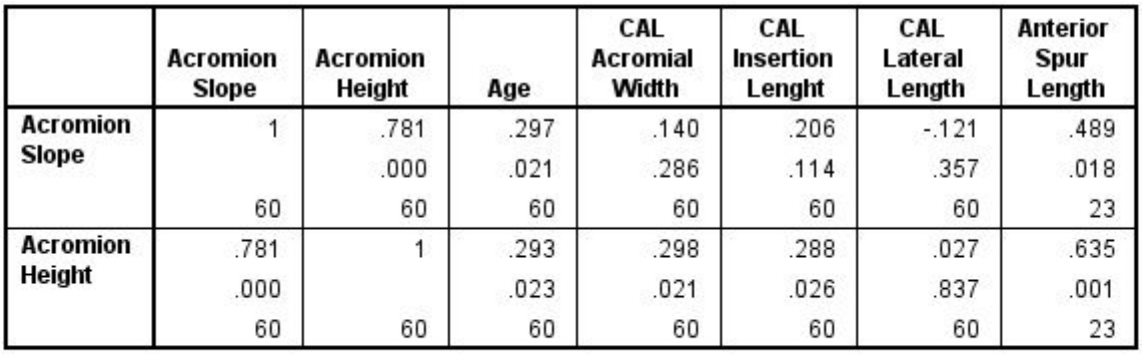


Figure 3.26 Pearson correlation between the length of the anterior acromial spur and lateral acromial curvature: (a) lateral acromial curvature height (R= 0.680, r^2 = 0.463, P < 0.001), (b) acromion slope angle (R = 0.420, r^2 = 0.176, P = 0.046).

Pearson correlation showed several significant relationships regarding acromial curvature (Table 3.29). A strong positive correlation was found between acromial slope and the height of the acromial curvature. Another strong correlation was found between the anterior spur length and acromion curvature height. However, an intermediate positive correlation was found between the anterior spur length and acromion slope. Small positive correlations were found between age and each of acromion slope and acromion curvature height. Inspecting the age according to rotator cuff tears showed no correlation in shoulders with intact rotator cuff tendons, while a larger significant correlation was found in shoulders with rotator cuff tears (R = 0.444, P = 0.010 for acromion slope, and R = 0.558, P = 0.001 for acromion height). With respect to the type of rotator cuff tears, there were strong correlations only in shoulders with partial rotator cuff tears: R = 0.799, P < 0.001 for acromion slope, and R = 0.851, P < 0.001 for acromion height. Inspecting the relationship between the CAL and acromial curvature showed significant weak positive correlations between acromion height curvature and each of CAL acromial width and insertion length.

Table 3.29 Pearson correlation table showing correlations between the acromion curvature slope and height to age, CAL parameters and spur length.



	Acromion Slope	Acromion Height	Age	CAL Acromial Width	CAL Insertion Lenght	CAL Lateral Length	Anterior Spur Length
Acromion Slope	1	.781	.297	.140	.206	-.121	.489
		.000	.021	.286	.114	.357	.018
	60	60	60	60	60	60	23
Acromion Height	.781	1	.293	.298	.288	.027	.635
	.000		.023	.021	.026	.837	.001
	60	60	60	60	60	60	23

With respect to age, individuals 90 years old or older had a greater acromion slope and height than other age groups (Table 3.30). Comparing acromial curvature with the incidence of rotator cuff tears showed a significant difference only in the height of the curvature. Shoulders with rotator cuff tears had a significantly higher acromial curvature than shoulders with normal rotator cuff tendons (P = 0.030): 5.48 ± 1.5 mm compared to 4.76 ± 0.9 mm, respectively. However, acromial slope angle showed no difference (P = 0.084) between shoulders with (27.22 ± 5.3°) and without tears (25.05 ± 4.1°). Furthermore, there was no difference in the acromial curvature between complete and partial tears: height 5.67 ± 1.4 mm compared to 5.24 ± 1.7 mm (P = 0.441), and slope angle 27.26 ± 5.0° compared to 27.18 ± 5.7° (P = 0.966), respectively.

Table 3.30 One way ANOVA comparison of acromion curvature (slope and height) according to age groups.

Acromion Curvature	Age Levels	N	Mean	Comparison (P Value)
Slope (°)	60	2	22.67 ± 6.6	90 > 60 (P = 0.034) 90 > 70 (P = 0.003) 90 > 80 (P < 0.001)
	70	26	25.65 ± 4.0	
	80	18	24.19 ± 5.1	
	90	14	30.67 ± 5.8	
Height (mm)	60	2	3.67 ± 1.1	90 > 60 (P = 0.009) 90 > 70 (P = 0.004) 90 > 80 (P < 0.001)
	70	26	5.06 ± 1.3	
	80	18	4.70 ± 1.2	
	90	14	6.37 ± 1.5	

3.2.2 Coracoid Spurs

Spurs formed at the coracoid insertion site of the CAL were observed in 33 specimens (55%) (Figure 3.27): 16 in right (53.3%) and 17 (56.7%) on the left. Bilateral incidence were seen in 15 cadavers (50%) compared to 3 cadavers (1%) with unilateral incidence. There was no association (P = 0.409) between the incidence of coracoid spurs and sex, with coracoid spurs seen in 13 male (65%) and 20 (50%) female specimens. There was no difference between the age of shoulders with and without coracoid spurs (P = 0.083): 83.24 ± 10.8 years compared to 79.44 ± 5.5 years, respectively.

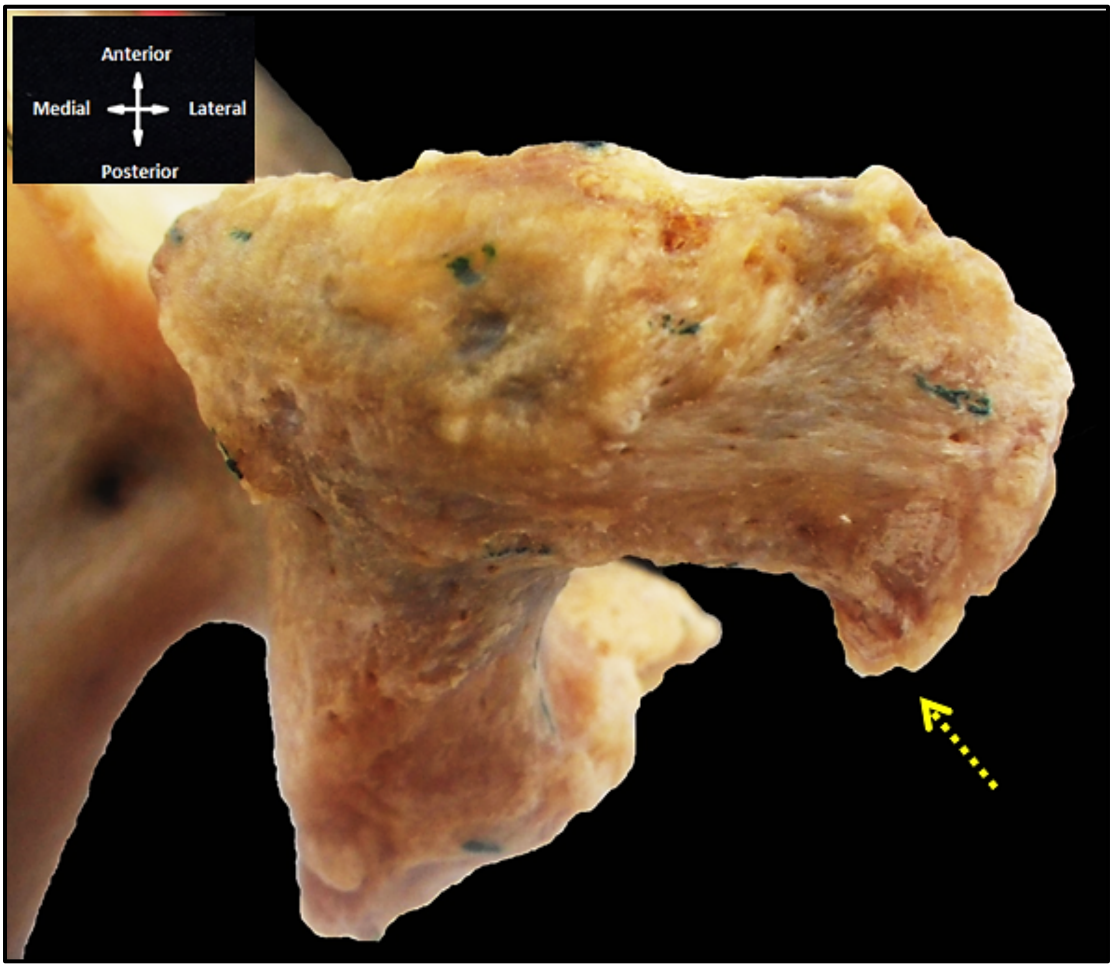


Figure 3.27 Superior view of the coracoid process: showing formation of a spur on the posterior aspect of the coracoid tip.

With respect to the CAL there was no correlation between the incidence of coracoid spurs and morphology and band number of the CAL (P = 0.423 and P = 0.367, respectively). However, there was a significant difference in the acromial attachment width between shoulders with and without coracoid spurs (P = 0.046). Shoulders with a coracoid spur had wider acromial attachment (17.57 ± 4.5 mm) than shoulders without coracoid spurs (15.47 ± 3.2 mm).

Comparing coracoid spurs to those formed on the acromion, they were smaller and formed on different sites along the posterior aspect of the coracoid process. Coracoid spurs were significantly associated (Cramer's V = 0.461, P = 0.001) with acromial spur incidence, being seen in 25 shoulders (75.8%) with acromial spurs compared to 8 shoulders (29.6%) without. Coracoid spurs were also positively correlated with the severity of spurs (R = 0.543, P < 0.001), shapes of anterior acromial spurs (R = 0.518, P < 0.001), subacromial surface appearance (R = 0.404, P < 0.001), and severity of CAL degeneration (R = 0.372, P = 0.003). Furthermore, a significant relationship was found between coracoid spurs and the type of rotator cuff tears (Cramer's V = 0.335, P = 0.034). A significant incidence of coracoid spurs was found in shoulders with complete tears (77.8%) compared to shoulders with partial tears (33.3%) and normal rotator cuff tendons (51.9%).

3.2.3 Degeneration of the ACJ

Degeneration of the acromioclavicular joint (ACJ) was characterised by an arthritic surface and osteophytes on the edge of the joint facet (Figure 3.28). It was seen in 42 shoulders (70%) with a rough appearing surface. Osteophytes were found in 35 shoulders (58.3%), mainly on the inferior edge of the acromial surface (77%) with mean inferior depth of 3.20 ± 1.1 mm. A significant association was found between degeneration of the ACJ and the formation of osteophytes on the edge of the joint (Cramer's V = 0.553, P < 0.001). Osteophytes were seen in 76.2% of shoulders with ACJ degeneration compared to 16.7% in shoulders with a normal ACJ.

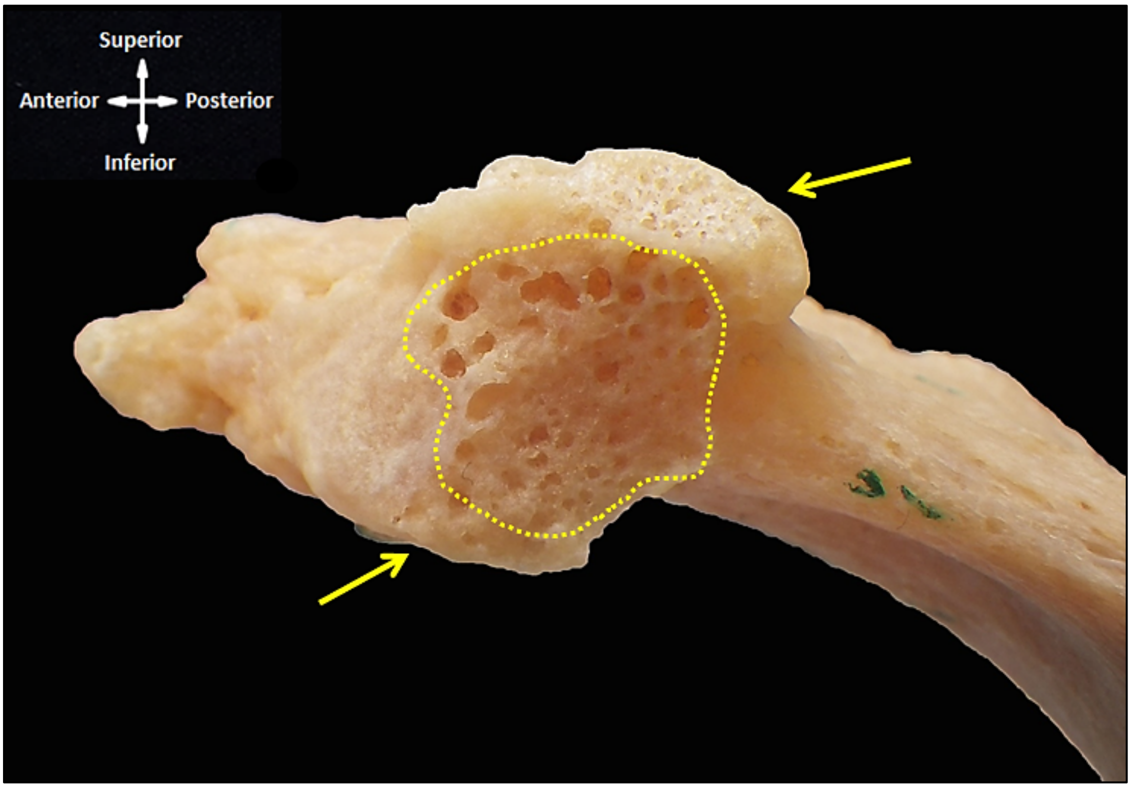


Figure 3.28 Medial view of the acromion: showing degeneration of the acromial facet in the ACJ (dashed area) and formation of superior and inferior osteophytes (arrows).

There was no association between side or sex and degeneration and spur formation in the ACJ (P > 0.050). However, shoulders with ACJ degeneration were older than shoulders with a normal ACJ (P = 0.001): 83.36 ± 9.8 years compared to 77.28 ± 4.3 years, respectively. A similar difference was found according to osteophyte formation. Both ACJ degeneration and osteophyte formation did not show a relationship to CAL morphology, band number, acromial attachment or ACJ attachment (P > 0.005).

Regarding acromial spurs, a significant association (Cramer's V = 0.431, P = 0.001) was found between ACJ degeneration and spur formation, in which ACJ degeneration was seen in 87.9% of shoulders with acromial spurs compared to 48.1% of shoulders with no spur formation. Furthermore, a significant association was found between osteophytes and acromial spurs (Cramer's V =

0.730, P < 0.001) (Figure 3.29). 90.9% of shoulders with acromial spurs also had osteophytes, while only 18.5% of shoulders without acromial spurs had osteophytes. ACJ degenerative changes and osteophytes also showed significant positive correlations to severe types of subacromial spur (R= 0.497 and P < 0.001, R = 0.715 and P < 0.001), subacromial surface appearance (R = 0.359 and P = 0.005, R = 0.412 and P = 0.001), and severe types of CAL degeneration (R = 0.308 and P = 0.016, R = 0.463 and P < 0.001). With respect to rotator cuff tears, there were significant associations between rotator cuff tears and both ACJ degeneration (Cramer's V = 0.349, P = 0.017) and osteophytes (Cramer's V = 0.340, P = 0.029). Shoulders with complete rotator cuff tears had a significant incidence of ACJ degeneration (94.4%) compared to those with partial rotator cuff tears (60%) and those with normal rotator cuff tendons (59.3%). In addition, osteophytes were found in 83.3% of shoulders with complete rotator cuff tears, while they were observed in 53.3% of shoulders with partial rotator cuff tears and in 44.4% of shoulders with normal rotator cuff tendons. Finally, statistical analysis showed no difference in the length of the inferior osteophyte according to an acromial spur, rotator cuff tears or CAL degenerative changes. However, shoulders with ACJ degenerative signs showed more curved acromions than shoulders without. Shoulders with degenerative changes in the acromial facet of the ACJ had a greater slope and curve height than shoulders with a normal facet: slope = 27.52 ± 5.6° compared to 23.82 ± 4.9° (P = 0.019), height = 5.56 ± 1.8 mm compared to 4.56 ± 0.9 mm (P = 0.026), respectively. Shoulders with osteophytes also had a greater slope and curve height than shoulders without osteophytes: slope = 27.85 ± 5.9°

compared to 24.40 ± 4.6º (P = 0.019), height = 5.74 ± 1.8 mm compared to 4.58 ± 0.9 mm (P = 0.002), respectively.

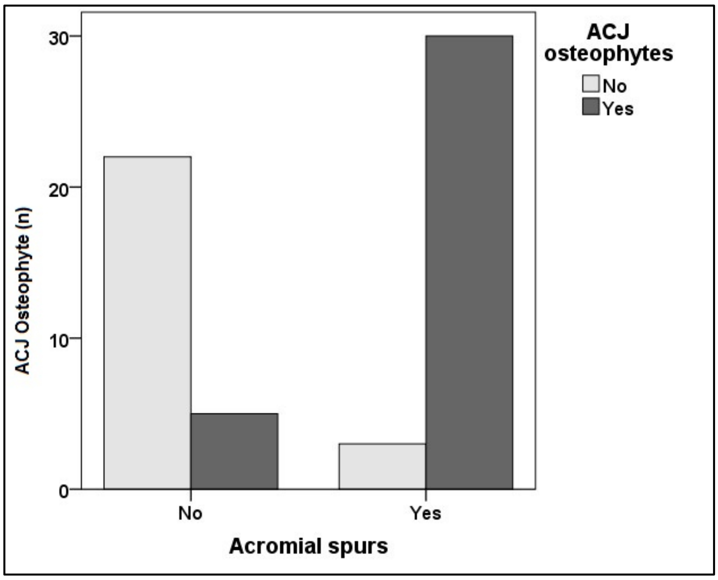


Figure 3.29 Association between the formation of acromial spurs and osteophytes: Cramer's V = 0.730, P < 0.001.

3.2.4 Degeneration of the CAL Subacromial Insertion

3.2.4.1 Subacromial Insertion of the CAL

The subacromial insertion of the CAL covered the anterior portion of the inferior surface of the acromion. It usually had a triangular shape in which the apex was along the lateral edge of the acromion and the base at the acromial attachment (Figure 3.30). The dimensions of this triangular area were as follows: lateral length 20.61 ± 6.6 mm, medial length 23.75 ± 5.0 mm and base 16.62 ± 4.1 mm. The area of the subacromial insertion was 17.84 ± 8.6 cm^2, which covered 22% of the subacromial surface. There was no significant difference in size of the subacromial insertion between right (18.05 ± 8.4 cm^2) and left (17.63 ± 9.0 cm^2) shoulders (P = 0.852). However, male shoulders had a greater CAL subacromial insertion than female shoulders (P = 0.002): 22.60 ± 9.0 cm^2 compared to 15.47 ± 7.4 cm^2, respectively.

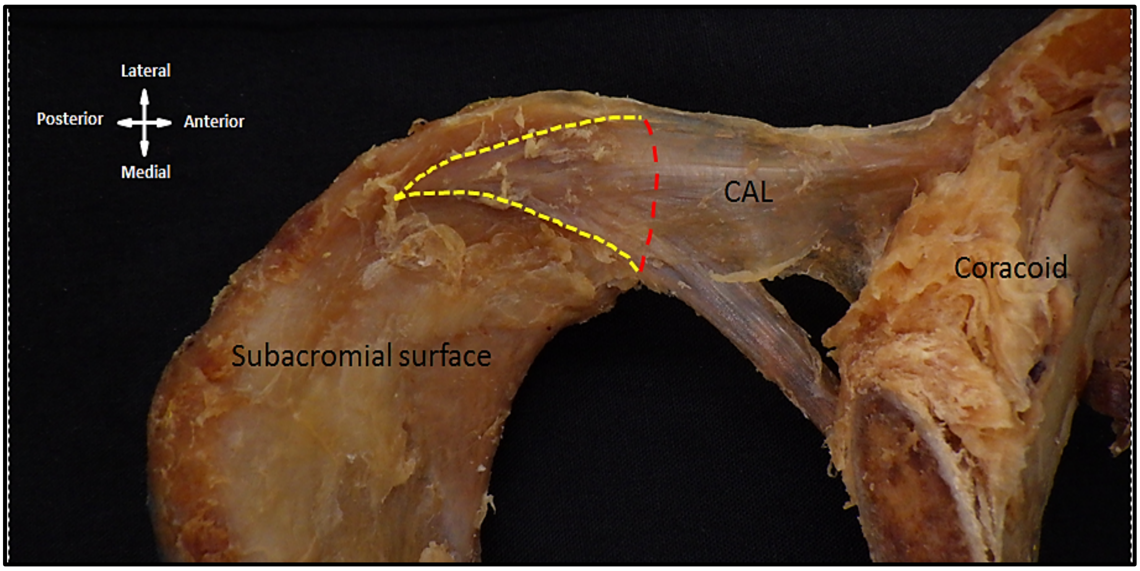


Figure 3.30 Subacromial insertion of the CAL: it is usually triangular in shape (dashed line) at the anterior portion of the subacromial surface as an undivided ligament. Yellow dashed lines represent the lateral and medial edges of the ligament, while the red dashed line represents the anterior edge of the acromion.

Statistical analysis showed a large positive correlation between acromial attachment width and lateral length of the subacromial insertion: $R = 0.539$, $r^2 = 0.291$, $P < 0.001$. A moderate positive correlation was also found between acromial attachment width and medial length of the CAL subacromial insertion: $R = 0.337$, $r^2 = 0.114$, $P = 0.008$. With respect to CAL morphology and band number there were large positive correlations between the size of the CAL subacromial insertion and both CAL morphology ($R = 0.627$, $r^2 = 0.393$, $P < 0.001$) and band number ($R = 0.618$, $r^2 = 0.0.382$, $P < 0.001$). In addition, there were significant differences in CAL parameters of the subacromial insertion between types of CAL band number (Table 3.31).

Table 3.31 One way ANOVA comparisons of the CAL subacromial insertion parameters according to the number of bands.

Parameters	CAL	N	Mean	Comparisons (P Value)
Lateral Length (mm)	1	10	15.76 ± 7.4	1 = 2 (P = 0.168) 3 > 1 (P = 0.001) 3 > 2 (P = 0.030)
	2	30	19.77 ± 5.1	
	3	20	24.30 ± 6.5	
Medial Length (mm)	1	10	20.61 ± 6.1	1 = 2 (P = 0.163) 3 > 1 (P = 0.011) 3 = 2 (P = 0.066)
	2	30	23.64 ± 3.5	
	3	20	25.68 ± 4.1	
Area (cm^2)	1	10	9.24 ± 5.4	2 > 1 (P = 0.016) 3 > 1 (P < 0.001) 3 > 2 (P = 0.001)
	2	30	16.51 ± 6.2	
	3	20	24.15 ± 7.9	

- CAL band number: one band (1); two bands (2); and three bands (3).

Both shoulders with acromial spurs and rotator cuff tears had greater CAL subacromial insertions than normal shoulders (P = 0.009 and P = 0.006, respectively). The mean insertion area in shoulders with acromial spurs was 20.42 ± 9.3 cm^2, greater than that in shoulders without acromial spurs (14.69 ± 6.6 cm^2). Shoulders with rotator cuff tears had a mean insertion area of 20.55 ± 8.5 cm^2 compared to 14.53 ± 7.7 cm^2 in shoulders with normal rotator cuff tendons. However, comparing shoulders with complete and partial rotator cuff tears showed no significant difference between the two groups (P = 0.338): 21.86 ± 7.2 cm^2 compared to 18.98 ± 9.8 cm^2, respectively.

3.2.4.2 Degeneration of CAL subacromial insertion

Gross inspection of the origin of the CAL at the subacromial surface showed degenerative features as a result of attrition with the rotator cuff tendons and shoulder impingement (attrition lesions). These features ranged from defects in the synovial membrane covering the subacromial surface of the CAL to degeneration and severe tears in the origin of the ligament. Degenerative defects were observed in 41 specimens (68.3%) and classified into three grades: a mild defect observed in 19 specimens (31.7%), a moderate defect observed in 8 specimens (13.3%) and a severe defect observed in 14 specimens (23.3%) (Figure 3.31). Compared to normal specimens (31.7%), mild defect specimens were characterized by release of the synovial membrane and the fibrofatty tissue over the CAL surface with dry bright fibres of the CAL. At the moderate level the defect involved a partial tear in the CAL tissue characterised by fraying and fissuring of the fibres. Specimens with a severe degenerative defect showed severe damage (tear) in the surface of the CAL extending throughout the whole thickness of the ligament into the subacromial surface. Calcification of the ligament was partially present in the moderate stage, while it was largely present in the severe stage.

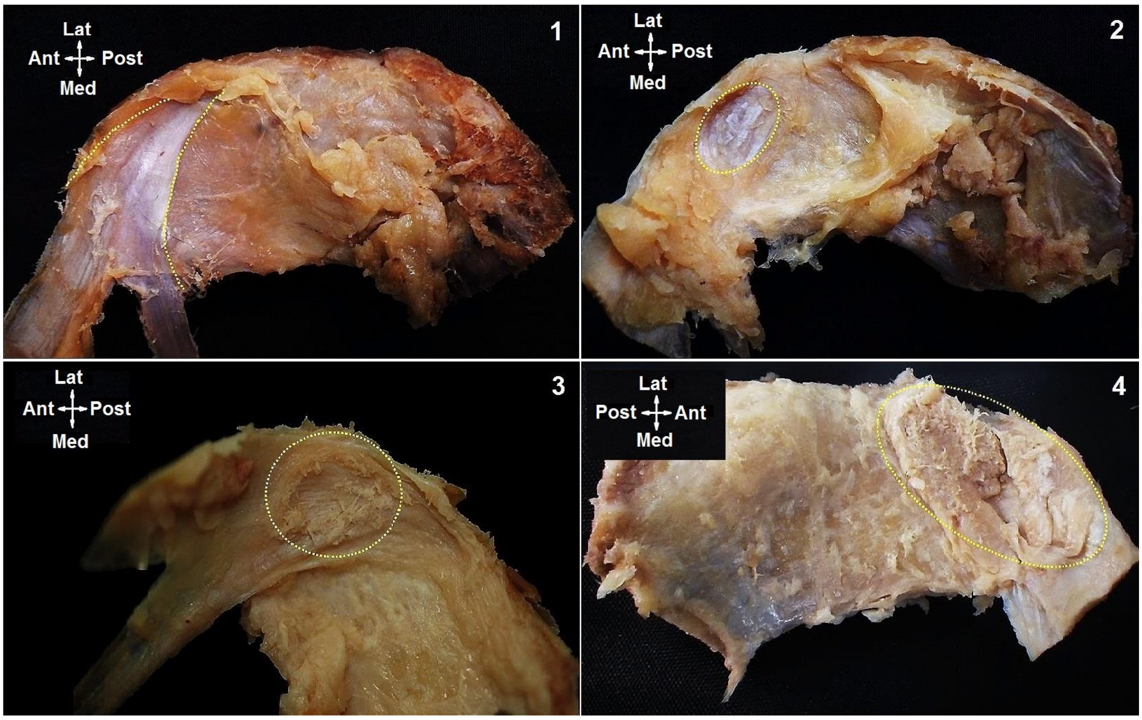


Figure 3.31 Subacromial views showing the grades of defect of the CAL subacromial insertion: normal subacromial insertion of the CAL (1) shows no damage to the ligament or to the synovial membrane covering the ligament. Mild CAL defect (2) shows damage to the synovial membrane and exposure of the ligament fibre tissue. Moderate CAL defect (3) shows a partial tear in the surface of the ligament characterised with fraying or fissuring of the fibres on the surface of the ligament. Severe CAL defect (4) shows a complete tear through whole thickness of the ligament with calcification formations. Lat: lateral, Ant: anterior, Med: medial, Post: posterior.

On the subacromial surface defects were significantly observed in the anterolateral portion of 25 specimens (61%), extending onto the anterior side in 12 specimens (29%) and the medial side in 4 specimens (10%). Parameters of the degeneration were as follows: mean length 19.61 ± 7.7 mm, mean width12.73 ± 6.5 mm and mean area 29.49 ± 23.9 cm^2. There was a high correlation between the severity of degeneration and the size of the degeneration: $R = 0.818$ for length, 0.830 for width, and 0.830 for area, $P < 0.001$. In addition, the results showed significant differences ($P < 0.050$) between the level of degeneration and the size of degeneration (Table 3.32). In severe degeneration there was a significantly larger defect than in moderate and mild degeneration. In addition, moderate degeneration also had a significantly larger defect than mild degeneration.

Table 3.32 One way ANOVA comparison the size of the CAL defect according to severity level.

Parameters	CAL defect levels	N	Mean	Comparisons (P Value)
Length (mm)	1	19	13.38 ± 4.2	1 < 2 (P= 0.001) 1 < 3 (P< 0.001) 2 < 3 (P= 0.001)
	2	8	20.00 ± 5.4	
	3	14	27.13 ± 4.2	
Width (mm)	1	19	7.79 ± 3.1	1 < 2 (P= 0.003) 1 < 3 (P< 0.001) 2 < 3 (P< 0.001)
	2	8	12.54 ± 1.9	
	3	14	19.76 ± 4.6	
Area (cm^2)	1	19	11.45 ± 7.7	1 < 2 (P= 0.001) 1 < 3 (P< 0.001) 2 < 3 (P= 0.001)
	2	8	24.96 ± 10.9	
	3	14	55.15 ± 19.8	

- CAL defect levels: mild (1), moderate (2), severe (3).

With respect to side and sex, there was no association between CAL defect incidence and side (P = 0.267) or sex (P = 0.772). However, there were more bilateral incidences of CAL defects than unilateral incidences, but this distribution was not significant (P = 0.064): 17 shoulders (57%) compared to 7 shoulders (23%), respectively. According to age, there was no difference (P = 0.065) between shoulders with and without CAL defects: 82.98 ± 9.2 years compared to 78.42 ± 7.7 years, respectively. However, in relation to CAL defect level a significant difference was present between the age of shoulders with severe CAL defects and those with no CAL defect: 86.14 ± 8.9 years compared to 78.42 ± 7.7 years, respectively.

3.2.4.3 Relation to CAL morphology and size

With respect to CAL parameters, there was no difference in any of the CAL parameters between shoulders with and without defects (P > 0.05). However, shoulders with defects showed a significantly larger CAL subacromial insertion than those without defects (P = 0.006): 19.89 ± 9.1 cm^2 compared to 13.44 ± 5.3 cm^2, respectively. In addition, a significant positive correlation was found between defect width and CAL acromial attachment width: R = 0.564, r^2 = 0.318, P < 0.001 (Figure 3.32). According to defect level significant differences were found between defect level in relation to the acromial attachment width and the size of the CAL subacromial insertion (P < 0.001) (Table 3.33). Regarding CAL morphology and band number no association was found in relation to CAL defects (P = 0.906 and P = 0.758, respectively).

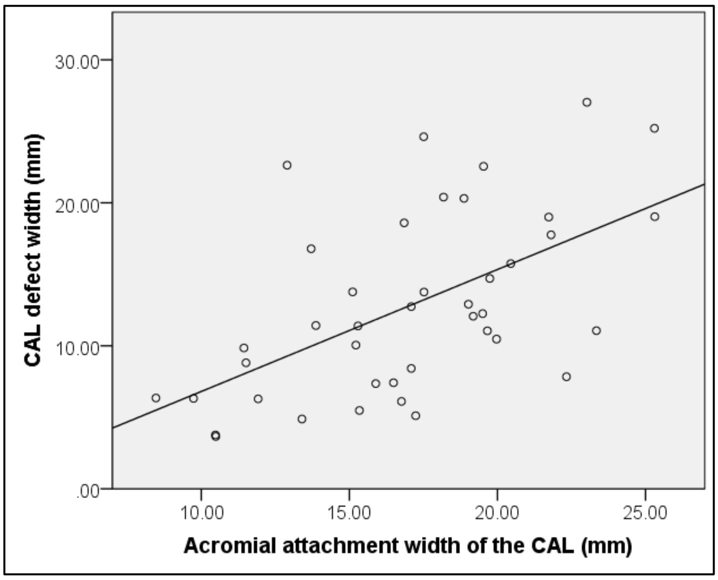


Figure 3.32 Pearson correlation between the acromial attachment width of the CAL and CAL defect width: R = 0.564, r^2 = 0.318, P < 0.001.

Table 3.33 One way ANOVA comparison of the defect levels of the CAL according to CAL parameters: (1) mild, (2) moderate, (3) severe.

CAL parameters	CAL defect levels	N	Mean	Comparisons (P Value)
CAL acromial Width (mm)	1	19	14.40 ± 3.5	1 < 2 (P= 0.005) 1 < 3 (P< 0.001) 2 = 3 (P= 0.623)
	2	8	18.82 ± 3.0	
	3	14	19.59 ± 3.7	
CAL subacromial area (cm^2)	1	19	14.27 ± 6.9	1 < 2 (P= 0.009) 1 < 3 (P< 0.001) 2 = 3 (P= 0.444)
	2	8	23.09 ± 8.2	
	3	14	25.7 ± 8.0	

- CAL defect levels: mild (1); moderate (2); severe (3).

3.2.4.4 Relation to acromial spurs

A significant association was found between CAL defects and acromial spurs (Cramer's V = 0.320, P = 0.024). In shoulders with acromial spurs there were 27 specimens (65.9%) with CAL defects compared to 6 specimens (31.6%) without CAL defects. A significant association was found between the severity of the defect and the incidence of acromial spurs (Cramer's V = 0.552, P < 0.001), (Figure 3.33). Shoulders with acromial spurs had a significant incidence of severe CAL defect (92.9%) compared to 7.1% of CAL defects in shoulders without spurs. Several significant positive correlations were found between the features of both acromial spurs and CAL defects. A significant correlation between the spur width and both the length and width of the CAL defect (P < 0.001) was observed (Table 3.34). A significant correlation was also found between spur length and CAL defect length, whereas no correlation was observed between spur length and CAL defect width. With respect to size, a significant positive correlation was found between spur size and CAL defect size: R = 0.761, r^2 = 0.579, P < 0.001 (Figure 3.34). In addition, a significant positive correlation between spur size and the severity level of the CAL defect: R = 0.759, $r^2 = 0.576$, $P < 0.001$ was also observed (Figure 3.35), and between both severity levels of spurs and CAL defects: R = 0.663, $r^2 = 0.440$, $P < 0.001$ (Figure 3.36). Finally, the severity of CAL lesions were positively correlated with severity of the subacromial surface appearance: R = 0.652, $r^2 = 0.425$, $P < 0.001$.

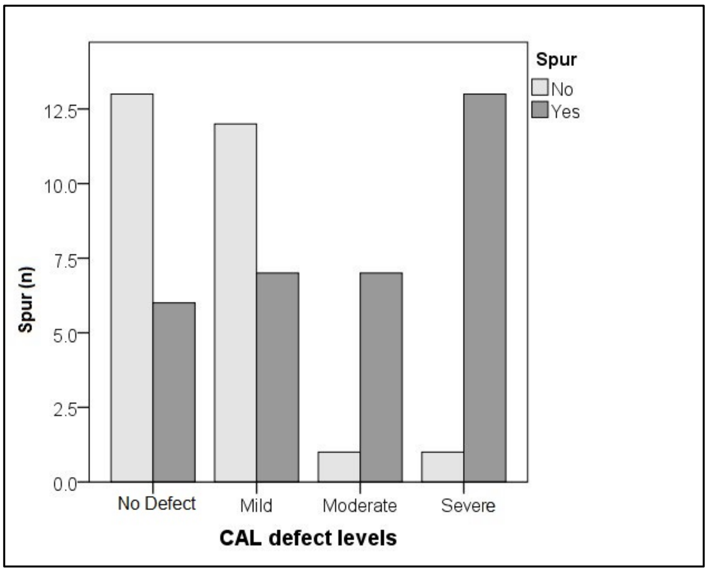


Figure 3.33 Association between CAL defect level and acromial spur incidence: Cramer's V (60) = 0.552, $P < 0.001$.

Table 3.34 Pearson correlation between the CAL defect and acromial spur according to length and width parameters.

CAL defect		Spur	
		Length	Width
Length	Pearson Correlation	.382*	.718**
	Sig. (2-tailed)	0.049	0.000
	N	27	27
	r^2	0.146	0.516
Width	Pearson Correlation	0.250	.818**
	Sig. (2-tailed)	0.208	0.000
	N	27	27
	r^2	0.063	0.669

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

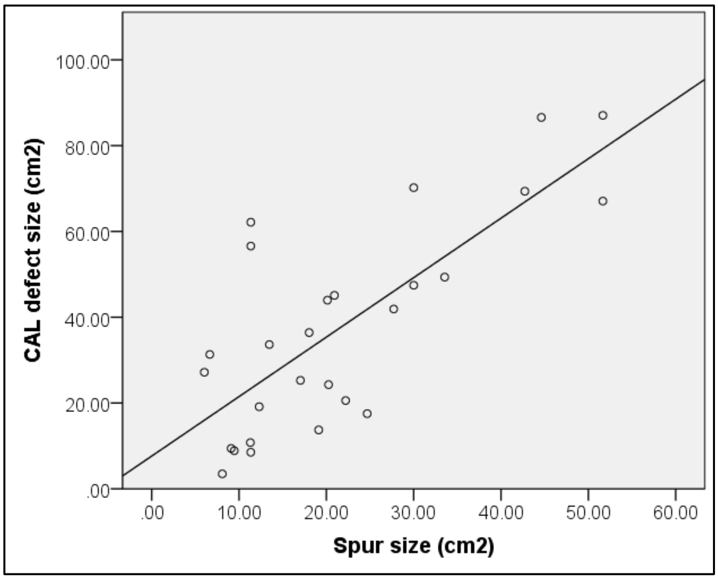


Figure 3.34 Pearson correlation between spur size and CAL defect size: R = 0.761, r^2 = 0.579, P< 0.001.

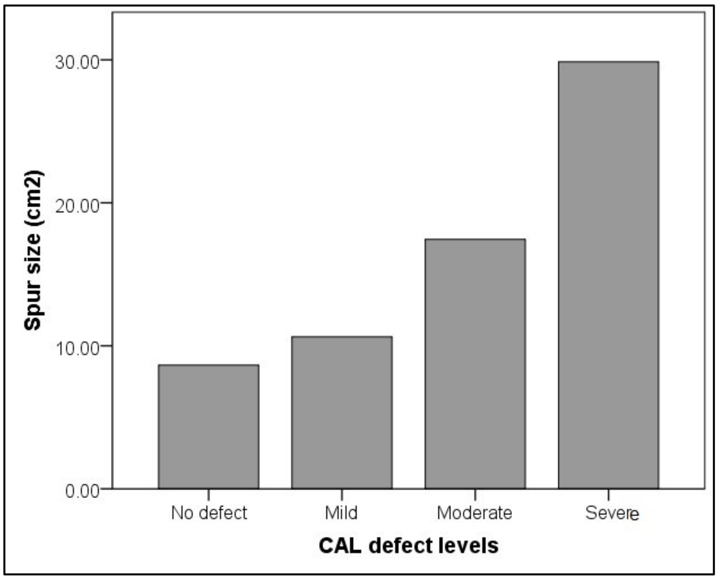


Figure 3.35 Spearman's correlation between CAL defect level and spur size: R = 0.759, r^2 = 0.576, P < 0.001.

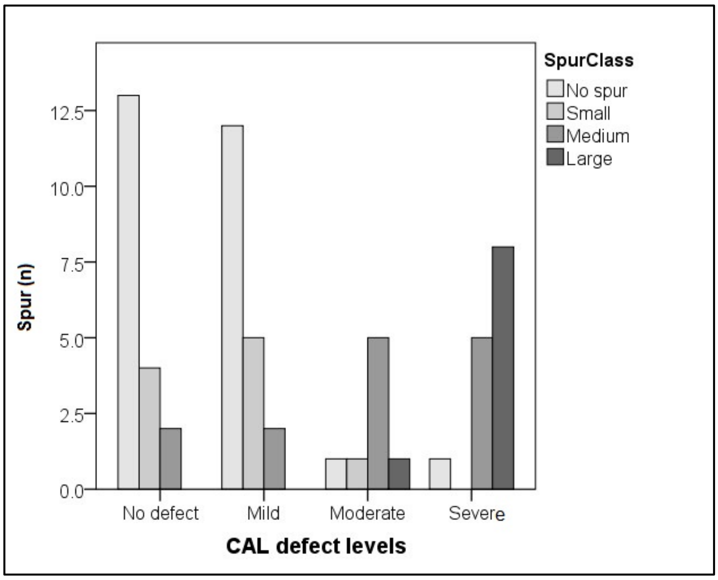


Figure 3.36 Spearman's Correlation between the severity level of acromial spurs and CAL defects: $R = 0.663$, $r^2 = 0.440$, $P < 0.001$.

In relation to the site of defect a significant correlation was found between the sites of spur and CAL defects: $R = 0.425$, $r^2 = 0.181$, $P = 0.001$. There was a significant association between the site and severity of CAL defects (Cramer's V = 0.714, $P < 0.001$). The site of the CAL defect was positively correlated with the severity of the spur ($R = 0.466$, $P < 0.001$) and rotator cuff tears ($R = 0.315$, $P = 0.014$), and with subacromial surface appearance ($R = 0.535$, $P < 0.001$). Moreover, there was a significant positive correlation between the severity of the CAL defect and the appearance of the subacromial surface: $R = 0.675$, $r^2 = 0.456$, $P < 0.001$ (Figure 3.37). A significant positive correlation was also found between the CAL defect level and each of the incidence and direction of anterior acromial spurs: $R = 0.674$, $r^2 = 0.454$, $P < 0.001$ (Figure 3.38), and $R = 0.647$, $r^2 = 0.419$, $P < 0.001$ (Figure 3.39), respectively. A significant association was also detected between the CAL defect severity level and the incidence of subacromial facets (Cramer's V = 0.464 $P = 0.006$). Shoulders with subacromial facets had significant incidence of a severe CAL defect (52.9%) in comparison to shoulders without a subacromial facet (11.6%).

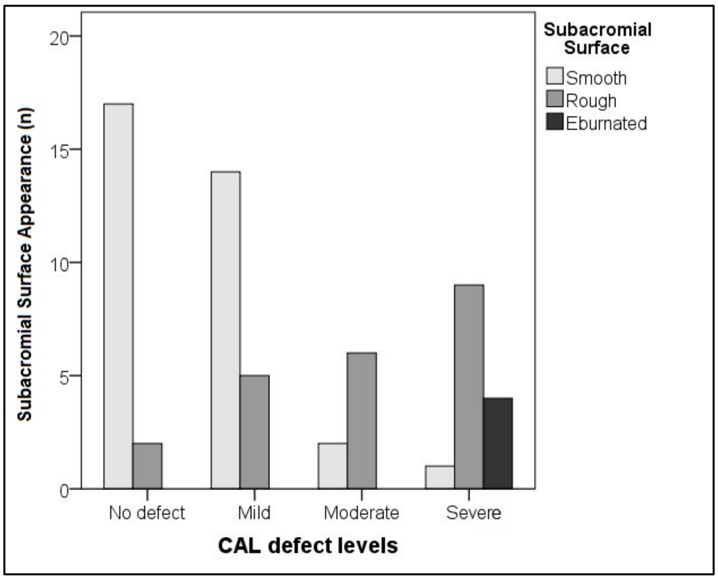


Figure 3.37 Spearman's correlation between the CAL defect levels and appearances of subacromial surface: R = 0.675, $r^2 = 0.456$, $P < 0.001$.

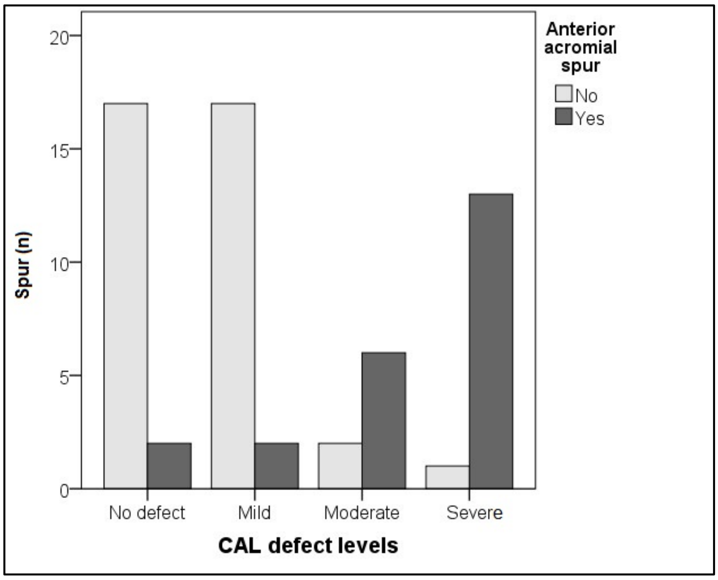


Figure 3.38 Spearman's correlation between CAL defect levels and incidence of anterior acromial spurs: R = 0.674, $r^2 = 0.454$, $P < 0.001$.

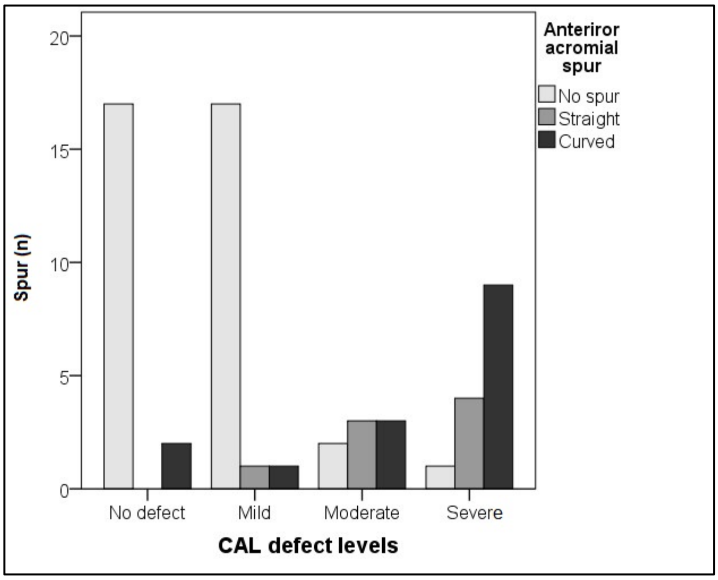


Figure 3.39 Spearman's correlation between CAL defect levels and the direction of anterior acromial spurs: R = 0.647, r^2 = 0.419, P < 0.001.

With respect to spur size, the results showed significant differences between CAL defect levels (P < 0.050) (Table 3.35). Shoulders with severe CAL defects had the largest acromial spurs compared to other levels: 29.86 ± 14.2 cm^2. There was no difference between spur size in shoulders with mild CAL defects and those without defects, while there was a significant difference between shoulders with moderate CAL defects and those with no defect. Furthermore, there was no difference in the size of spur between shoulders with mild CAL defects and those with moderate CAL defects.

Table 3.35 One way ANOVA comparisons of spur size according to the CAL defect levels.

CAL defect level	Spur N	Mean (cm^2)	Comparisons (P Value)
No Defect	6	8.65 ± 3.9	0 = 1 (P = 0.399) 0 < 2 (P = 0.024) 0 < 3 (P < 0.001) 1 = 2 (P = 0.054) 1 < 3 (P < 0.001) 2 < 3 (P = 0.045)
Mild	7	10.63 ± 4.2	
Moderate	7	17.44 ± 7.4	
Severe	13	29.86 ± 14.2	

- CAL defect levels: no defect (0); mild (1); moderate (2); severe (3).

3.2.4.5 Relation to rotator cuff tears

Statistical analysis showed a significant correlation between the subacromial CAL lesion and rotator cuff tear incidence: R = 0.442, $r^2 = 0.195$, P < 0.001. A positive correlation was also found between tear type and the severity levels of the CAL defect: R = 0.502, $r^2 = 0.252$, P < 0.001 (Figure 3.40). Shoulders with rotator cuff tears had a significantly larger size of CAL defect than shoulders with normal rotator cuff tendons (Table 3.36). Shoulders with normal cuff tendons had smaller CAL defects than shoulders with partial and complete rotator cuff tears. However, there was no difference in parameters of CAL defect between shoulders with complete and partial rotator cuff tears.

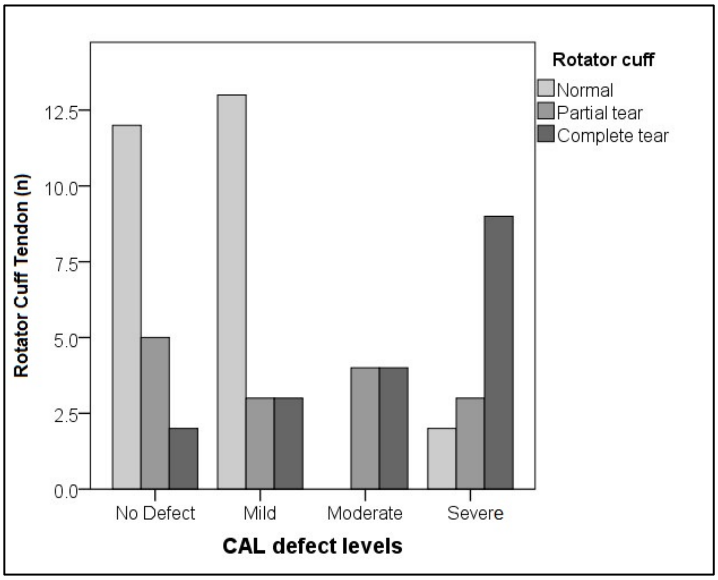


Figure 3.40 Spearman's correlation between the severity of CAL defects and tear types: R = 0.502, $r^2 = 0.252$, P < 0.001.

Table 3.36 One way ANOVA compare CAL defect parameters according to rotator cuff tears.

CAL defect	Rotator cuff tendon	Number	Mean	Comparison (P Value)
Length (mm)	N	15	14.82 ± 6.8	N < P (P = 0.007) N < C (P = 0.007) P = C (P = 0.740)
	P	10	22.95 ± 8.1	
	C	16	22.01 ± 6.4	
Width (mm)	N	15	8.48 ± 5.1	N < P (P = 0.024) N < C (P = 0.001) P = C (P = 0.385)
	P	10	13.95 ± 6.2	
	C	16	15.96 ± 5.9	
Area (cm^2)	N	15	15.62 ± 18.3	N < P (P = 0.028) N < C (P = 0.006) P = C (P = 0.797)
	P	10	36.09 ± 25.9	
	C	16	38.38 ± 22.5	

- Rotator cuff tendon: normal cuff tendon (N); partial tear (P); complete tear (C).

3.2.4.6 Relation to acromion

In relation to the acromion parameters, there were positive correlations between the length of the anterior acromion edge and the degeneration length (R = 0.452, P = 0.003), width (R = 0.337, P = 0.031) and area (R = 0.356, P = 0.022). However, there was no correlation between the subacromial lesion parameters and the length of the acromion. With respect to acromion curvature, there were positive correlations between the height of the acromial curvature and the lesion length (R = 0.334, P = 0.033), width (R = 0.393, P = 0.011) and area (R = 0.412, P = 0.007). However, there was no correlation between the parameters of the subacromial lesion and acromial slope.

4 Discussion

4.1 CAL Band Number and Morphology

Previous studies have described the coracoacromial ligament (CAL) as being trapezoidal (Gallino *et al*., 1995) or triangular (Moorman *et al*., 2008; Ciochon and Corruccini, 1977) originating from the anterior undersurface of the acromion and twisting as a helix to insert onto the posterior aspect of the coracoid process. In the current study, the superior view of the CAL generally showed it to be a trapezoidal ligament, while viewed inferiorly the acromial undersurface attachment showed a triangular shaped ligament. The current study inspected the CAL with respect to band number and morphology in relation to acromial spurs and rotator cuff tears.

4.1.1 Band Number

The CAL is most commonly formed by two distinct ligamentous bands separated by a thinner intervening portion of diaphanous membrane that may be either weak or completely absent (Brodie, 1890; Fealy *et al*., 2005; Moorman *et al*., 2008). Brodie (1890) described these two bands as external and internal bands, while Fealy *et al*. (2005) described them as anterolateral and posteromedial bands. The CAL may also consist of three ligamentous bands (Flatow *et al*., 1995; Pieper *et al*., 1997; Fealy *et al*., 2005; Moorman *et al*., 2008). Fealy *et al*. (2005) described the third band as an accessory band. Table 4.1 shows the incidence of band numbers found in previous studies: as can be seen the most frequent number of bands is two, observed in 59% to 95% of previous studies. The one-band form was observed in 2.5% to 34% of previous studies, while the three-band form was the least common being seen in 2.5% to 14.5% of studies.

The findings of the current study disagree with previous studies regarding the distribution of band number of the CAL (Table 4.1). CALs with three or more bands were the most common form in the current study, being observed in 46% of specimens: CALs with two bands were observed in 38% of specimens, while those with one band were the least commonly observed (16%). The current study is comparable with Pieper *et al*. (1997), Fremerey *et al*. (2000) and Flatow *et al*. (1996) in observing the three band form of the CAL. However, Edelson and Luchs (1995) observed only one (34%) and two band (66%) ligaments, while Moorman *et al*. (2008) reported two (92.9%) and three bands (7.1%). According to the type of the ligament, CALs with three or more bands in the current study were greater than those in previous studies. This finding is in line with the suggestion of Holt and Allibone (1995) that more multiple-banded or three band ligaments may be observed in larger studies. In contrast, CALs with two bands were less than reported previously; however CALs with one band (16%) lay within the range of previous studies.

Table 4.1 Incidences of CAL band number in previous studies compared to the current study.

Study	Sample N	1 Band (%)	2 Bands (%)	≥ 3 Bands (%)
Flatow ***et al***. (1995)	56	11 (20)	42 (75)	2 (3)
Edelson and Luchs (1995)	100	34(34)	66(66)	
Pieper ***et al***. (1997)	124	32 (25.8)	74 (59.7)	18 (14.5)
Fremerey ***et al***. (2000)	40	1 (2.5)	38 (95)	1 (2.5)
Moorman ***et al***. (2008)	28		26 (92.9)	2 (7.1)
The current study	**220**	**35 (16)**	**84 (38)**	**101 (46)**

Difference in the band number of CAL between the current study and previous studies may be returned to way of identification. No study previously has reported the way of identification of the morphology and band number of the CAL except Fealy *et al*. (2005). Fealy *et al*. (2005) used a fiberoptic lamp to identify the band number of the CAL, but they did not report the distribution of CAL band number or morphology. However, the current study used several steps to identify the morphology and band number of the CAL. First, ethanol was used to remove any fatty tissue from the ligament surface. Every specimen was dried of any liquids prevent clear observation of the ligament. Blunt dissection was then used to remove the diaphanous membranes between the ligament bands. A high beam lamp was used also to identify and confirm the ligament bands of the CAL. This methodology helped in identifying the morphology and band number of the CAL. In addition, the length and division of the ligament band could be another cause for different reporting bands number of CAL. Lateral and medial bands of the CAL usually obvious because: a large diaphanous membrane between the two bands and have apparent lengths division mark at the middle of the ligament. In contrast, the medial bands of the CAL were packed close to each other with short length, small diaphanous membrane, and no obvious division marks (Figure 3. 5,6, and 7). The current study considered these short bands when identifying the morphology or band number of the CAL, while previous studies have not discussed this.

4.1.2 Diaphanous Membrane

A diaphanous membrane was usually present between the bands as a very thin membranous tissue. However, according to division angle, the diaphanous membrane between the lateral and medial bands was larger than that between the most medial bands. The diaphanous membrane between the lateral and medial bands commonly had a defect near the coracoid attachment with blood vessels passing through it. These vessels were branches from the suprascapular vessels. In contrast, Brodie (1890) observed pectoralis minor passing through this deficiency to insert into the shoulder capsule, with the membrane being either partially or entirely absent. Holt and Allibone (1995) noted that the tendon of pectoralis minor was involved in the CAL in 14% of specimens: 11% with a Y-shaped ligament and 3% with a broad band ligament. Furthermore, they found small vessels in 12 of 13 Y-shaped ligaments. Okutsu *et al*. (1992) and Panni *et al*. (1996) reported that the CAL is supplied by the acromial branch of the thoracoacromial artery that courses superior to the ligament, while Gallino *et al*. (1995) found that these blood vessels were branches of the suprascapular artery.

There is no clear function for the diaphanous membrane in the literature. However, the current study assumes the diaphanous membrane is part of fibrous tissue covering the CAL superior surface. It supports and protects the ligament structure. The CAL normally exposures to inferior contact pressure as a result of superior humeral head displacement (Yamamoto *et al*.; 2010). Presenting the diaphanous membrane between the CAL bands may protect the ligament bands and prevent further division between the bands against this pressure. In addition, the diaphanous membrane may also increase flexibility of the CAL. Therefore, the current study assume that the diaphanous membrane protects and supports the CAL as well as increase the flexibility of the ligament.

4.1.3 CAL Shape

CAL shape is variable as reported in previous studies (Edelson & Luchs, 1995; Holt and Allibone, 1995; Kesmezacar *et al*., 2008) (Table 4.2). Salter *et al*. (1987) and Gagey *et al*. (1993) observed a Y-shaped ligament in all specimens investigated (20 and 15 respectively). In 1995, Holt and Allibone observed 3 main types of CAL: quadrangular, Y-shaped and broad-band ligaments. In addition, they introduced the multiple-banded ligament for the first time, which was seen in only 1 (2%) shoulder. Shaffer *et al*. (1997) observed only Y-shaped and quadrangular ligaments. In two biomechanical studies by Fagelman *et al*. (2007) and Hu *et al*. (2009) three morphological types were observed: Y-shaped, quadrangular and broad-band ligaments. A recent study by Kesmezacar *et al*. (2008) inspected the morphology of the CAL and reported 5 types: broad-band, quadrangular, Y-shaped, multiple-banded and V-shaped ligaments. The most frequent configurations observed were the Y-shaped ligament, followed by the quadrangular ligament with the multiple-banded, and the V-shaped ligaments being less common.

Table 4.2 Distribution of CAL shape in previous studies compared to the current study.

Study	N	B	Q	Y	M	V
Salter ***et al***. (1987)	20			20 (100%)		
Gagey ***et al***. (1993)	15			15 (100%)		
Holt & Allibone (1995)	48	4 (8%)	23 (48%)	20 (42%)	1 (2%)	
Shaffer ***et al***. (1997)	28		18 (64%)	10 (36%)		
Kopuz ***et al***. (2002)	110	32 (29%)	30 (27%)	48 (44%)		
Fagelman ***et al***. (2007)	7	2 (28.5%)	3 (43.0%)	2 (28.5%)		
Kesmezacar ***et al***. (2008)	80	18 (22.5%)	11 (13.8%)	33 (41.3%)	9 (11.2%)	9 (11.2%)
Hu ***et al***. (2009)	9	4 (44.4%)	4 (44.4%)	1 (11.1%)		
Current study	**220**	**14 (6%)**	**21 (10%)**	**84 (38%)**	**101 (46%)**	

- CAL shapes: broad band (B), quadrangular band (Q), Y-shaped ligament (Y), multiple banded (M) ligament and V-shaped ligament (V).

The current study observed morphological variations of the CAL as follows: 6% broad band, 10% quadrangular, 38% Y-shaped and 46% multiple banded. No V-shaped ligaments were observed in contrast to Kesmezacar *et al*. (2008), since the CAL always originated as an undivided single band at the anterior edge of the acromion. Both multiple banded and Y-shaped ligaments were observed in the current study significantly more than the broad band and quadrangular types. The proportion of multiple banded ligaments found in the current study was greater than reported previously (Holt and Allibone, 1995; Kesmezacar *et al*., 2008). This is in line with Holt and Allibone (1995) who suggested that the multiple-banded ligament may be more commonly observed in larger studies. However, the incidence of the Y-shaped ligament was less than reported by Salter *et al*. (1987), Gagey *et al*. (1993), Holt and Allibone (1995), Kopuz *et al*. (2002) and Kesmezacar *et al*. (2008). The incidence was similar to that reported by Shaffer *et al*. (1997) and more than that reported by

Fagelman *et al*. (2007) and Hu *et al*. (2009). The incidence of the quadrangular ligament was less than reported by Holt and Allibone (1995), Shaffer *et al*. (1997), Kopuz *et al*. (2002), Fagelman *et al*. (2007) and Hu *et al*. (2009), and similar to that reported by Kesmezacar *et al*. (2008). The incidence of the broad band ligament was less than reported by Kopuz *et al*. (2002), Fagelman *et al*. (2007), Kesmezacar *et al*. (2008), and Hu *et al*. (2009), but similar to that reported by Holt and Allibone (1995). Different incidence observations from previous studies may be due to the population studied and the methodology employed. For example, Kopuz *et al*. (2002) used neonatal cadavers, and Kesmezacar *et al*. (2008) used autopsy specimens.

According to ligament type, Holt and Allibone (1995) also found that the coracoid attachment was wider than the acromial attachment in quadrangular, Y-shaped and multiple-banded ligaments. In agreement with Holt and Allibone (1995), the current study found that each of the quadrangular, Y-shaped and multiple banded ligaments had a significantly wider coracoid attachment than acromial attachment. This was also the case according to the number of bands. In addition, Holt and Allibone (1995) report that the length of the lateral border of the CAL, or the distance between the acromion and coracoid for each ligament, were similar. In contrast, the current study found that all CAL shapes had a significantly longer lateral side (in ligaments with one band) or band (in ligaments with more than one band) than the medial side.

In shoulders with a Y-shaped ligament, the lateral band was larger than the medial band in 80% of specimens. Both quadrangular (32.8 mm) and Y-shaped (31.2 mm) ligaments had significantly greater coracoid attachment widths than the broad band ligament (20.0 mm). However, a significant relationship has been found in shoulders presenting with the broad band type and people taller than 180 cm (Holt and Allibone, 1995). Regarding the number of bands, Pieper *et al*. (1997) found no difference in length or thickness between the three types of ligaments. Kesmezacar *et al*. (2008) reported that the quadrangular band ligament had a significantly greater lateral band width than other ligament types. However, they observed no difference in other CAL parameters between each type. They also observed that the mean width of the quadrangular and broad band types at the insertion to the coracoid was greater than that of the lateral band of other band types. In addition, the mean lateral border length of the one-band ligaments was longer than in CALs composed of more than 1 band (Kesmezacar *et al*., 2008).

In contrast, several differences were observed in the current study between CALs with different numbers of bands. Firstly, significant differences were found in the widths of the acromial and coracoid attachments. CALs with three bands had a significantly wider attachment to both processes than those with two or one bands. CALs with two bands also had significantly wider acromion and coracoid attachments than CALs with one band. However, CALs with one band had significantly longer lateral side lengths than those with two and three bands. The medial length of the CAL showed no difference between the three types of ligament. Furthermore, CALs with three bands had a significantly thicker acromial attachment than those with one band. Another difference was found regarding the space/diaphanous membrane width and the division distance from the anterior edge of the acromion between the lateral and medial bands, in which CALs with two bands had a significantly wider diaphanous membrane and a shorter division distance than CALs with three bands. However, the division angle between the lateral and medial bands did not show any difference between CALs with two and three bands.

Pieper *et al*. (1997) reported a significant positive correlation between the coracoid attachment width and the number of bands. However, Kesmezacar *et al*. (2008) emphasized that the number of bands changed only the width of the coracoid attachment of the anterolateral band, stating that the coracoid width of this band is biomechanically important because it is the region that would most likely impinge on the rotator cuff. In agreement, the current study found a significant correlation between CAL band number and the width at both attachment sites. However, no correlation was found between band number and the lengths of the lateral and medial bands.

Previous studies found no significant difference or correlation in CAL measurements, band number or shape with respect to age, sex or side (Holt and Allibone, 1995; Pieper *et al*., 1997; Kopuz *et al*., 2002; Fealy *et al*., 2005; Kesmezacar *et al*., 2008; Wu *et al*., 2010 a and b). However, Wasmer *et al*. (1985 cited in Pieper *et al*., 1997) reported that two band CALs were observed in 80% of older people with an average age of 75 years, and in 100% of young people. Furthermore, an association between band number and CAL morphology has been observed bilaterally (Pieper *et al*., 1997; Kopuz *et al*., 2002; Kesmezacar *et al*., 2008). Fealy *et al*., 2005 found no correlation found between CAL measurements and size of the glenoid fossa and humeral head.

The current study agrees with previous studies (Holt and Allibone, 1995; Pieper *et al*., 1997; Kopuz *et al*., 2002; Fealy *et al*., 2005; Kesmezacar *et al*., 2008; Wu *et al*., 2010 a and b) in which no association was found between the shape or band number of the CAL and the factors of side, sex and age. However, comparing the CAL parameters with respect to sex revealed differences between males and females, with males being significantly larger than females. This was seen in the width of both attachment sites and in the length of both borders. This suggests that an association between the sizes of scapula and CAL. Furthermore, males had significantly thicker acromial attachments, a significantly wider diaphanous membrane (or distance between the lateral and medial bands) and a longer division length than females. With respect to bilateral distribution the current study agrees with Pieper *et al*. (1997), Kopuz *et al*. (2002) and Kesmezacar *et al*. (2008) in which CAL shape and band number were similar in the majority (89%) of specimens, with differences in shape and band number present in the remainder.

4.1.4 Development of the CAL

There are two theories explaining variations in CAL morphology: whether it is primarily formed during gestation or is later formed in adults due to developmental and degenerative changes (Brodie, 1890; Fealy *et al*., 2000; Holt and Allibone, 1995; Kopuz *et al*., 2002). Brodie (1890) reported that the lateral band was more developed in fetuses than the medial band: it also showed fibers passing to the short head of the biceps tendon (the CAL falx). In their investigation of fetal shoulders Fealy *et al*. (2000) observed that by 13 weeks the CAL was clearly evident, as were individual anterolateral and posteromedial bands by 14 weeks gestation. Furthermore, by 36 weeks the collagen fibers of the CAL were well organized.

Holt and Allibone (1995) hypothesized that the final shape of the CAL may be determined by loss of tissue within the quadrangular type ligament during embryologic development of the shoulder joint. Therefore, the open oriental fan (quadrangular type) can be closed (broad band type) or break into two (Y-shaped type) or more segments (multiple-banded type). This process could be influenced by two factors: the stresses associated with movement in the growing joint and/or by degenerative changes in the adult.

In 1999, Kopuz *et al*. observed three morphological types of CAL in neonatal cadavers in which 29.1% had broad band ligaments, 27.3% quadrangular ligaments and 43.6% U-shaped ligaments. Unlike adult CALs, broad-band and quadrangular ligaments in neonatal cadavers had greater attachment widths than ligament length. In addition, U-shaped ligaments showed similar features to those seen in the adult Y-shaped ligament, being formed by two separated bands at the coracoid attachment site with a diaphanous region between them. The lateral band was wider than the medial band. Comparing the morphological types of CAL in neonatal shoulders to those in adult shoulders led Kopuz *et al*. (2002) to suggest that the broad band was the basic primordial type with either one or two tissue bands. Due to shoulder developmental differential growth, the single tissue band transformed into a quadrangular ligament, while the two bands, or the U-shaped fetal ligament, developed into the adult Y-shaped ligament. Kopuz *et al*. (2002) explained the presentation of the quadrangular ligament in their study as being due to early transformation that could take place during the intrauterine period. In addition, they related the incidence of two bands to mesenchymal differentiation or development of the vasculature early in embryonic life. Based on these results Kopuz *et al*. (2002) hypothesized that the final shape of the CAL was determined by developmental factors rather than degenerative changes. This hypothesis is supported by Kesmezacar *et al*. (2008) who suggested that the multiple-banded ligament develops from the U-shaped ligament.

However, the current study found that the distance between the lateral and medial bands was negatively correlated with the distance of the division point from the anterior edge of the acromion. This means as the width of space increases as the size of the ligament before division decreases. This relationship suggests that development of the coracoid process may increase the division angle between the two bands and decrease the division distance. Thus, this process may explain how the primary U-shaped ligament found by Kopuz *et al*. (2002) in neonatal shoulders developed into a Y-shaped ligament in adult shoulders. In addition, CALs with multiple bands were found to have a variable number of bands (up to 6 bands) and insertions into the root of the coracoid or the roof of the glenoid fossa. The most medial bands were found packed close to each other and some had a branching pattern. Moreover, the current study found that the medial band crossed over the lateral band in three specimens (4%). In addition, this study identified that a similar CAL shape and band number were present in 89% of bilateral shoulders. These observations suggest that the bands of the CAL may be primarily formed during gestation in which there could be double or more of the U-shaped ligaments. This agrees with the findings of Brodie (1890) and Fealy *et al*. (2000) who observed the two band form clearly developed in the human fetus, as well as the suggestion of Kopuz *et al*. (2002) who related the incidence of two bands to mesenchymal differentiation or development of the vasculature early in embryonic life.

Therefore, the current study supports the view that CAL band number is primarily formed during gestation, whereas the final shape of the CAL is related to growth changes in the coracoid process.

4.1.5 CAL Parameters

Measurements of the CAL in the literature show variations (Table 4.3). Generally, the current study reported acromial attachment width (15.96 ± 8.0 mm) equivalent to that reported by Shaffer *et al*. (1997) and Hu *et al*. (2009), but larger than than reported by Morisawa (1998) and Fealy *et al*. (2005). The current study involved any extension at lateral and medial edges of the acromion; while the Fealy *et al*. (2005) excluded the lateral extension of the ligament (CAL falx), and Morisawa (1998) used operative removed specimens that may shrink after they resected. According to CAL types, the results of the current study equivalent to that reported by Kesmezacar *et al*. (2008) and less than that reported by Holt and Allibone (1995). The reason behind these difference is unknown as Holt and Allibone (1995) did not give details on how they measured the acromial width.

For the coracoid attachment width of the CAL, the current study found the general coracoid width (31.58 ± 4.0 mm) wider than that reported by the Hu *et al*. (2009); (Table 4.3). This difference may be returned to sample size, racial differences between the population groups studied, as well as the current study found more CAL with three or more bands. With respect to CAL types, the results of the current study comparable to that reported by Pieper *et al*. (1997), but less than reported by Holt and Allibone (1995) except for Y-shaped ligament. The reason for this difference is unknown since Holt and Allibone (1995) did not give measurement details for the width of coracoid attachment.

Table 4.3 Parameters of the CAL in previous studies compared to the current study.

Study	N	AW (mm)	CW (mm)	LL (mm)	ML (mm)	MT (mm)
Holt & Allibone (1995)	48	Q: 19.4 Y: 19.4 B: 19.0 M: 21.0	Q: 32.8 Y: 31.2 B: 20.0 M: 44.0	Q: 23.1 Y: 25.0 B: 25.0		Q: 1.3 Y: 1.3 B: 1.2 M: 1.3
Pieper ***et al***. (1997)	124		I: 27 II: 34 III: 37	I: 36.0 II: 35.0 III: 32.0		I: 1.4 II: 1.4 III: 1.4
Shaffer ***et al***. (1997)	28	15.6 (12.0-20.0)		26.7 (15.5-31)		
Morisawa (1998)	23	11.70 ± 2.4		28.05 ± 5.3		
Fealy ***et al***. (2005)	56	7.90 ± 3.4		31.0 ± 4.7	30.70 ± 5.3	
Fagelman ***et al***. (2007)	7			39.6	29.2	
Kesmezacar ***et al***. (2008)	80	Y: 15.60 ± 2.7 B: 13.66 ± 3.5 Q: 14.18 ± 4.7 V: 11.88 ± 2.4 M: 15.44 ± 2.8		Y: 34.57 ± 3.1 B: 35.11 ± 5.8 Q: 38.36 ± 8.9 V: 34.00 ± 4.7 M: 32.00 ± 2.7		
Hu ***et al***. (2009)	9	15.86 ± 2.28	26.80 ± 10.24	31.90 ± 4.21	28.91 ± 5.56	1.16 ± 0.36
Wang ***et al***. (2009)	50			31.20 ± 2.99		1.97 ± 0.49
Current study	**220**	**B: 11.84 ± 1.7** **Q: 13.47 ±3.9** **Y: 15.35 ± 3.6** **M: 17.57 ± 3.9**	**B: 11.68 ± 1.9** **Q: 23.42 ± 5.2** **Y: 32.38 ± 5.6** **M: 35.38 ± 4.9**	**B: 40.94 ± 3.7** **Q: 39.51 ± 6.9** **Y: 37.08 ± 5.0** **M: 37.61 ± 5.4**	**B: 33.00 ± 4.4** **Q: 30.91 ± 5.0** **Y: 33.13 ± 4.8** **M: 33.29 ± 4.4**	**B: 1.01 ± 0.2** **Q: 1.14 ± 0.3** **Y: 1.08 ± 0.3** **M: 1.06 ± 0.2**

- CAL parameters: acromial width (AW), coracoid width (CW), lateral length (LL), medial length (ML) and middle thickness (MT).
- CAL shapes: broad-band (B), quadrangular ligament (Q), Y-shaped ligament (Y), V-shaped ligament (V) and multiple-banded ligament (M).
- CAL band number: one band ligament (I), two band ligament (II) and three band ligament (III).

Comparing the acromial and coracoid attachment widths, both Holt and Allibone (1995) and Hu *et al*. (2009) found that the CAL coracoid attachment (32.00 mm and 26.80 mm, respectively) was wider than the acromial attachment (19.7 mm and 14.15 mm, respectively). The current study agrees with these observations, with the coracoid attachment (31.58 ± 8.0 mm) being double the width of the acromial attachment (15.96 ± 4.0 mm). This may be caused by development of the coracoid which grows laterally and extends the corresponding attachment of CAL. Furthermore, the current study found a strong positive correlation between the acromial and coracoid attachment widths. Both CAL attachment widths were positively associated with the length of the anterior edge of the acromion and coracoid process. Therefore, large scapulae may have larger size CAL than small scapulae.

The mean length of the anterolateral band showed more variation than the posteromedial band. Previous studies (Holt and Allibone, 1995; Shaffer *et al*., 1997; Morisawa, 1998) reported the mean length of the anterolateral band to be less than 30 mm; five studies (Pieper *et al*., 1997; Fealy *et al*., 2005; Kesmezacar *et al*., 2008; Hu *et al*., 2009; and Wang *et al*., 2009) measured it as between 31 mm and 35 mm, and one study reported the length as 39.6 mm (Fagelman *et al*., 2007). The current study found the mean length of the anterolateral band to be 37.80 mm, which is closer to that of Fagelman *et al*. (2007). The difference in the measurements may be due to a number of reasons: (1) the method of measuring in comparison to Holt and Allibone (1995), who considered the length of the CAL as the minimum distance measured from a variable point on the coracoid to the most medial aspect of the acromion, and Wang *et al*. (2009) who used ultrasound; (2) the specimens examined in which Morisawa (1998) used CAL specimens removed surgically from patients, thus the specimens may have shrunk or were not resected completely; (3) the sample size in comparison to Hu *et al*. (2009); and (4) race in comparison to Hu *et al*. (2009) and Wang *et al*. (2009). In contrast, previous studies (Fealy *et al*., 2005; Fagelman *et al*., 2007; and Hu *et al*. 2009) reported the mean medial length of the CAL to range from 28.91 mm to 30.70 mm. The current study agrees with these studies, with mean medial length of the CAL being 32.98 ± 4.6 mm.

Comparing the anterolateral and posteromedial bands, both have almost the same length according to Fealy *et al*. (2005) and Hu *et al*. (2009). However, Fagelman *et al*. (2007) reported that the anterolateral band was longer than the posteromedial band, being 39.6 mm and 29.2 mm respectively. In agreement with Fagelman *et al*. (2007), the current study found that the lateral length of the CAL (37.80 ± 5.4 mm) was significantly longer than the medial length of the CAL (32.98 ± 4.6 mm). This may be returned to the triangular or diagonal shape of the ligament, in which the medial band deviates postero-laterally to meet the straight lateral band to inserts into the anterior edge and undersurface of the acromion. As a result, a part of the medial band hides under the acromion. This makes the lateral band looks longer than the medial band.

However, the current study compared the length of lateral and medial bands in Y-shaped ligament since they have constant attachment sites and relatively size. In contrast, previous studies (Fagelman *et al*., 2007; Fealy *et al*., 2005; Hu *et al*., 2009) reported their results generally including lengths of all CAL types. This may not valid to compare the lengths of lateral and medial bands. First, previous studies used the length of medial edge of the single band ligament as the length of medial band length. Second, in CAL with three or more bands, the medial band length was measured as the length of the most medial band. This is not equivalent, in the anatomical site and size, to the medial band in two bands ligament. Therefore, the result of the current study was more valid than previous studies, in which comparing the lateral and medial bands (sides) will be more accurate within the ligament type.

With respect to the subacromial insertion of the CAL, Shaffer *et al*. (1997) reported the mean lengths of the insertion as 12.3 mm and the mean of the whole lateral length of the CAL as 39 mm (range 23 to 50 mm). The current study determined the lateral and medial lengths of the subacromial insertion observing the mean lengths to be 20.61 ± 6.61 mm and 23.75 ± 5.02 mm, respectively. Therefore, the whole length of the lateral side of the CAL was 58.57 mm and medial side was 56.76 mm, which the lateral band almost longer than the medial band.

In addition, the lateral band is usually stronger and broader than the medial band (Brodie, 1890; Holt and Allibone 1995). In agreement with these studies, the current study found that the anterolateral band was significantly wider and thicker than the posteromedial band: 14.05 ± 3.41 mm compared to 7.23 ± 3.37 mm, and 1.34 ± 0.3 mm compared to 0.86 ± 0.36 mm. This may return to the development of the ligament and formation of bands, in which the lateral wider band attaches to the lateral straight aspect of the coracoid while the medial narrower band attaches to medial curved aspect of the coracoid. CALs with two bands showed a positive correlation between the width of the anterolateral band and the whole coracoid width of the ligament. Therefore, the width of the anterolateral band may increase as the size of the ligament attachment increases.

Regarding CAL thickness, Fealy *et al*. (2005) found that the anterolateral band had a thicker acromial (1.00 ± 0.5 mm) than coracoid attachment (0.88 ± 0.6 mm), whereas the posteromedial band had a thicker coracoid (1.2 ± 0.95 mm) than acromial attachment (0.6 ± 0.4 mm). Moreover, previous studies (Holt and Allibone, 1995; Pieper *et al*., 1997; Hu *et al*., 2009; Wang *et al*., 2009) reported that the midpoint or middle thickness of the CAL ranged between 1.16 mm and 1.97 mm (Table 4.3). In contrast, the current study found that the CAL had a significantly thicker acromial attachment (2.05 ± 0.6 mm) than coracoid attachment (1.29 ± 0.3 mm) and middle thickness (1.07 ± 0.2 mm). The coracoid attachment was also significantly thicker than the middle thickness. The thickness of the acromial and coracoid attachments of the CAL were greater than reported by Fealy *et al*. (2005). However, the middle thickness of the CAL was thinner than that reported previously (Holt and Allibone, 1995; Pieper *et al*., 1997; Hu *et al*., 2009; Wang *et al*., 2009). In addition, a positive correlation between acromial width and thickness of the CAL was observed. However, the middle thickness of the CAL is more accurate in measuring thickness of the ligament, which acromial and coracoid thicknesses may be affected by ossification and formation of spurs within the attachments. In addition, the coracoid attachment may be affected by the development of the coracoid and division of the ligament into bands while the acromial attachment undivided.

Variations have been observed regarding the distance and angle between the anterolateral and posteromedial bands. Holt and Allibone (1995) reported the mean distance between the two bands at the coracoid as 6.8 ± 3.7 mm in two band ligaments and 3 mm in three band ligaments. Edelson and Luchs (1995) reported the distance between the anterolateral band and posteromedial bands ranged from 5.0 to 15.0 mm. In contrast, the current study found the mean distance between the two bands was 11.41 ± 4.7 mm for two band ligaments and 8.30 ± 3.9 mm for the first space in three band ligaments. This in same range that reported by Edelson and Luchs (1995), and less than that reported by Holt and Allibone (1995). However, Fealy *et al* (2005) reported the angle between the anterolateral and posteromedial bands as 36.3 ± 8.2º. Similar to Fealy *et al*. (2005), the current study found the mean angle between the anterolateral and posteromedial bands was 35.83 ± 10.0º for two band ligaments, and 33.43 ± 9.7° at the first space for the three band ligaments. In addition, the current study found a positive correlation between space width and division angle, and a negative correlation between space width and division distance. This relationship suggests that as the coracoid developed laterally, as the coracoid attachment of the CAL extended and divided into bands. In turn increase the space between the bands resulting in extending the division length into the acromion. Therefore, the size of the space or diaphanous membrane may help determine how these bands are formed.

4.1.6 Relation to Acromial Spurs

Acromial spurs are formed as a result of ossification of the acromial insertion of the CAL (Uhthoff *et al*., 1988; Edelson, 1995; Hernigou, 1994; Fealy *et al*., 2005; and Natsis *et al*., 2007). With respect to CAL morphology, Pieper *et al*. (1997) found no association between acromial spurs and morphology. In contrast, Fealy *et al*. (2005) reported a relationship between acromial spurs and CAL morphology, in shoulders with acromial spurs having a focal morphology compared to a diffuse morphology when no spur existed. They found that CALs with spurs had a smaller angle between the anterolateral and posteromedial bands compared to CALs without spurs; 31° and 45° respectively. Subsequently, the space between the anterolateral and posteromedial bands at the coracoid attachment site was shorter in CALs with spurs (23.9 mm) than in those without (32.2 mm). The results of the current study support the findings of Pieper *et al*. (1997) in which there is no association between the presence of an acromial spur and CAL morphology or band number. In addition, the angle between the anterolateral and posteromedial bands showed no difference in relation to the presence of an acromial spur: 35.97 ± 11.4° in shoulders with spurs and 33.31 ± 8.3° in shoulders without. However, shoulders with acromial spurs had a wider space between bands than shoulders without spurs: 10.60 ± 5.4 mm compared to 8.98 ± 3.6 mm, respectively.

Acromial spurs are mainly associated with the anterolateral band (Edelson, 1995; Fealy *et al*., 2005; Uhthoff *et al*., 1988). Shoulders with acromial spurs were found to have calcified attachments (Giordano, 1972; Morimoto *et al*., 1988) and thicker CALs at both their origin and insertion (Fealy *et al*., 2005). The current study observed acromial spurs within the CAL in 43% of specimens, mainly palpable within the lateral half of the acromial attachment of the CAL. Furthermore, the current study found that shoulders with acromial spurs had significantly thicker acromial and coracoid attachments than shoulders without spurs. This difference may be caused by formation of acromial spurs within the attachments. However, the midpoint thickness of the lateral band in shoulders with spurs was significantly thicker than those without spurs: 1.13 ± 0.3 mm compared to 1.03 ± 0.2 mm, respectively. Therefore, the presence of acromial spurs leads to geometric changes in all parts of the CAL.

Both Zuckerman *et al*. (1992) and Fealy *et al*. (2005) reported shorter CALs in shoulders with acromial spurs. In contrast, the current study found no difference in the lateral and medial lengths of the CAL in the presence of an acromial spur. Moreover, comparison of acromion length did not show a difference between the two groups: 44.72 ± 5.8 mm in shoulders without acromial spurs and 45.05 ± 6.0 mm in shoulders with acromial spurs. Therefore, spurs were usually formed within the acromial attachment of the CAL without calcification of the outer fibers of the ligament and any change in ligament length. However, formation of acromial spurs at the anterior edge of acromion narrow the coracoacromial space.

Fealy *et al*. (2005) reported that CALs with spurs had narrower acromial attachments than those without spurs; 5.53 mm and 11.9 mm ($P < 0.001$) respectively. Disagreeing with Fealy *et al*. (2005) the current study found that both the acromial (17.03 ± 3.8 mm) and coracoid attachments (32.97 ± 7.4 mm) of the CAL in shoulders with acromial spurs were wider than those in shoulders without acromial spurs: 15.15 ± 4.0 mm and 30.52 ± 8.3 mm ($P < 0.001$ and $P = 0.024$) respectively. Fealy *et al*. (2005) assumed CAL with wider attachment dampening the forces transmitted through the CAL, which minimize the traction forces on the anterior aspect of the acromion and formation of acromial spurs. However, the current study found that spurs formed primarily at the undersurface of the acromion as ossification of the subacromial insertion of the CAL. With further impingement, as indicated by attrition lesions on the subacromial insertion of the CAL and surface changes on the undersurface of the acromion, the size of the ligament increase and extends to anterior edge of the acromion. In addition, the size of spur associated with size of the subacromial insertion of the CAL. Therfore, the formation of the acromial spur more related to the humeral head impingement on the undersurface of acromion as well as the size of subacromial insertion than attrition forces transsimitted through the ligament. An increase in attachment width of the CAL may also narrow the subacromial space mainly at the subacromial portion of the ligament. This in turn will lead to greater impingement and an increased tension in the CAL.

Previous studies have shown that acromial spur formation was influenced by repetitive attrition and impingement of the rotator cuff and greater tubercle against the subacromial arch which caused chronic impingement and increased tension in the CAL (Neer, 1972; Cone *et al*., 1984; Aoki *et al*., 1986; Tada *et al*., 1990; Prescher, 2000; Mahakkanukrauh and Surin, 2003; Ko *et al*., 2006). Tada *et al*. (1990) stated that acromial spurs started to form as an enthesis at the subacromial attachment of the CAL and with repetitive impingement [stresses] develop into a spur extending within the CAL. Yamamoto *et al*. (2010) claimed that the osteophyte traction formed at the insertion of the CAL to the acromion was due to increased contact pressure between the coracoacromial arch and the rotator cuff tendons and a bending deformation of the CAL in this area. Therefore, an increase in the acromial attachment width of the CAL may lead to greater subacromial impingement and attrition against the subacromial surface and the CAL which would influence enthesis formation and spur growth.

4.1.7 Relation to Rotator Cuff Tears

Previous studies have stated that the CAL plays a significant role in the development of subacromial impingement syndrome, especially in shoulders without bony abnormalities or articular deformities in the subacromial space or surrounding structures (Uhthoff *et al*., 1988; Fremerey *et al*., 2000; Sarkar *et al*., 1990). Neer (1983) described subacromial impingement as friction of the rotator cuff tendon against the anterior edge and undersurface of the anterior third of the acromion, the coracoacromial ligament and sometimes the acromioclavicular joint during arm elevation. As a result, CAL strain and thickness will increase which may narrow the subacromial space and lead to further friction and impingement (Uhthoff *et al*., 1988; Gallino *et al*., 1995). Overexpansion of the subacromial structures against an unyielding CAL leads to degenerative changes in the CAL, such as fibrillation, fatty infiltration, microtears (Uhthoff *et al*., 1988), and spur formation (Neer, 1972; Cone *et al*., 1984; Aoki *et al*., 1986; Tada *et al*., 1990; Miles, 1996; Prescher, 2000; Mahakkanukrauh and Surin, 2003; Ko *et al*., 2006). However, it is unclear whether degenerative and geometric changes of the CAL are the result or the cause of the impingement (Uhthoff *et al*., 1988; Soslowsky *et al*., 1994; Fremerey *et al*., 2000).

The current study observed rotator cuff tears in 50% of specimens, mainly in the tendon of supraspinatus. The incidence and type of rotator cuff tears were more common bilaterally than unilaterally. No association was observed between the sex of the individuals and rotator cuff tears. These results suggest a degenerative role in rotator cuff tears, shoulders with rotator cuff tears were from older individuals than those without cuff tears: 83.87 ± 8.6 years compared to 79.56 ± 9.9 years, respectively. An association was also found between rotator cuff tears and age: eighty and ninety year or older specimens had more than a 50% incidence of rotator cuff tears: 54.5% and 67.6%, respectively. With respect to the type of rotator cuff tear, specimens with complete tears were older than those with normal rotator cuffs, whereas no difference was found between specimens with partial bursal tears and those with normal rotator cuff tendons or complete rotator cuff tears. This suggests association between the rotator cuff tears and age of individuals, which the partial bursal tear a middle stage between the normal cuff tendon and complete cuff tears. In addition, an association was found between females and rotator cuff tears. This association may due to the age difference between females and males, as females (84.05 ± 9.3 years) were significantly older than the males (80.43 ± 8.6 years). Therefore, the current study found that age plays a significant role in rotator cuff tear formation as a result of degenerative changes in the CAL, spur formation, and may shoulder muscles weakness and tendinopathy.

With respect to the number of bands, Pieper *et al*. (1997) found no association between CAL band number and rotator cuff tears observing the incidence of rotator cuff tears as follows: 34.4% had one band, 44.6% had two bands and 27.8% had three bands. In contrast, the current study found a significant association between rotator cuff tears and CAL band number. More than half (56.3%) of specimens with three or more bands had rotator cuff tears, while around two thirds (71.4%) of specimens with a one band ligament had normal rotator cuff tendons. The incidences of rotator cuff tears according to CAL band number were: 10.4% had one band, 37.7% had two bands and 51.9% had three bands. Thus, increase the size or band number of the CAL may narrow the subacromial space or limit and contradict supraspinatus function. Comparing the incidence of rotator cuff tears in the current study to Pieper *et al*. (1997), the current study detected fewer rotator cuff tears in shoulders with CALs composed of one and two bands and more rotator cuff tears in shoulders with CALs with three bands. However, there was no association between the number of bands and rotator cuff tears according to the type of tear: a larger sample study would be required for this. Therefore, the current study found that increasing CAL band number may increase the possibility of a rotator cuff tear incidence. Increasing band number may narrow the subacromial space and lead to further impingement and attrition between subacromial structures and the CAL.

Kesmezacar *et al*. (2008) did not detect any relationship between CAL morphology and rotator cuff tears reporting the incidence of tears as: 39% had a Y-shaped ligament, 28% had a broad band ligament, 0% had a quadrangular ligament, 44% had a V-shaped ligament and 56% had a multiple-banded ligament. However, they did find a significant relationship between rotator cuff tears and CALs with more than one band. The current study agrees with Kesmezacar *et al*. (2008) in that there is no association between CAL morphology and rotator cuff tears. The incidence of rotator cuff tears according to CAL morphology in the current study was: 3.9% had a broad ligament, 6.5% had a quadrangular ligament, 37.7% had a Y-shaped ligament and 51.9% had a multiple banded ligament. These observations suggesting the relationship between the rotator cuff tears and changing in the size of the CAL, which these changes more seen in the coracoid attachment than in the acromial attachment ends. Comparing these observations to Kesmezacar *et al*. (2008) the current study found fewer rotator cuff tears in broad band ligaments, more in quadrangular band ligaments and almost the same in Y-shaped and multiple band ligaments. The current study therefore supports Kesmezacar *et al*. (2008)

in which a low incidence of rotator cuff tears was found in shoulders with single band CALs, whereas a greater incidence of rotator cuff tears was observed in shoulders with CAL of more than one band.

Previous studies have reported that shoulders with rotator cuff tears are characterized by larger cross sectional areas at the midpoint of the lateral band compared to those without rotator cuff tears (Soslowsky *et al.*, 1994; Fremerey *et al.*, 2000) (Table 4.4). The current study found similar results: shoulders with rotator cuff tears had a significantly larger cross sectional area than those with normal rotator cuff tendons. According to the type of rotator cuff tear, shoulders with complete tears had a significantly larger cross sectional area than shoulders with normal rotator cuff tendons and partial bursal tears. However, comparing the cross sectional area of shoulders with normal rotator cuff tendons to those with partial bursal tears did not show any differences.

Table 4.4 Cross sectional area of the CAL at the midpoint of the lateral band in relation to rotator cuff tears.

Study	N	Age	Rotator Cuff Tears (mm^2)	No Cuff Tears (mm^2)
Soslowsky ***et al***. (1994)	20	61- 87	12 ± 3.8*	8 ± 3.8
Fremerey ***et al***. (2000)	38	< 60 > 60	13.8 ± 5.4* 12.3 ± 3.5*	10.7 ± 4.6 9.0 ± 2.9
Current study	**155**	**53 - 101**	**13.20 ± 5.5***	**11.03 ± 4.0**
			P= 11.14 ± 3.6 **C= 14.90 ± 6.2***	

- Cuff tears: partial tear (P), complete tear (C).
- Significant difference (*): < 0.050

At the midpoint of the lateral band of the CAL, both Soslowsky *et al*. (1994) and Fremerey *et al*. (2000) found no difference in mean width and thickness of CAL in relation to rotator cuff tears. Soslowsky *et al*. (1994) reported the mean width of CAL as 10. 2 ± 2.8 mm and thickness as 1.21 ± 0.36 mm in shoulders with rotator cuff tears compared to 8.0 ± 2.1 mm and 0.96 ± 0.33 mm in the shoulders with normal rotator cuff tendons. In younger individuals, Fremerey *et al*. (2000) determined the mean width of CAL as 11.2 ± 2.4 mm and the mean thickness of CAL as 1.2 ± 0.3 mm in shoulders with rotator cuff tears compared to 10.1 ± 2.7 mm and 1.1 ± 0.3 mm in shoulders with normal rotator cuff tendons. While in older individuals, Fremerey *et al*. (2000) reported the mean width of CAL as 8.5 ± 2.0 mm and thickness as 1.5 ± 0.4 mm in shoulders with rotator cuff tears compared to 7.7 ± 1.9 mm and 1.2 ± 0.3 mm in shoulders with normal rotator cuff tendons. In contrast, the current study found that CALs in shoulders with cuff tears were significantly thicker (1.11 ± 0.3 mm) at the midpoint of the lateral band than CALs in shoulders with normal rotator cuff tendons (1.02 ± 0.2 mm). This difference was also detected between CALs in shoulders with complete tears (1.17 ± 0.3 mm) and those in shoulders with normal rotator cuff tendons (P = 0.007), while there was no difference found in CALs in shoulders with partial bursal tears (1.05 ± 0.2 mm). Regarding width at the midpoint of the lateral band of the CAL there was no difference between shoulders with rotator cuff tears (11.62 ± 3.0 mm) and those with normal rotator cuff tendons (10.79 ± 2.9 mm). However, in relation to the type of rotator cuff tear, CALs in shoulders with complete tears were wider (12.64 ± 3.46 mm) than CALs in shoulders with normal (10.79 ± 2.9 mm) and those in shoulders with partial bursal tears (10.39 ± 1.8 mm).

In addition, the current study also compared the attachment widths of the CAL at the acromion and coracoid processes in relation to rotator cuff tears. Shoulders with rotator cuff tears had significantly CALs with wider acromial and coracoid attachment widths than did shoulders with normal rotator cuff tendons.

At the acromial attachment the mean width of CAL was 17.73 ± 3.7 mm in shoulders with rotator cuff tears and 15.66 ± 4.1 mm in shoulders with normal rotator cuff tendons. At the coracoid attachment the whole width (including the spaces between CAL bands) was 33.27 ± 7.0 mm in shoulders with rotator cuff tears and 29.90 ± 9.4 mm in shoulders with normal rotator cuff tendons. Regarding tear type, shoulders with complete tears had a significantly CALs with wider acromial attachment (18.81 ± 4.1 mm) than CALs in shoulders with normal rotator cuff tendons (15.66 ± 4.1 mm) and partial bursal tears (16.56 ± 3.0 mm). However, there was no difference in coracoid attachment width in relation to tear type.

The CAL in shoulders with rotator cuff tears present with shorter lateral bands (Fremerey *et al*., 2000; Kesmezacar *et al*., 2008; Soslowsky *et al*., 1994; Zuckerman *et al*., 1992). However, Wu *et al*. (2010a, 2012) reported no difference in CAL length between tear and normal groups, or between symptomatic shoulders and asymptomatic shoulders. The current study revealed no significant differences in the length of the lateral and medial bands of the CAL in relation to rotator cuff tears or type of cuff tears.

The medial band dimensions have not shown differences between normal and degenerated shoulders (Soslowsky *et al*., 1994; Neer, 1972; Kesmezacar *et al*., 2008); however studies suggest that pathological changes involve all parts of the CAL (medial and lateral bands) when rotator cuff tears are present (Fealy *et al*., 2005; Fremerey *et al*., 2000; Pieper *et al*., 1997; Zuckerman *et al*., 1992; Salter *et al*., 1987). Wu *et al*. (2010a, 2012) observed no difference in the thickness of the CAL between tear and normal groups, or between symptomatic shoulders and asymptomatic shoulders. However, the current study found that shoulders with rotator cuff tears had a significantly thicker acromial attachment (2.19 ± 0.8 mm) compared to shoulders with normal rotator cuff tendons (1.78 ± 0.4 mm). Similarly, shoulders with complete rotator cuff tears had a significantly thicker acromial attachment (2.38 ± 0.8 mm) than shoulders with normal rotator cuff tendons and partial bursal tears (1.98 ± 0.7 mm). However, lateral and medial band thicknesses at the coracoid attachment did not show any relationship to rotator cuff tears. Nevertheless, the current study observed a significant difference in the thickness of the acromial attachment of the medial band of CAL between shoulders with complete tears (1.02 ± 0.4 mm) and those with normal rotator cuff tendons (0.77 ± 0.3 mm). Therefore, shoulders with rotator cuff tears showed degenerative changes in all parts of the CAL.

4.2 Attachment Sites of the CAL

Gross inspection showed that the CAL attached to the anterior edge of the acromion process and the posterior aspect of the coracoid process. Anatomical variations were observed in the current study regarding the CAL attachment sites which may be related to the size of the ligament or bony process. The CAL was also found to interconnect with several ligaments, tendons and other soft tissues in the shoulder. In addition, the current study classified the attachment sites of the CAL at the acromion and coracoid process and considered these in relation to subacromial impingement syndrome.

4.2.1 Acromial Attachment

At the acromial attachment site, the CAL has been reported to insert into the undersurface of the acromion (Edelson and Luchs, 1995; Hunt *et al*., 2000;

Moorman *et al*., 2008) covering the anteromedial undersurface (Edelson and Luchs, 1995). The mean length of this insertion was 12.3 mm (Shaffer *et al*., 1997) and 18.5 mm (Fealy *et al*., 2005). The medial part of the CAL passes under part or the entire undersurface of the capsule of the acromioclavicular joint (Salter *et al*., 1987; Edelson and Luchs, 1995; Hunt *et al*., 2000). Salter *et al*. (1987) observed that the CAL extended onto the inferior acromial surface via a broad area interconnecting with the inferior capsular ligament of the acromioclavicular joint. They assumed that the CAL acts to buffer this area from the subacromial soft tissues, as well as support the acromioclavicular joint.

In the current study, a coronal section of 20 specimens showed that the CAL fibres divided and passed superiorly and inferiorly at both sites of attachment. At the acromion the superior fibres attached into the anterior edge of the acromion overlapping with the deltoid fibres in agreement with Hunt *et al*. (2000), and with deltoid fascia at the lateral margin of the acromion in agreement with (Edelson and Luchs, 1995). The inferior fibres extended beneath the acromion and covered the entire anterolateral third of the undersurface. The mean length of the subacromial insertion of the CAL was 20.61 mm covering 46% of the acromion length, a figure comparable to the 18.5 mm determined by Fealy *et al*. (2005).

The medial fibres of the CAL extended into the anteromedial aspect of the acromion in the majority (60.9%) of specimens being restricted to the anterior edge of the acromion in the remainder. At the anteromedial aspect of the acromion the medial fibres of the CAL extended to the acromial facet of the acromioclavicular joint in approximately half (49.5%) of specimens. The mean width of this part was 5.75 ± 2.4 mm, being 34% of the total CAL width at the acromial side and 33% of the length of the acromial facet of the acromioclavicular joint. As described by Pieper *et al*. (1997) this part of the ligament was usually hidden beneath the clavicle, consequently dissection of the acromioclavicular joint and displacement of the clavicle was needed to enable a clear view of these medial fibers.

In contrast, the current study found that the third band was significantly attached to the acromioclavicular joint; however the medial border of CALs with one band and the posteromedial band of CALs with two bands were also found to attach to the acromioclavicular joint. Attachment of the CAL to the acromioclavicular joint according to the number of CAL bands was observed as follows: 6 specimens (5.5%) with one band, 36 specimens (33%) with two bands, and 67 specimens (61.5%) with three or more bands. A significant association was found between CALs with three or more bands and an acromioclavicular joint attachment. CALs with an acromioclavicular joint attachment also had a significantly wider acromial attachment than those without, being 17.70 ± 3.9 mm compared to 14.26 ± 3.4 mm, respectively. A significant association was observed between shoulders with CALs attached to the acromioclavicular joint and rotator cuff tears, with tears found in 66.2% of specimens with CALs attached to the acromioclavicular joint compared to 33.8% of specimens without a CAL attachment to the acromioclavicular joint. In addition, a significant association was found between shoulders with CALs attached to the acromioclavicular joint and acromial spurs. Acromial spurs were found in 61.1% of specimens with CALs attached to the acromioclavicular joint compared to 38.9% of specimens without.

4.2.2 Coracoid Attachment

At the coracoid attachment site, Brodie (1890) observed that the anterolateral band ligament had a constant attachment to the lateral tip of the coracoid process, while the posteromedial band had varied attachment sites along the base of the coracoid. Edelson and Luchs (1995) reported that two band CALs had an attachment to the base of the coracoid in one third of specimens. Moreover, Fealy *et al*. (2005) observed that CALs with three bands had a wider coracoid attachment extending to the base of the coracoid.

In agreement with previous studies (Brodie, 1890; Edelson and Luchs, 1995; Fealy *et al*., 2005), the current study found that CALs with one band and the anterolateral band of CALs with two or three bands showed a consistent attachment to the lateral end of the coracoid. However, the posteromedial, or third, band had a variable insertion along the posterior aspect of the coracoid to its base and root. This part of the ligament was usually hidden below the clavicle. The coracoid attachment of the CAL extended beyond (medial to) the base of the coracoid in 74.5% of specimens, while in the remainder it had a coracoid attachment extending between the lateral tip and base of the coracoid. The medial band of the CAL was attached to the roof of the glenoid, medial to the glenoid tubercle and inferior to supraspinatus in 10% of specimens with CALs composed of three bands or more. Identification of these attachment may help in understanding the shoulder biomechanics, as well as in proper resection of the CAL during subacromial decompression surgery.

A coracoacromial falx has been described as a continuation of the lateral band of the CAL with either the aponeurosis of coracobrachialis (Renoux *et al*., 1986), the short head of biceps (Brodie 1890; Birnbaum *et al*., 1998; and Lee *et al*., 2001) and both the tendons of biceps and coracobrachialis (Hunt *et al*. 2000, and Fealy *et al*., 2005). Fealy *et al*. (2005) observed the falx in 75% of their specimens, being present posteriorly at the lateral lip of the acromion extending anterolaterally from the CAL along its whole course and blending anteriorly with the conjoined tendon at the lateral aspect of the coracoid process. Other CAL connection is the coracoacromial viel. The coracoacromial veil is described as a subcoracoid connection between the CAL and either the coracohumeral ligament (Jerosch *et al*., 1990), subacromial bursa (Birnbaum *et al*., 1998) or the anterosuperior rotator interval capsule (Moorman *et al*., 2008).

Coronal sections in the current study showed that the fibers of the CAL split at the coracoid attachment into superior and inferior fibers. The superior fibres spread over the posterior surface of the medial end of the coracoid, interconnecting with the coracoclavicular ligament, while the inferior fibres interconnected with the common origin of coracobrachialis and the short head of biceps (coracoacromial falx) and the coracohumeral ligament (coracoacromial veil). These observations agree with Hunt *et al*. (2000) and Fealy *et al*. (2005) who both found that the coracoid attachment of the CAL is continuous with the conjoined tendon of biceps and coracobrachialis, and Salter *et al*. (1987) who also noted that the CAL interconnected with the coracoclavicular and coracohumeral ligaments at the coracoid attachment. Therefore, these connections may increase instability of the CAL and have other biomechanical function in shoulder as Birnbaum et al. (1998) suggested having a role in facilitating the gliding behaviour of the subacromial bursa and the shoulder joint capsule in shoulder abduction.

In the current study a coracoacromial falx was observed 51% of specimens with a mean width of 4.68 ± 1.7 mm attached to the joint tendon of coracobrachialis and the short head of the biceps. The coracoacromial falx was significantly associated with the presence of acromial spurs, being found in 63.1% of specimens with a coracoacromial falx. This suggests that the coracoacromial falx may increase the traction forces applied on the anterior edge of the acromion and promote the formation of acromial spurs.

4.2.3 Classification of the CAL Attachment

The present study classified the CAL according to its attachment to the acromion and coracoid, being the first such classification in the literature (Figures 2.1 and 2.2). The classification aimed to identify the geometric differences between CALs according to their attachments and relation to acromial spurs and rotator cuff tears. In addition, it aimed to determine if there was a relationship between a medial expansion of the CAL and rotator cuff tears.

With respect to the acromial attachment, there was an association between the attachment sites of the CALs and the number of bands of the CAL (Table 3.7 and 8). CALs with one band were attached to the anterior edge of the acromion, and into lateral edge of the coraoid; while CALs with three or more bands were attached to the anterior edge of the acromion with the medial fibers extending into the anteromedial aspect of the acromion, and into the medial end of the coracoid. CALs with three or more bands also significantly hid underneath the clavicle. These observations may provide a way to locate attachment sites of the CAL to achieve proper resection or reattachment of the ligament during the subacromial decompression surgery.

A significant association observed between CALs with a medial acromial and coracoid attachments and the incidence of acromial spurs and rotator cuff tears. Association of medial acromial and coracoid attachment ligaments with acromial spurs and rotator cuff tears may result from that these ligaments have larger size of CAL. Analysis of variance showed that CALs with medial acromial and coracoid attachments had a significantly wider attachments than those with a lateral attachments. Thus, large size of CALs may narrow the subacromial space and conflicts with function of the supra spinouts. This may lead to more shoulder impingement and attrition between the CAL and supraspinatus tendon resulting in degeneration of CAL and formation of spur and rotator cuff tears.

There are three factors which could affect the attachment site of the CAL: (1) the size of the ligament or number of bands, (2) the length of the anterior edge of the acromion or posterior aspect of the coracoid process, and (3) the lateral deviation angle of the CAL. CALs with medially attached fibers had wider acromial and coracoid attachments than those with a lateral attachment. The medially attached CALs were associated with three band ligaments, while laterally attached CALs were associated with one band ligaments. At the acromial attachment, shoulders with a medial attachment had a shorter anterior acromion length than those with a lateral attachment: 16.97 ± 2.7 mm compared to 18.22 ± 2.6 mm, respectively. At the coracoid attachment, shoulders with a medial attachment had a shorter coracoid length than those with a lateral attachment: 42.43 ± 5.0 mm compared to 44.63 ± 6.5 mm, respectively.

Therefore, the increased width of the ligament in shorter processes allowed the attachment to spread medially. In addition, medial extension of the CAL at the acromion could be result from increase the acromion-scapula spine angle, which would cause the CAL to deviate medially at the anterior edge of the acromion to correct the alignment of the ligament with the coracoid attachment. Statistical analysis showed that shoulders with a medial acromial attachment had a higher acromion-scapula spine angle than those with a lateral acromial attachment: 45.14 ± 10.38º compared to 42.11 ± 9.5º. The deviation angle of the lateral band in shoulders with a medial acromial attachment was higher than those with a lateral acromial attachment: 116.89 ± 8.4º compared to 113.88 ± 7.2º.

4.2.4 Relation to Rotator Cuff Tears

Previous studies have debated whether the medial fibers of the CAL were involved in impingement syndrome or not. Fealy *et al*. (2005), Fremerey *et al*. (2000), Pieper *et al*. (1997), Zuckerman *et al*. (1992) and Salter *et al*. (1987) all observed similar pathologic changes in all parts of the CAL, i.e. medial and lateral bands, with degenerated rotator cuff tendons. The third band assumed to narrow the subacromial space and cause further impingement on the rotator cuff (Pieper *et al*., 1997). In contrast, Neer (1972), Soslowsky *et al*. (1994) and Kesmezacar *et al*. (2008) have reported that degenerative and geometric changes in the CAL were present only in the anterolateral portion of the ligament, with no change observed in the medial band dimensions between normal and degenerated shoulders. Therefore, both Soslowsky *et al*. (1994) and Fremerey *et al*. (2000) stated that dimensional changes in the lateral band of the CAL would narrow the subacromial space, which no differences were found in the medial band of the CAL between shoulders with rotator cuff tears and shoulders without.

However, the current study found that shoulders with a medial CAL attachment to the acromion and coracoid processes had a significant association with rotator cuff tears and acromial spurs. CAL dimensions also showed differences according to attachment sites of the ligament, in which CALs with medial attachments had wider acromion and coracoid attachments, as well as thicker acromial attachments, than those with lateral attachment sites. Therefore, this study agrees with Pieper *et al*. (1997) and suggests that medially attached fibers of the CAL may narrow the subacomial space leaving less clearance for the supraspinatus tendon that could lead to impingement of the subacromial tissues against the coracoacromial arch.

Masciocchi *et al.* (1993) inspected shoulder impingement points using MRI in impingement syndrome patients. Their results showed that the critical impingement points were: 65% between acromioclavicular arthritis and the supraspinatus tendon, 35% between acromioclavicular arthritis and supraspinatus, and 44% between the CAL and supraspinatus. In addition, Wang *et al*. (2009) found that the CAL was displaced superiorly during different testing protocols of shoulder impingement and active shoulder motion. In the current study, 49.5% of specimens had a CAL with a subacromial insertion extending medial to the inferior surface of the acromioclavicular joint: the mean width of this part being 5.75 ± 2.4 mm. CALs with an attachment involving the acromioclavicular joint were wider and thicker than those without acromioclavicular joint involvement: widths were 17.70 ± 3.9 mm compared to

14.26 ± 3.4 mm, and thicknesses 2.16 ± 0.7 mm compared to 1.96 ± 0.6 mm, respectively. Shoulders with a CAL involving the acromioclavicular joint were associated with rotator cuff tears and acromial spurs. Therefore, these results suggest that CALs involving the acromioclavicular joint may narrow the subacromial space and increase the risk of supraspinatus impingement as described by Masciocchi *et al* (1993). The part of the CAL extension below the acromioclavicular joint may degenerate and become stiff due to an increase in thickness or expansion of the inferior joint capsule in acromioclavicular joint arthritis, as well as superior/inferior displacement of acromioclavicular joint. In addition, the medial CAL fibers underneath the clavicle may decrease the superior displacement of these fibers during shoulder motion; therefore subacromial pressure builds on these fibers leading to degenerative changes in the CAL.

Lee *et al*. (2001) evaluated contact geometry at the subacromial surface of the acromion in relation to rotator cuff tears and found no difference in the anteroposterior dimension, but a difference in the mediolateral dimension. Yamamoto *et al*. (2010) assumed that the daily repetition of contact between the CAL and rotator cuff tendons responsible for formation of an attraction osteophyte. This agrees with the findings of the current study, in which medial extension of the CAL attachment showed an association with rotator cuff tears and acromial spurs. Increased subacromial attachment of the CAL may increase subacromial contact and the formation of acromial spurs.

4.2.5 Note on Attachment of the CAL

The attachment of the CAL at both the acromion and coracoid may provide stability for the ligament and improve its biomechanical function. The current study showed that the CAL had an acromial attachment to the anterior edge of the acromion and a long subacromial insertion. On the coracoid, the CAL was found to have a wide attachment to the posterior aspect of the coracoid with interconnections with the conjoined tendon of the short head of biceps and coracobrachialis, the coracoclavicular and coracohumeral ligaments. These attachments and interconnections may help the CAL to resist subacromial pressure and traction forces during shoulder movements, which prevent humeral dislocation or fracture of the acromion and/or coracoid processes. Burns and Whipple (1993) observed impingement against the CAL in different shoulder movements. Yamamoto *et al*. (2010) measured the contact pressure beneath the acromion and CAL which ranged from 0.04 to 0.07 MPa at 0° of each motion. As the angle of shoulder motion increased, the sites of the contact pressure beneath the CAL shifted through the whole length of the ligament, which normally displaced anterosuperiorly. In addition, the CAL works as a dynamic brace ligament transferring tensile forces between the acromion and coracoid to distribute the muscle forces applied to these two processes (Putz *et al*., 1988; Gallino *et al*., 1995).

In 1972, Neer developed open anterior acromioplasty to decompress the subacromial space and relieve impingement on the rotator cuff that involved resection of the CAL. Resection of the CAL has been considered as a part of successful subacromial decompression and is supported by some (Neer, 1972; Gartsman, 1990; Ellman and Kay, 1991; Okutsu *et al*., 1992; Burns and

Whipple, 1993; Delforge *et al*., 2014), especially if there are no bony abnormalities (Uhthoff *et al*., 1988; Watson, 1985). Approximately 80% to 90% of patients who underwent subacromial decompression showed successful results (Ellman and Kay, 1991; Uhthoff *et al*., 1988). In contrast, release of the CAL has been criticised due to complications and poor results. Resection of the lateral acromial attachment of the CAL cannot be achieved without release of the deltoid attachment (Groh *et al*., 1994; Edelson and Luchs, 1995). Detaching some of the anterior deltoid from the acromion may result in weakened shoulder flexion (Ellman and Kay, 1991). In addition, resection of the medial fibres of the subacromial insertion from the undersurface of the acromioclavicular joint may cause bleeding (Edelson and Luchs, 1995). Biomechanically, resection of the CAL leads to a significant increase in anterosuperior shoulder translation (Lee *et al*., 2001; Hockman *et al*., 2004; Chen *et al*., 2009; Su *et al*., 2009). As a result, reattachment of the CAL after anterior acromioplasty has been suggested to regain ligament function and avoid shoulder dislocation (Flatow *et al*., 1994; Shaffer *et al*., 1997; Fagelman *et al*., 2007). The CAL is also used as a graft to fix acromioclavicular dislocation (Sood *et al*., 2008). However, studies (Bak *et al*., 2000; Levy and Copeland, 2001; Hansen *et al*., 2004) have identified regeneration or regrowth of the CAL and claimed that this played a role in recurrent impingement syndrome.

Pieper *et al*. (1997) claimed that the previous unsatisfactory results of surgical treatment for subacromial impingement pain could be caused by unsuccessful resection of the third band (release and regeneration of the CAL). Edelson and Luchs (1995) stated that knowledge of the anatomical variations of the CAL could be important in the successful outcome of shoulder surgery. The current study identified that the attachment sites of the CAL may be important in complete release or successful reattachment of the CAL. Releasing the medial fibres of the CAL involved in the acromioclavicular joint may lead to damage of the inferior joint capsule causing bleeding. Careful detachment may be needed to release the CAL from the anterior and lateral edges of the acromion to which deltoid also inserts. Excessive release of the lateral band from the coracoid may lead to: (i) weakness in coracobrachialis and short head of biceps function as a result of resection of the coracoacromial falx; (ii) decreased shoulder joint stability as a result of resection of the CAL interconnection with the coracohumeral ligament and joint capsule (coracoacromial veil); and (iii) decreased clavicle stability as a result of damage to the coracoclavicular ligaments. In addition, attention should be given to those bands of the ligament attached to the root of the coracoid and roof of the glenoid fossa beneath supraspinous.

4.3 Acromial Spur

4.3.1 Incidence

The average incidence of acromial spurs in previous studies (Table 4.5) is 30.7%, ranging from 5% to 97%. The current study investigated acromial spurs initially in cadaveric specimens and then in dry scapulae. In the first stage (cadaveric specimens), acromial spurs were detected in 43% of specimens, while they were observed in 55% of dry scapulae. However, there was no difference in the results of the two stages (P = 0.266). Comparing these observations with previous studies showed that more acromial spurs were found in the second stage of the current study (P = 0.013). However, the incidence of acromial spurs in previous studies was variable according to the age of individuals and type of specimens studied. Specimens in previous studies can be classified into 4 types: dry scapulae, cadaveric shoulders, patients with shoulder pain or subacromial impingement syndrome, and patients with rotator cuff tears. Studies involving patients with subacromial impingement syndrome mainly used radiographic images (9 studies) compared to operative specimens (4 studies).

Most previous studies used specimens from collections of dry scapulae (11 of 26) to investigate acromial spurs, with acromial spurs being observed in nearly 23% of such specimens. On the other hand, there were fewer studies using cadaveric shoulders (5 studies) compared to dry scapulae. Nevertheless, more acromial spurs were detected in the cadaveric samples (58%) than in the dry specimens. The reason for this difference may be due to the studies on dry scapulae having a wider age range than those on cadaveric shoulders. With respect to dry scapulae, the current study found more acromial spurs than previously reported ($P < 0.001$). This difference may be due to the age, which in previous studies was on a wider range of specimens than the current study: 15-100 years compared to 62-101 years, respectively. However, there was no difference between the current study and previous studies in the incidence of acromial spurs in cadaveric shoulders ($P = 0.163$), with the incidence in the current study being comparable to that reported by Tada *et al*. (1990) and Panni *et al*. (1996), but less than reported by Flatwo *et al*. (1996) and Ogawa *et al*. (2005).

Table 4.5 Incidence of acromial spurs reported in previous studies compared to the current study.

Study	Type	N	Age	Spur
Gray (1942)	Dry scapulae	1085	> 60	240 (22.1%)
	Dry scapulae	80	<60	5 (6.2%)
Neer (1972)	Dry scapulae	100	60	8 (8%)
Cone ***et al***. (1984)	Shoulders with pain (RDGs)	103	52	26 (25%)
	Pathological specimens (OP)	80	*	18 (23%)
	Fluoroscopic examination	12	*	9 (75%)
Aoki ***et al***. (1986)	Dry scapulae	130	57.5 (34-83)	38(29.2%)
Hardy ***et al***. (1986)	Patients with acute SIS (RDGs)	38	56 (22-89)	26 (68%)
Postacchini (1989)	Patients with SIS (OP)	18	44 (21-67)	3 (17%)
Tada ***et al***. (1990)	Cadaveric shoulders	74	76.8 (44-93)	34 (46%)
Ono ***et al***. (1992)	Shoulders with SIS (RDGs): - Anteroposterior view - 30° Caudal tilt view	73	60.1 (25-79)	27 (37%) 52 (71%)
Edelson & Taitz (1992)	Dry scapulae	200	30-70	46 (23%)
Gohlke ***et al***. (1993)	Cadaveric shoulders	57	75(47-90)	22 (38.6%)
Hernigou (1994)	Patients with RCTs (RDGs)	50	*	12 (24%)
Chun and Yoo (1994)	Patients with SIS (RDGs) Patients without SIS (RDGs)	100 100	*	52 (52%) 5 (5%)
Edelson & Luchs (1995)	Dry scapulae	300	> 60	69 (23%)
Flatwo ***et al***. (1996)	Cadaveric shoulders	16	77.8 (50-94)	10 (62.5%)
Getz ***et al***. (1996)	Dry scapulae	394	(20-89)	157 (40%)
Panni ***et al***. (1996)	Cadaveric shoulders	80	58.4 (26-82)	35 (43.7%)
Nicholson ***et al***. (1996)	Dry scapulae	420	21-70	61 (14.5%)
Mahakkanukrauh & Surin (2003)	Dry scapulae	692	15-100	200 (28.9%)
Ogawa ***et al***. (2005)	Shoulder without pain (RDGs)	644	44 (16-79)	193 (30%)
	Cadaveric shoulders	241	77 (38-96)	169 (70%)
	Shoulders with RCTs (OP)	144	46 (18-66)	120 (83.3%)
TaheriAzam ***et al***. (2005)	Patients with SIS (RDGs)	89	56.4 (34-80)	8 (9%)
Ko ***et al***. (2006)	Patients with partial RCTs (OP)	66	52.2 (25-72)	64 (97%)
Natsis ***et al***. (2007)	Dry scapulae	423	*	66 (15.6%)
Sangiampong ***et al***. (2007)	Dry scapulae	154	49 (16-87)	23 (14.9%)
Paraskevas ***et al***. (2008)	Dry scapulae	88	*	19 (21.5%)
Oh ***et al***. (2010)	Patients with FT RCTs (RDGs)	106	59.6 (49-78)	83 (78%)
	Patients without RCTs (RDGs)	102	57.5 (45-79)	59 (58%)
Hamid ***et al***. (2012)	Patients with asymptomatic RCTs (RDGs)	216	64.8 (37-90)	49 (23%)
The Current Study	**Cadaveric shoulders**	**220**	**82 (53-102)**	**95 (43.2%)**
	Dry scapulae	**60**	**81.5 (62-101)**	**33 (55%)**
	Shoulders with normal cuff	**78**	**80 (53-101)**	**14 (18%)**
	Shoulders with RCTs	**77**	**84 (56-97)**	**56 (73%)**
	Shoulders with partial tears	**37**	**81 (56-94)**	**24 (65%)**
	Shoulders with FT RCTs	**40**	**86 (72-97)**	**32 (80%)**

- Type: radiographs (RDGs), operational study (OP), subacromial impingement syndrome (SIS), rotator cuff tears (RCTs), full thickness rotator cuff tears (FT RCTs).
- Age: no data found (*).

Studies involving patients with shoulder pain or subacromial impingement syndrome were observed to have acromial spurs in 41.1% of specimens. In contrast, a higher incidence of acromial spurs (56.4%) was seen in studies involving patients with rotator cuff tears. The current study found acromial spurs in 73% of specimens with rotator cuff tears compared to 18% in shoulders with normal rotator cuff tendons. There was no difference (P = 0.471) between the current study and Ogawa *et al*. (2005). However, the current study observed more acromial spurs than Hernigou (1994) and Hamid *et al*. (2012) (P < 0.001). This difference may be due to the methodology employed in which both Hernigou (1994) and Hamid *et al*. (2012) used radiographs to determine the presence of acromial spurs. According to the type of rotator cuff tear, acromial spurs were observed in 80% of shoulders with complete tears and in 65% of shoulders with partial tears. With respect to complete tears, both the current study and that of Oh *et al*. (2010) reported a similar incidence of acromial spurs: 80% and 78% (P = 0.937). However, Ko *et al*. (2006) reported a greater incidence of acromial spurs in shoulders with partial tears than was observed in the current study: 97% compared to 65% (P = 0.015). The reason for this difference is not clear, but is probably due to the methodology used and the study sample, with Ko *et al*. (2006) investigating patients diagnosed with partial tears.

Both age and subacromial impingement syndrome play a role in the incidence of acromial spurs reported in previous studies. Chun and Yoo (1994) detected spurs in 52% of shoulders with impingement syndrome compared to 5% in those without impingement; however, the age of the patients was not given. Ogawa *et al*. (2005) investigated the incidence of acromial spurs in 1029 shoulders: radiographs of shoulders without pain (control group, 644), cadaveric shoulders (241) and operative specimens of shoulders with subacromial impingement syndrome and rotator cuff tears (144). The cadaveric shoulders showed a higher incidence of acromial spurs than did the control group: 70% and 30%, respectively. This may be related to the mean age of the samples, since the cadaveric group had a higher average age (77 years) than did the control group (44 years). However, shoulders with impingement pain and rotator cuff tears were younger than the cadaveric group being almost the same mean age as the control group, yet showed the highest incidence of acromial spurs (83.3%). Oh *et al*. (2010) also investigated the incidence of acromial spurs in 208 patients with subacromial impingement syndrome (102 shoulders) and full thickness rotator cuff tears (106 shoulders) using radiographs, MR arthrography and CT arthrography. Acromial spurs were found in 142 shoulders (68%), with shoulders with full thickness tears having more spurs (78%) than those with shoulder pain (58%).These examples confirm how the incidence of acromial spurs could be influenced by the age and source of the samples studied, with the source of samples asserting more influence than age.

In the current study, there were differences in the incidence of acromial spurs according to whether the specimens were cadaveric shoulders or dry scapulae, whether they had rotator cuff tears and their age. More acromial spurs were observed in dry scapulae (55%, n = 33) than cadaveric shoulders (43.2%, n = 95), but this was not significantly so (P = 0.266), since small spurs could not be palpated at the subacromial surface. Therefore, macerating the scapulae to remove all soft tissue was needed to discover any small spurs. Furthermore, there were more significant spurs in shoulders with rotator cuff tears (73%, n =

56) than those with normal rotator cuff tendons (18%, n = 14) (P < 0.001), as well as more, but not significantly, in shoulders with complete tears (80%, n = 32) than those with partial tears (65%, n = 24) (P = 0.245). According to age, significant differences were found in both groups of rotator cuff tears and complete thickness tears between shoulders with and without acromial spurs. In the rotator cuff tear group, shoulders with acromial spurs were older than shoulders without acromial spurs (P = 0.001): 86 ± 7 years compared to 79 ± 10 years, respectively. In the complete tear group, shoulders with acromial spurs were older than those without acromial spurs (P = 0.016): 87 ± 6 years compared to 81 ± 8 years, respectively.

4.3.2 The Relationship between Acromial Spurs and Side, Sex and Age

4.3.2.1 Side

More acromial spurs have been observed in right shoulders and with a bilateral incidence (Gray, 1942; Edelson, 1995; Panni *et al*., 1996; Miles, 1996; Mahakkanukrauh and Surin, 2003; Ogawa *et al*., 2005). Gray (1942) observed more subacromial spurs in right shoulders (54%) than left (46%). In 334 paired scapulae, a greater bilateral incidence of spurs (14%) was detected than a unilateral incidence (10%). An identical incidence of the same size and other characteristics was seen in 7% of scapulae. Spurs were larger and rougher on the right side than on the left side. Edelson (1995) detected more acromial spurs in both shoulders (73%). Panni *et al*. (1996) observed an acromial spur in 35 shoulders (43.7%): being unilateral in 1 individual and bilateral in 17. Miles (1996) reported subacromial spurs on both sides in all samples, but they were more severe on the right. Mahakkanukrauh and Surin (2003) also found more spurs in right than left shoulders (P < 0.050): symmetrical spurs were found in

15.9% of scapulae. Ogawa *et al*. (2005) observed more acromial spurs formed on the right than on the left in males, but not in females.

The current study observed no difference in the incidence of acromial spurs between right (47.8%) and left (52.2%) shoulders, or between bilateral (31%) and unilateral (25%) incidence. There was also no difference in the size of acromial spurs between the right and left shoulders. In addition, there was no association between side and the type of subacromial spur or the incidence of anterior acromial spurs. These results suggest that side has no role in the development of acromial spurs. Therefore, the current study disagrees with previous reports that support a higher incidence of acromial spurs in right shoulders and a greater bilateral incidence. However, this result may relate the age of studied samples, in which had average age older than previous studies. Therefore, the current study found that development of acromial spurs more related to degenerative changes due to aging and the development of shoulder impingement rather than shoulder side.

4.3.2.2 Sex

With respect to gender more acromial spurs have been observed in males than females (Tada *et al*., 1990; Edelson, 1995; Ogawa *et al*., 2005; Paraskevas *et al*., 2008). Tada *et al*. (1990) investigated acromial spurs in 74 cadaveric shoulders observing them in 34 (46%), with a greater incidence in males (62%) than females (38%). This is supported by Edelson (1995) who detected more spurs in males than females (7:3). Ogawa *et al*. (2005) also reported significantly more acromial spurs in males than females. Paraskevas *et al*. (2008) observed acromial spurs in 21.5% of 88 dry scapula, predominantly in males (25%). In contrast, Mahakkanukrauh and Surin (2003), Ho *et al*. (2009), and Hamid *et al*. (2012) observed a similar incidence of acromial spurs in males and females. Hamid *et al*. (2012) found acromial spurs in 49 (23%) of 216 patients, presenting in 26 (53%) male shoulders and 23 (47%) female shoulders.

The current study found no difference in the incidence of acromial spurs between males (46.3%) and females (53.7%), or any association between acromial spurs and the sex of specimens. Furthermore, there was no difference between males and females in any subacromial spur parameters. There was also no association between sex and the type of subacromial spur or the incidence of anterior acromial spurs. However, males were more associated with curved anterior acromial spurs than females as males have longer spur than females. With respect to sex, the current study observed the same incidence of acromial spurs as that reported by Hamid *et al*. (2012). Therefore, the current study agrees with Mahakkanukrauh and Surin (2003), Oh *et al*. (2010) and Hamid *et al*. (2012) in which there is no relationship between acromial spurs and sex. These results may be affected by the age of specimens in which most of the specimens were old and had degenerative changes.

4.3.2.3 Age

An association between spur incidence and age has been observed in most previous studies (Graves, 1922; Cone *et al*., 1984; Tada *et al*., 1990; Edelson, 1995; Getz *et al*., 1996; Panni *et al*., 1996; Ogawa *et al*., 1996; Mahakkanukrauh and Surin, 2003; Oh *et al*., 2010), supporting the view that acromial spurs form as a result of degenerative processes. Acromial spurs were found to be associated with age, not being found in younger specimens (Graves, 1922). The incidence and size of spurs starts to increase at thirty years of age. However, the presence of acromial spurs is related to pathological processes, since degenerative changes seen in the scapula either result from ossification or atrophic processes, both of which usually occur after the bone has reached maturity.

Shoulders with acromial spurs are older than those without (Cone *et al*., 1984; Tada *et al*., 1990; Panni *et al*., 1996), with Edelson (1995) reporting that the incidence and size of acromial spurs are positively associated with age. Furthermore, more acromial spurs are found in older than younger shoulders. Nicholson *et al*. (1996) observed that the formation of a spur is an age-dependent process, in which 30% of spurs were significantly ($P < 0.05$) greater in specimens from patients older than 50 years compared to 7% in those younger than 50 years. Ogawa *et al*. (1996) found that acromial spur formation began to develop in some shoulders of individuals in their 20s. Furthermore, they also reported that the rate of spur formation was associated with age, reaching 50% in the 6th decade and 68% in the 7th decade. Mahakkanukrauh and Surin (2003) observed more spurs in specimens (34.7%) from individuals 55 years or older than in specimens (11.2%) younger than 55 years. Finally, Oh *et al*. (2010) noted that the incidence of spur formation increased with age, with patients older than 65 showing a greater incidence (80%) than those younger than 55 years (58%), ($P < 0.006$).

In contrast, only three studies do not support this view, stating no significant association or difference observed between spur incidence and age (Ogata and

Uhthoff, 1990; Sangiampong *et al*., 2007; Hamid *et al*., 2012). Ogata and Uhthoff (1990) did not detect any association between age and degenerative changes on the subacromial surface: subacromial spurs and thickened CAL, except in very advanced ages. Sangiampong *et al*. (2007) reported no correlation between the incidence of spurs and age, finding that the incidence of spurs was as follows: 4.4% in specimens < 30 years, 69.6% in specimens aged between 30 and 60 years, and 26.1% in specimens > 60 years. Hamid *et al*. (2012) also found no difference between the age of shoulders with and without acromial spurs, 67.2 (range, 53.1-82.9 years) and 64.0 (range, 37.1-90.2 years), respectively.

The age in the current study was limited between 52 and 102 years, which means that it was not possible to compare the findings between young and older people. The current study found no association between the incidence of acromial spurs and any specific age, but more spurs were found as the sample became older: R = 0.187, P = 0.005. Therefore, the current study agrees with previous studies stating that there is a relationship between age and acromial spurs (Graves, 1922; Cone *et al*., 1984; Tada *et al*., 1990; Edelson, 1995; Getz *et al*., 1996; Panni *et al*., 1996; Ogawa *et al*., 1996; Mahakkanukrauh and Surin, 2003; Ho *et al*., 2009). Furthermore, the current study also agrees with Cone *et al*. (1984), Tada *et al*. (1990) and Panni *et al*. (1996) in which shoulders with acromial spurs are older than shoulders without acromial spurs. Statistical analysis of the current study did not reveal a correlation between spur parameters and the age of specimens. In addition, there was no difference between the different types of subacromial spur. With respect to anterior acromial spurs, shoulders with anterior acromial spurs were older than those without. However, there was no difference in the age between subacromial spurs whether extended beyond the tip of acromion or not.

The current study also supports the view that acromial spurs may be formed as a result of degenerative changes, specifically if associated with other changes in the shoulder. However, there was no relationship between age and either the size or severity of acromial spurs, with the current study suggesting that these are more related to chronic and repetitive impingement. This supports Panni *et al*. (1996) who believe that an acromial spur is an age-related change and that a rotator cuff tear could accelerate the formation of an acromial spur through increased tension on the CAL causing a proliferative stimulus on the acromial attachment. In addition, Ogawa *et al* (1996) believe that an increasing size of spur is caused by clinical impingement represented by rotator cuff pathology. Ogawa *et al*. (2005) also stated that the presentation of small spurs in shoulders without rotator cuff tears or a prolonged duration of symptoms suggests that there are other factors influencing the growth of an acromial spur. The current study identified irritation and impingement features on the surfaces of medium and large subacromial spurs compared to a round smooth surface on small subacromial spurs. Therefore, the formation of acromial spurs could be related to degenerative changes, however development and increase in the size of acromial spurs is more likely to be related to the development of rotator cuff tears and an increase in impingement on the subacromial surface.

4.3.3 The Relationship between the Acromial Spurs and Rotator Cuff Tears

4.3.3.1 Incidence of Acromial spurs in Shoulders with Cuff Tears

Previous studies have reported a higher incidence of acromial spurs in shoulders with rotator cuff tears (Bigliani *et al*., 1986; Tada *et al*., 1990; Gohlke *et al*., 1993; Hamid *et al*., 2012) (Table 4.6). The incidence ranging from 43.3% to 86.4% in shoulders with rotator cuff tears compared to 4.4% to 51% in shoulders with rotator cuff tears and no acromial spurs. The current study is in agreement with previous studies observing a higher incidence of acromial spurs in shoulders with rotator cuff tears (80%) compared to shoulders with rotator cuff tears but without acromial spurs (25%). The incidence of acromial spurs reported in the current study is comparable to those reported previously, however, it was greater than reported by Bigliani *et al*. (1986) and Tada *et al*. (1990).. This difference may difference may be returned to the lower incidences of cuff tears found in Bigliani *et al*. and Tada *et al*. studies. The current study also found a significant association between rotator cuff tears and the incidence of acromial spurs.

Table 4.6 Comparison of the incidence of acromial spurs in shoulders with rotator cuff tears in previous studies and the current study.

Study	Sample N	Cuff Tears	Spur	No Spur
Bigliani ***et al***. (1986)	140	33 (24%)	14 (70%)	19 (16%)
Tada ***et al***. (1990)	74	14 (19%)	13 (43.3%)	1 (4.4%)
Gohlke ***et al***. (1993)	54	31 (57.4%)	19 (86.4%)	12 (38.7%)
Hamid ***et al***. (2012)	216	123 (57%)	38 (78%)	85 (51%)
The current study	**155**	**77 (49.7%)**	**56 (80%)**	**21 (25%)**

According to the type of rotator cuff tear the current study found a significant association between acromial spurs and both partial (65%) and complete tears (80%). However, there was no difference in the incidence of acromial spurs between partial and complete tears. Nevertheless, the severity of rotator cuff tears may be more related to the size of the acromial spur and severity of the case rather than just acromial spur incidence. Gohlke *et al*. (1993) also reported a higher incidence of acromial spurs in shoulders with complete rotator cuff tears (67%) than in shoulders with partial tears (58%). Hamid *et al*. (2012) reported a significant incidence of acromial spurs in shoulders with full thickness tears (78%) comparable to that reported in the current study. However, Hamid *et al*. (2012) did not consider the incidence of acromial spurs in shoulders with partial rotator cuff tears.

Despite a higher incidence of acromial spurs in shoulders with rotator cuff tears, there were a small number of shoulders with rotator cuff tears but with no acromial spurs. Thus, shoulders with rotator cuff tears but without acromial spurs may develop from articular-side rotator cuff tears. According to Ko *et al*. (2006) shoulders with articular-side partial tears show less acromion degeneration and less prominent acromial spurs than those with bursal side partial tears. In addition, rotator cuff tears may develop as a result of attrition of the rotator cuff tendon against the toughed fibers of the CAL, mainly at the subacromial insertion of the ligament. Previous studies (Ogata and Uhthoff, 1990; Tada *et al*., 1990, Ozaki *et al*., 1998) have confirmed histological changes in the subacromial insertion of the CAL in shoulders with rotator cuff tears. Lee *et al*. (2001) reported larger attrition defects associated with the subacromial insertion of the CAL in shoulders with rotator cuff tears than in shoulders with intact rotator cuff tendons.

4.3.3.2 Severity of Acromial Spurs in Shoulders with Rotator Cuff Tears

An association between the severity of rotator cuff tears and the size of acromial spurs has been identified (Ogawa *et al*., 1996; Yoshida and Ogawa, 1996; Ogawa *et al*., 2005; Hamid *et al*., 2012). Ogawa *et al*. (1996) observed small acromial spurs in 80% of shoulders with intact rotator cuff tendons, while medium and large acromial spurs were found in 60% of shoulders with partial and full-thickness tears. They also observed medium and large spurs in 49% of specimens obtained by anterior acromioplasty from shoulders with partial and full thickness tears. Later Ogawa *et al*. (2005) stated that small acromial spurs have no significant influence on rotator cuff tears but medium and large acromial spurs do. In addition, Yoshida and Ogawa (1996) found that shoulders with complete and bursal side partial tears had larger acromial spurs than shoulders with furry fibers, intratendinous or articular side partial tears. Hamid *et al*. (2012) observed large acromial spurs in 88% of shoulders with full thickness tears compared to 53% shoulders without a large acromial spur. They also identified a significant relationship between the width of the rotator cuff tear and large acromial spurs. However, Oh *et al*. (2010) reported no association between spur incidence and the size or retraction of the tears in MR arthrography and CT radiography.

The current study found that subacromial spurs in shoulders with rotator cuff tears were larger than those in shoulders with normal rotator cuff tendons. A similar difference was also found between shoulders with complete rotator cuff tears and normal rotator cuff tendons. However, no difference was found between the size of subacromial spurs in shoulders with partial tears and those with normal rotator cuff tendons or shoulders with complete tears. The difference was in both the width and circumference but not in the length of the subacromial spurs. This may support Hamid *et al*. (2012) who identified a larger rotator cuff tear width in shoulders with larger acromial spurs. In addition, the observations of the current study are in agreement with Lee *et al*. (2001), who found that acromial spurs developed more medially in shoulders with rotator cuff tears than those in intact shoulders. In their study, Lee *et al*. (2001) inspected the contact geometry between the subacromial surface and the rotator cuff tendons in relation to rotator cuff tears and found no difference in the anteroposterior dimension, whereas a difference was observed in the mediolateral dimension. Furthermore, the current study found significant correlations between the type of rotator cuff tear and the development of subacromial spurs medially and the severe type of subacromial spur. Therefore an increase in the size of acromial spurs, mainly the width (mediolateral dimension), appeared to be influenced by the severity of the rotator cuff tear.

Shoulders with partial rotator cuff tears have been described to have acromial spurs develop within the CAL, while shoulders with complete tears have acromial spurs develop in the subacromial space (Ozaki *et al*., 1988; Ogata and Uthoff, 1990; Gohlke *et al*., 1993). Ozaki *et al*. (1988) and Gohlke *et al*. (1993) have both suggested increases in the size of acromial spurs may lead to mechanical irritation of the rotator cuff tendons, as shoulders with rotator cuff tears have a larger anterior acromial projection than those with an intact rotator cuff. This is supported by Sakoma *et al*. (2013) who believed that the increased bony coverage over the rotator cuff may lead to the development of rotator cuff tears. Torrens *et al*. (2007) reported that shoulders with rotator cuff tears presented with a higher acromial coverage (the size of acromial above the humeral head) than those with intact rotator cuff tendons.

In contrast to Ozaki *et al*. (1988), Ogata and Uthoff (1990) and Gohlke *et al*. (1993), the current study found that acromial spurs start to form at the anterolateral aspect of the subacromial surface, and as the impingement developed they extend anteriorly inside the CAL beyond the tip of the acromion. A significant incidence of rotator cuff tears was found in shoulders with spurs extending to the tip of the acromion compared to shoulders with spurs restricted to the undersurface of acromion: 91.3% compared to 20%, respectively. Statistical analysis showed no difference in the dimensions of anterior acromial spurs between partial and complete rotator cuff tears. However, shoulders with anterior acromial spurs had a longer acromion and a smaller space between the acromion and coracoid. This is in line with Sakoma *et al*. (2013) and Torrens *et al*. (2007) in which development of the acromial spur into the anterior edge of the acromion increases the bony covering over the rotator cuff and increases the chance of rotator cuff tears. This may occur through two ways: (i) increasing the point of contact between the rotator cuff and the undersurface of the acromion, which maximizes the subacromial pressure; (ii) preventing normal humeral head displacement and a smooth range of motion by narrowing the coracoid-acromion space thereby harming the rotator cuff tendons.

4.3.3.3 Do Acromial Spurs cause Rotator Cuff Tears, or does the Cuff Tear Lead to Spur Growth?

Despite a higher incidence of rotator cuff tears in shoulders with acromial spurs, the relationship between cuff tears and acromial spurs remains contentious. A correlation between acromial spurs and rotator cuff tears has been confirmed (Bigliani *et al*., 1986; Ogata and Uhothoff, 1990; Zuckerman *et al*., 1992; Hernigou, 1994; Panni *et al*., 1996; Yoshida and Ogawa, 1996). Some authors support the view that acromial spurs form as a result of repetitive attrition and impingement of the rotator cuff and greater tubercle against the subacromial arch (Neer, 1972; Cone *et al*., 1984; Aoki *et al*., 1986; Tada *et al*., 1990; Prescher, 2000; Mahakkanukrauh and Surin, 2003; Ko *et al*., 2006). Following which protrusion of the spur on the supraspinatus tendon leads to a rotator cuff tear. However, others believe that acromial spurs and degenerative changes have no role in the development of rotator cuff tears, which they state are caused by primary intrinsic tendinopathies (Codman, 1934; Loehr and Uhthoff, 1987; Ozaki *et al*., 1988; Uhthoff *et al*., 1988; Sarkar *et al*., 1990; Yoshida and Ogawa, 1996; Chambler *et al*., 2003a; Pearsall *et al*., 2003). Thus, spur formation develops secondary to the presence of established rotator cuff tears.

The current study observed a significant relationship between acromial spurs and rotator cuff tears, as well as partial and complete rotator cuff tears. Considering the size of acromial spurs, the results showed a significant correlation between the size of the acromial spur and the rotator cuff tear, in which shoulders with complete tears had larger spurs than those with normal rotator cuff tendons. According to the morphology, severe types of acromial spurs showed a significant incidence of rotator cuff tears compared to mild types. In addition, a significant correlation was observed between spur size and the degenerative appearance of the subacromial surface. Thus, an acromial spur develops as subacromial impingement increases. The current results support the view that repetitive impingement and attrition between the rotator cuff tendon and the undersurface of the acromion leads to calcification of the subacromial insertion of the CAL and spur formation. With repetitive shoulder use, spur size increases leading to further impingement on the rotator cuff tendon causing rotator cuff tears. Therefore, the current study agrees with Neer (1972), Cone *et al*. (1984), Aoki *et al*. (1986), Tada *et al*. (1990), Prescher (2000), Mahakkanukrauh and Surin (2003) and Ko *et al*. (2006) who state that the spur is formed as a result of impingement and not as a result of an established rotator cuff tear.

4.3.4 The Relationship between the Size of Acromial Spurs and the CAL

Miles (1996) assumed that subacromial spurs formed as a result of ossification of the subacromial bursa. However, Ogata and Uhthoff (1990) and Edelson and Taitz (1992) described acromial spurs as calcification of the acromial attachment of the CAL and not of the acromion, usually being associated with the anterolateral band of the CAL (Uhthoff *et al*., 1988; Edelson and Luchs, 1995; Fealy *et al*., 2005). Tada *et al*. (1990) stated that an acromial spur starts to form as an enthesis at the subacromial attachment of the CAL and, with further impingement, develops to form a spur extending within the CAL. Pieper *et al*. (1997) reported no association between the morphology of the CAL and acromial spurs; however Fealy *et al*. (2005) reported that acromial spurs associated with a focal CAL were narrower than a diffuse CAL without a spur.

In agreement with previous studies (Ogata and Uhthoff, 1990; Tada *et al*., 1990; Edelson and Taitz, 1992), the current study found that an acromial spur usually begins to form as a small spur hidden beneath the anterolateral side of the subacromial insertion of the CAL. However, large spurs involve calcification of most or all of the subacromial insertion of the CAL and develop anteriorly extending within the ligament even into the anteromedial band. In contrast to Miles (1996), the current study found that only the superior fibers of the CAL attached to the undersurface of the acromion became calcified, whereas the inferior fibers and the subacromial bursa remained uncalcified. In addition, the spur usually took the shape of the CAL insertion and was not present on the posterior part of the subacromial surface.

In agreement with Pieper *et al*. (1997), the first stage of the current study revealed no association between acromial spurs and CAL morphology. In contrast to Fealy *et al*. (2005), the current study found a significant correlation between spur width at the anterior of the acromion and the width of the acromial attachment, as well as between spur circumference and the area of the subacromial insertion of the CAL. With respect to CAL morphology and band number, significant correlations were observed between spur width at the anterior edge of the acromion and both CAL morphology and band number. Statistical analysis showed that large spurs had larger subacromial insertions than did shoulders with medium and small spurs, as well as shoulders without spurs. In addition, shoulders with acromial spurs had wider acromial attachments than shoulders with small spurs and those without spurs. Therefore, the size of the acromial spur was correlated with the size of the CAL. However, there was no association between CAL morphology or band number and the incidence or direction of anterior acromial spurs. This may suggest that other factors than the CAL morphology control development of an acromial spur anteriorly, such as repetitive impingement and tensile forces transmitted through the CAL.

4.3.5 Classification of Acromial Spurs

4.3.5.1 Subacromial facet

In 1942, Gray classified subacromial facets according to their protrusion or depression on the subacromial surface into elevated (62%) or sunken (15%). In addition, Gray (1942) classified the surface appearance of each facet into: smooth (34%), polished or eburnated (7%) and rough or reactive (55%). Facets with elevated and rough surfaces were found in 36% of specimens. In contrast, the current study described the subacromial facets as round concave areas on the undersurface of the acromion: these were detected in 17 specimens (28.3%). According to their protrusion, an elevated facet was observed in 9 specimens (15%) with claws surrounding the facet, while sunken facets were observed in 8 specimens (13.3%). In those specimens with sunken facets acromial spurs were found in 37.5% (n = 3), with the remaining 62.5% (n = 5) having no spurs. With respect to surface appearance, a smooth surface was found in 56.7% of specimens (n = 34), while 36.7% (n = 22) had a rough surface and 6.7% (n = 4) an eburnated surface. Elevated and rough facets were found in 10% of specimens (n = 6). The current study supports Neer (1972) who related eburnation and erosion on the subacromial surface to advanced stages of impingement. Both the rough and eburnated surfaces were related with severe types of acromial spur and rotator cuff tears.

In older specimens, Edelson and Luchs (1995) described different shapes acromial spurs as a result of impingement: cupping, thinning and distortion. Miles (1996) found that the borders of subacromial facets were greater and elevated on the posterior side. Large facets were cupped and corresponded to the convexity of the humeral head. Buttress-like ridges may have formed at the margins of the facet as a result of tension applied to the remaining attachments of the subacromial bursa. These ridges may flatten in response to repetitive humeral impingement (Miles, 1996). In agreement with these observations, the current study observed cupped spurs in 27.3% of specimens (n = 9) with acromial spurs, being characterized by larger sized spurs mainly reaching the anteromedial band of the CAL: they were concave rough facets with raised eburnated borders or claws. The observed features suggest that: (i) a chronic case of shoulder impingement, and (ii) humeral head impingement on the undersurface of the acromion may have implications for the morphology and size of an acromial spur.

4.3.5.2 The subacromial spur

With respect to the severity of acromial spurs Hardy *et al*. (1986) classified subacromial spurs detected in anteroposterior radiographs into mild, moderate and severe. Hardy *et al*. (1986) identified acromial spurs in 68% of patients with acute subacromial impingement syndrome, most of which were mild (62%), with both moderate and severe spurs observed equally in 19% of patients. Tucker and Snyder (2004) described acromial spurs as being characterized by the formation of central, longitudinal, downward sloping spurs on the subacromial surface, which they referred to as a keeled acromion. A keeled acromion was found in 20 (1.2%) of 1700 patients who underwent arthroscopic treatment for impingement syndrome. Patients with a keeled acromion showed a significant incidence of bursal side rotator cuff tears, with full-thickness tears detected in 60% of these patients. Thus, the keel applies pressure on the bursal side of the rotator cuff acting as a plow scuffing the rotator cuff tendon. Furthermore, Oh *et al*. (2010) identified acromial spurs in 142 patients (68%), classifying their morphological appearance into six types: (1) heel type spurs with a quadrangular spur protruding inferiorly from the undersurface of the anterolateral acromion; (2) medial spurs located at the medial end of the acromion or distal end of the clavicle; (3) lateral traction spurs located at the lateral end of the acromion being congruent with the acromial undersurface or parallel to the direction of the rotator cuff; (4) lateral bird beak spurs located at the lateral end of the acromion which are not congruent with the acromial undersurface or the rotator cuff; (5) anterior traction spurs are anterior bony projections along the CAL and are congruent with the acromial undersurface or parallel to the rotator cuff; and (6) anterior bird beak spurs which are bony projections along the acromion but not congruent with the acromial undersurface or parallel to the rotator cuff. The most common type was the heel type, which was detected in 59 patients (56%) in the rotator cuff tear group and in 36 patients (35%) in the control group. Oh *et al* (2010) suggest that the heel type spur is a risk factor which might contribute to a full-thickness rotator cuff tear.

The current study classified subacromial spurs according to their extent, size, and appearance into small, medium and large spurs. Small spurs (17%) were located at the anterolateral side of the undersurface of the acromion and were characterized by a smooth surface with no raised borders and were restricted to the undersurface of the acromion. Medium spurs (23.3%) were larger than small spurs and characterized by a rough surface, raised borders and extension beyond the lateral and anterior edges of the acromion. Large spurs (15%) were larger than both small and medium spurs and were characterized by a rough and eburnated surface, raised borders forming claws, a subacromial facet and extention to the anteromedial edge of the acromion. Compared to Hardy *et al*. (1986), the current study classified acromial spurs and specified the features for each severity level, while Hardy *et al*. scored the severity of the spur from 0 to 3 without giving a description of the scale. The current study did not observe the keeled acromion spur type described by Tucker and Synder (2004); however it suggests that keeled acromion spurs belong to the medium size spur group given its downward growth and no facet. Consequently, the current study's classification may be used to determine the severity of subacromial spurs considering its development beyond the edges of the acromion and its protrusion inferiorly towards the rotator cuff tendons.

Compared to Oh *et al*. (2010), the heel spur type had proximal features of large spurs, as it formed at the undersurface of the acromion with downward claws and a facet at the center of the spur. Furthermore, both the lateral traction and lateral bird beak types are equivalent to the medium spur, in which the spur develops as far as the lateral edge of the acromion. The medial acromial spur is the same osteophyte described in the current findings at the inferior edge of the acromial facet. Finally, anterior traction and bird beak spurs were similar to medium and large spurs, in which the spur extends anteriorly. In addition, the current study classified anterior acromial spurs into straight and curved spurs. Straight spurs are similar to anterior traction spurs, which were found in 35.7%

of medium spurs and 33.3% of large spurs. A curved spur is similar to the bird beak spur, which was found in 64.3% of medium spurs and 66.7% of large spurs. However, Oh *et al*.'s (2010) description of acromial spurs did not consider small spur formation, as these may not be detected in radiographs or have any implications for the patient. In addition, Oh *et al*.'s (2010) description was based on observations of the spur from one side of the acromion only without considering its development and extent to other sides of the acromion. For example, in both anterior traction and bird beak spurs types, they did not consider formation of the spur on the subacromial surface or its spread into the anteromedial side of the acromion. Therefore, the detailed description and classification of acromial spurs in the current study is appropriate and applicable in the investigation and determination of the severity of acromial spurs in radiographs.

4.3.5.3 Anterior acromial spur

With respect to spurs formed at the anterior edge of the acromion, Ono *et al*. (1992) classified such spurs in 30° caudal tilt radiographs based on the shape of its anterior protrusion to the coracoid: sharp spurs (20.5%) and wide spurs with a round base (50.7%). Acromial spurs have also been classified according to their direction. Cone *et al* (1984) found acromial spurs in 18 (23%) of 80 pathological specimens, with most spurs (n = 14, 77.8%) directed anteriorly and inferiorly, 3 (16.7%) projecting inferiorly and one (5.6%) projecting anteriorly. On the other hand, Mahakkanukrauh and Surin (2003) described two types of acromial spur: a traction (straight) spur (87%) and a claw (curved or hooked) spur (13%). A claw type spur indicates greater impingement and degeneration, which increases the risk of a rotator cuff tear. This type of spur was observed more in specimens aged over than 55 years.

The current study observed anterior acromial spurs in 23 specimens (38.3%), and they were classified according to Mahakkanukrauh and Surin (2003) into straight and curved spurs. However, in contrast to Mahakkanukrauh and Surin (2003) the current study observed more curved (65%) than straight (35%) spurs. However, the observations of the current study are in agreement with Mahakkanukrauh and Surin (2003), in which curved spurs pose a greater risk of impingement on the rotator cuff tendon than straight spurs. Fifty percent of complete rotator cuff tears were found in shoulders with curved spurs compared to 33.3% in shoulders with straight spurs and 16.7% in shoulders without anterior acromial spurs. Therefore, a curved acromial spur may increase the risk of rotator cuff tears by decreasing the size of the subacromial space or pressure on the rotator cuff tendon.

Tada *et al*. (1990) classified anterior acromial spurs according to the size of the spur into less than 1 cm and more than 1 cm: they extended into the middle third of the CAL. Ono *et al*. (1992) classified the length of acromial spur from 30° caudal tilt view radiographs into: small (< 5mm), medium (5 - 10 mm) and large (> 10 mm). Of 73 patients the size of acromial spurs were: 17 small (23.3%), 25 medium (34.2%) and 10 large spurs (13.7%). In addition, Ogawa *et al*. (1996) classified the length of acromial spurs into three types: small (< 5mm), medium (5 - 10mm) and large (> 10 mm) spurs. Of 644 asymptomatic shoulders most spurs were small, with medium and large spurs being observed in only 7% of individuals. In 241 cadaveric shoulders no or small spurs were detected in 80% of shoulders with a normal or fibrillated rotator cuff. In contrast, medium or large spurs were observed in 60% of shoulders with partial or full-thickness rotator cuff tears. Yoshida and Ogawa (1996) classified the size of acromial spurs in the same way as Ogawa *et al*. (1996) and found that shoulders with complete and bursal side tears had larger acromial spurs than shoulders with an intact rotator cuff, fuzzy fibers, intratendinous or articular side tears.

The current study measured the mean length of anterior acromial spurs as 6.32 ± 2.4 mm, being 25% of the original subacromial spur length. Most previous studies (Tada *et al*., 1990; Ono *et al*., 1992; Ogawa *et al*., 1996; Yoshida and Ogawa, 1996) did not consider this part of the spur. Previous studies recorded the highest pressure underneath the acromion centered at the anterolateral border of the acromion (Burns and Whipple, 1993; Hyvönen *et al*., 2003; Wang *et al*., 2009; Yamamoto *et al*., 2010). In addition, statistical analysis in the current study found that the length of acromial spurs, either anterior or subacromial spurs, had no significant impact on rotator cuff tears. Therefore, the length of the acromial spur is not important in relation to rotator cuff tears, however it may be significant in advanced stages of shoulder impingement.

4.3.6 Changes in Acromion Geometry in Relation to Spur Formation

4.3.6.1 Acromial dimensions and coracoid-acromion space

In 1922 Graves reported that acromial spurs increase the tip of the acromion by 2 - 8 mm or more, the geometric parameters of the spur being: thickness 2 mm, length 5 to 35 mm and width 4 to 25 mm. Graves (1922) stated that a large size acromial spur may interfere with shoulder function and is often associated with other scapular degenerative changes. Later, Nasca *et al*. (1984) assumed that acromial spurs are responsible for narrowing the subacromial space. Edelson and Taitz (1992) found a correlation between degenerative changes and the length of the acromion.

The current study observed that the formation of an acromial spur changed the geometric dimensions of the acromion. Comparing the dimensions of the acromion and acromial spur incidence showed that shoulders with acromial spurs had thicker and wider acromions than those without spurs. Compared to Graves (1922) the dimensions of the anterior acromial spur were measured as 6.32 ± 2.4 mm long, 12.58 ± 3.0 mm wide and 4.08 ± 1.0 mm thick. When an acromial spur formed at the anterior edge of the acromion, the length of the acromion increased by 13.5% over the original length. Thus, shoulders with anterior acromial spurs had a longer acromion than those without spurs. This result agrees with Edelson and Taitz (1992) who reported that degenerative changes were associated with an increase in length of the acromion. In turn, shoulders with anterior acromial spurs had a narrower space between the coracoid and the acromion than shoulders without spurs. This may lead to further impingement by increasing the acromial coverage over the humeral head and subacromial pressure. Therefore, the current study supports both Graves (1922) and Nasca *et al*. (1984) in that large acromial spurs may interfere with shoulder function and cause a narrowing of the subacromial space.

4.3.6.2 Acromial lateral curvature

Bigliani *et al*. (1986) classified the morphology of the acromion into flat, curved and hooked, reporting significant incidences of rotator cuff tears in shoulders with a hooked acromion (69.8%). Bigliani *et al*. (1986) also measured acromial slope in each acromion type as follows: flat 13.1˚, curved 26.9˚ and hooked 26.7˚. They reported a higher acromial slope in shoulders with rotator cuff tears than in shoulders with normal cuff tendons: 28.7˚ compared to 22.7˚. Other studies have also reported a significant incidence of rotator cuff tears in shoulders with a hooked acromion (Ogata and Uhthoff, 1990; Epstein *et al*., 1993; Chun and Yoo, 1994; Farley *et al*., 1994; Toivonen *et al*., 1995; Shah *et al*., 2001; Worland *et al*., 2003). Another way of expressing the degree of acromion curvature was described by Edelson and Taitz (1992) who measured the maximum height above a straight line drawn between its ends. However, other studies have reported no relationship between rotator cuff tears and type of acromion or difference in acromial slope (Wang and Shapiro, 1997; Hirano *et al*., 2002; Aydin, *et al*., 2011; Musil *et al*., 2012; Balke *et al*., 2013; and Moor *et al*., 2014). Aydin *et al*., (2011) reported that arthroscopic subacromial decompression without acromioplasty showed significantly improved results. Follow up results did not show any difference between the three types of acromion. This suggests that acromial morphology has no role in the etiology of chronic impingement (Aydin, *et al*., 2011).

It has been debated whether a hooked acromion is a congenital or an acquired (developmental) phenomenon. Nicholson *et al*. (1996) supported congenital formation since they found no significant relationship between acromial morphology and either age or the presence of an acromial spur. Thus, variations in acromial morphology are primary anatomic characteristics which contribute to impingement, independent and in addition to, age-related processes. Sangiampong *et al*. (2007) believed that a hooked acromion and acromial spurs may or may not result from degenerative changes or cause rotator cuff tears. In contrast, other studies support the view that a hooked acromion is an acquired or developmental phenomenon: tensile forces applied on the acromion by the CAL (Shah *et al*., 2001), the degenerative changes of aging (Wang and Shapiro, 1997; MacGillivray *et al*., 1998; Speer *et al*., 2001, Vassalou *et al*., 2012) and misinterpretation regarding the formation of an acromial spur (Edelson and Taitz, 1992; Epstein *et al*., 1993; Edelson, 1995; Edelson and Luchs, 1995; Getz *et al*., 1996; Prescher, 2000).

In 2001 Shah *et al*. investigated developmental changes occurring at the anterior and inferior surfaces of the three shapes of acromion. Their results revealed histological changes in curved and hooked acromions, mainly at the anterior of the acromion. Therefore, they suggested that tensile forces transferred through the CAL play role in the morphology of the acromion.

With respect to age, Wang and Shapiro (1997) inspected acromial morphology in 272 patients: the results showed a prevalence of a hooked acromion and a decrease in the flat type of acromion in patients older than 50 years. A hooked acromion was found more in asymptomatic patients than in symptomatic patients. Wang and Shapiro (1997) emphasised that acromial morphology changes with age, and as such may contribute to spur formation at the anterior edge of the acromion. MacGillivray *et al*. (1998) reported that the shape of the acromion changes with age from flat in younger individuals to hook in older individuals. The downward angulation of the acromion also increased with increasing age. Speer *et al*. (2001) observed rare incidences of a hooked acromion in young asymptomatic male athletes, suggesting that the increase in hooked acromions in older populations was caused by secondary degenerative changes in the acromion. Whereas, Vassalou *et al*. (2012) believe that a hooked acromion is formed in response to degenerative disease. In contrast, several studies have reported no relationship between the shape of the acromion or slope and age (Banas *et al*., 1995; Nicholson *et al*., 1996; Panni *et al*., 1996; Getz *et al*., 1996; Vahakari *et al*., 2010, and Balke *et al*., 2013).

Some studies support the view that acromial morphology is more of a developmental phenomenon related to subacromial spur formation than it is an acquired condition (Edelson and Taitz, 1992; Edelson and Luchs, 1995; Getz *et al*., 1996; Prescher, 2000; Lee *et al*., 2001). Epstein *et al*. (1993) assumed that a hooked acromion in MR images represents the formation of an acromial spur on the subacromial surface. Edelson (1995) suggested that CAL calcification and spur formation at the anterior edge of the acromion was responsible for producing the hooked acromion configuration. A relationship between age and the presence of a hooked acromion was also identified, in which no hooked forms were found in specimens less than 30 years of age. Hooked acromions started to appear from 40 years of age and more were found at the subacromial insertion site of the CAL, matching its shape. Prescher (2000) found no hooked types of acromion and support the view that the hooked form may be a misinterpretation of acromion spur formation. Lee *et al*. (2001) believed that the different acromial shapes seen in the supraspinatus outlet view are the result of different sizes of acromion and spur, noting that increasing spur length in the anteroposterior direction with different projection angles might demonstrate a flat, curved or hooked acromion on radiographs.

Acromial spurs have been found associated with the hooked acromial type. Several studies have observed a higher incidence of acromial spurs in the hooked acromial type than in other acromial types (Ogata and Uhthoff, 1990; Getz *et al*., 1996; Panni *et al*., 1996; Natsis *et al*., 2007; Paraskevas *et al*., 2008). Getz *et al*. (1996) inspected acromial spur formation in 394 cadaveric scapulae and observed spur formation in nearly 40% of specimens, which was more common in the hooked type (59%) compared to the curved and flat types, 42.6% and 24% respectively. Natsis *et al*. (2007) evaluated the relationship between acromial shape and the formation of acromial spurs in 423 scapulae: acromions were categorized independently of the presence of a spur. Spurs were found in 66 scapulae (15.6%), more significantly associated with hooked shapes (37.7%) than with flat (2%) and curved (7.9%) shapes. Paraskevas *et al*. (2008) observed acromial spurs in 21.5% of 88 scapulae, predominantly in the hooked type (75%). However, both Nicholson *et al*. (1996) and Sangiampong *et al*. (2007) found no correlation between the incidence of acromial spurs and morphology of the acromion.

The current study inspected the relationship between the shape of the acromion and acromial spur using measurement of acromion slope and maximum acromial height. There was no difference in both measurements regarding shoulder side, while males showed a higher acromial curvature than females. With respect to anterior acromial spurs, shoulders with acromial spurs showed greater acromial curvature (both slope and height) than shoulders without spurs. Comparing the acromial curvature parameters with and without acromial spurs showed a significant difference. However, there was no difference when comparing the original acromial curvature of shoulders with spurs and those without. In addition, there were significant correlations between the acromial curvature parameters and the length of anterior acromial spurs. With respect to the shape of anterior acromial spurs, shoulders with curved acromial spurs had a greater acromial curvature than shoulders with straight acromial spurs. Thus, the shape or curvature of the acromion is associated with anterior acromial spurs (incidence, length and shape). Therefore, the current study supports the view that a hooked acromion may be formed due to the formation of an acromial spur or misinterpretation regarding the formation of an acromial spur. This is in agreement with Edelson and Taitz (1992), Epstein *et al*. (1993), Edelson (1995), Edelson and Luchs (1995), Getz *et al*. (1996) and Prescher (2000).

With respect to the CAL, the current study found a significant correlation between acromial curvature and both the CAL’s acromial width and subacromial insertion length. This supports Shah *et al*. (2001) who suggested a relationship between the tensile forces passing through the CAL and the morphology of the acromion. The current study has shown that an increased acromial attachment of the CAL is associated with an increased size of acromial spur. Therefore, an increased acromial attachment of the CAL may lead to increased tensile forces which place the acromion under high attachment forces. As a result an acromial spur may be formed at the anterior acromion and lead to an increase in curvature of the acromion.

In disagreement with previous studies (Banas *et al*., 1995; Nicholson *et al*., 1996; Panni *et al*., 1996; Getz *et al*., 1996; and Balke *et al*., 2013), the current study found a significant correlation between acromial curvature and age. This correlation was also present when considered within the rotator cuff tear groups. There was no correlation between age and acromial curvature in the group of shoulders with intact rotator cuffs. This supports Vahakari *et al*. (2010) who found no relationship between acromial slope and age in shoulders with an asymptomatic rotator cuff. However, the current study found a correlation between these two factors for shoulders with partial rotator cuff tears, but not for shoulders with complete thickness tears. Therefore, the observations of the current study are in agreement with previous studies (Wang and Shapiro, 1997; MacGillivray *et al*., 1998; Speer *et al*., 2001, Vassalou *et al*., 2012) in which degenerative changes may play a role in the morphology of the acromion.

With respect to rotator cuff tears, the current study disagrees with Bigliani *et al*. (1986) in which there were no significant differences in acromial slope between shoulders with and without rotator cuff tears. This supports Musil *et al*. (2012), Balke *et al*. (2013) and Moor *et al*. (2014) who found that there was no difference in acromial slope between shoulders with rotator cuff tears and those with intact rotator cuff tendons. However, the current study found a significant difference in maximum acromial height between shoulders with rotator cuff tears and those with intact rotator cuff tendons. With respect to the type of rotator cuff tear, the results did not show significant differences in maximum acromial height between shoulders with complete tears, partial tears and those with intact rotator cuff tendons. Therefore, the current study supports previous studies regarding acromial slope (Wang and Shapiro, 1997; Hirano *et al*., 2002; Aydin, *et al*., 2011; Musil *et al*., 2012; Balke *et al*., 2013; and Moor *et al*., 2014) in which there is no relationship between the morphology of the acromion and rotator cuff tears.

4.4 Degenerative Changes on the Subacromial Surface

4.4.1 Changes in the Undersurface of the Acromion

In addition to an acromial spur, there are several degenerative changes which can develop on the subacromial surface of the acromion, these being mainly associated with the anterior one third of the surface. These changes include fraying and hypertrophy of the CAL, erosion and eburnation of the subacromial surface, and formation of a subacromial facet (Neer, 1972; Ozaki *et al*., 1988; Edelson and Taitz, 1992; Prescher, 2000; Paraskevas *et al*., 2008). Neer (1972) noted acromial alterations in 11% of specimens: in the severe stage of impingement, eburnation with erosion was observed in 3% of specimens. In most radiographs of shoulders with a normal rotator cuff Ozaki *et al*. (1988) demonstrated a regular trabecular pattern without any signs of sclerosis, hypertrophic or cystic changes. Some specimens did show spurs or osteophytes. Specimens from shoulders with rotator cuff tears however, showed irregular patterns of trabeculae with sclerosis and hypertrophic or cystic changes in the anterior third of the acromion.

Edelson and Taitz (1992) observed acromial degenerative changes in 18% of 200 dry scapulae. The changes involved two signs: a traction spur and an eburnated facet similar to a pseudo-articular surface for the humeral head. Both signs were limited to the anterior third of the subacromial surface and were seen in 23% of degenerated samples. A grinding facet “facies articularis acromialis” may form at the inferior surface of the acromion as a result of grinding against the greater tubercle: this may also lead to complete attrition of the greater tubercle (Prescher, 2000). Paraskevas *et al*. (2008) reported that the anterior one third of the subacromial surface was smooth in 37 specimens

(42%) and rough in 51 (58%). Shoulders with a hooked acromion and being male showed a greater incidence of a rough surface, 81.2% and 70.4% respectively.

In agreement with Edelson and Taitz (1992) and Paraskevas *et al*. (2008), the current study found degenerative changes or attrition defects (43%) on the anterior one third of the subacromial surface, being smooth in 56.7% of specimens (n = 34), rough in 36.7% (n = 22) and eburnated in 6.7% (n = 4). There were significant correlations between the attrition lesions on the subacromial surface and the severity of subacromial spurs, CAL degenerative changes and rotator cuff tears. With respect to age, shoulders with rough and eburnated surfaces were older than those with smooth surfaces. Furthermore, shoulders with rough and eburnated surfaces had higher acromial curvatures than shoulders with smooth surfaces, while the acromial slope was not different between the two groups. With respect to sex and side, there was no association between these factors and the appearance of the subacromial surface. Therefore, the current study supports Neer (1972) and Edelson and Taitz (1992) in which attrition lesions on the subacromial surface were associated with severe stages of shoulder impingement. Growth and an increasing size of a subacromial spur leads to a reduction in the subacromial space that results in further impingement and attrition. Repetitive impingement will lead to lesions in both the rotator cuff tendons and the subacromial insertion of the CAL, as well as to attrition defects in both the subacromial surface and greater tubercle. This is in agreement with Miles (1996) who reported an association between degenerative changes in the greater tubercle and those seen on the subacromial surface.

4.4.2 Changes in the Subacromial Insertion of the CAL

Previous studies have reported degenerative changes and wearing of the subacromial insertion of CALs in shoulders with rotator cuff tears (Ozaki *et al*., 1988; Ogata and Uhthoff, 1990; Tada *et al*., 1990). Ozaki *et al*. (1988) reviewed degenerative changes on the subacromial surface in relation to rotator cuff tears in 200 cadaveric shoulders with an average age of 72.3 years (range 38 to 95 years): rotator cuff tears were observed in 48% of specimens. Gross inspection of the subacromial surface of shoulders with intact rotator cuff tendons revealed a smooth and glossy synovial tissue covering the surface. Shoulders with partial bursal or complete tears showed an attritional lesion on both the CAL and the anterior third of the subacromial surface. However, shoulders with partial tears on the articular side of the rotator cuff had an intact smooth surface. Finally, eburnated bone was seen on the subacromial surface of shoulders with massive rotator cuff tears (Ozaki *et al*., 1988). The presence of degenerative changes on the subacromial surface was observed in shoulders with bursal partial tears, but not in those with articular side tears suggesting that these changes are secondary to a bursal side tear. Ozaki *et al*. (1988) support the intrinsic theory of rotator cuff tears, which are caused by a degenerative process due to ageing.

Histological inspection of the subacromial surface of shoulders with a normal cuff showed four layers of tissue at the anterior third: synovial, collagenous, fibrocartilaginous and osseous (Ozaki *et al*., 1988), with each layer showing a regular pattern of fiber tissue. The posterior two-thirds of the subacromial surface is composed of two layers only: synovial and osseous. In contrast, shoulders with rotator cuff tears showed several changes: an irregular pattern of collagen fiber bundles, attrition of the fibrocartilage and/or hypertrophy of the osseous trabeculae. Shoulders with bursal side partial tears were characterized by a defect in the synovial layer and attritional lesion of the collagenous layer. No significant change was observed in the acromial undersurface in shoulders with articular side partial tears. Shoulders with complete rotator cuff tears showed an irregular pattern in the collagenous and fibrocartilaginous zones. A large defect in the fibrocartilaginous layer and hypertrophy of the trabeculae were seen in shoulders with massive tears. Therefore, the severity of the histological changes observed in the subacromial surface is correlated with the severity of the rotator cuff tear (Ozaki *et al*., 1988). The histological changes observed at the anterior third of the subacromial surface highlight the importance of the role of the acromion in shoulder movement as a subacromial joint.

Ogata and Uhthoff (1990) also reviewed the degenerative changes of subacromial surface in shoulders with rotator cuff tears. Normally, the subacromial surface is covered by a fibrofatty tissue making a smooth concave surface, with both the fibrofatty tissue and the insertion of the CAL being covered by loose areolar tissue constituting the outer wall of the subacromial bursa. These normal features were observed in 16 specimens (21.1%), whereas degenerative changes were observed in 86% of shoulders with articular-side partial tears and in all shoulders with full thickness tears. Ogata and Uhthoff (1990) classified the degenerative changes at the acromial insertion into four grades. Grade I was characterized by localized loss of the areolar tissue with or without small excrescences, as well as osseous protrusions from the underlying bone surrounded by a layer of fibrocartilage in the direction of the anchoring fibers of the CAL. In grade II, the width of the CAL is increased and elevated compared to the remaining subacromial surface as a result of thickening of the fibrocartilage layer and projection of the spur at the anteroinferior corner of the acromion. Grade III showed an irregular surface and broken up fibers of the CAL, with the collagenous and fibrocartilaginous layers at the undersurface of the spur being eroded. In comparison to grade II, the spur was larger and showed a rounded tip. Finally, in grade 4 the subacromial surface was eburnated and devoid of any CAL fibers. The incidence of these degenerative changes was observed as follows: 17 shoulders (22.4%) of grade 1, 24 shoulders (31.6%) of grade 2, 16 shoulders (21.1%) of grade 3, and 3 shoulders (3.9%) of grade 4. There was a significant difference between the average age of specimens with grade 3 changes (75.1 ± 7.9 years) and normal specimens (63.4 ± 13.8 years). However, there was no difference between any other grades. In addition, Tada *et al*. (1990) reported wearing and defects of the synovial membrane covering the subacromial surface in all specimens with acromial spurs and in 75% of specimens without spurs.

The current study inspected the size of the subacromial insertion of the CAL and found a significant correlation between the size of the insertion and CAL morphology and band number. Male shoulders also had larger CAL subacromial insertions than female shoulders. With respect to acromial spurs and rotator cuff tears, shoulders with acromial spurs and rotator cuff tears had larger insertion areas than shoulders without spurs and tears. In addition, shoulders with CAL defects or attrition lesions had larger subacromial insertions of the CAL than shoulders without defects. Therefore, the size of the CAL subacromial insertion appears to be related to CAL morphology, band number and acromial attachment width. Moreover, a significant difference was observed in the size of the subacromial insertion according to sex, the presence of an acromial spur, rotator cuff tears and CAL defects.

The current study observed attrition lesions in 68.3% of specimens examined. This was less, but not significantly so, than that reported by Ogata and Uhthoff (1990). Normally, the subacromial surface was covered by fibrofatty tissue and synovial membrane with a smooth surface without attrition lesions. When present, lesions were classified into mild, moderate and severe. Mild lesions were observed in 31.7% of shoulders and characterized by a defect in the synovial membrane and a raised brightened area of the CAL insertion. Moderate lesions were observed in 13.3% of shoulders and were characterized by fraying and fissuring of the fibers. Severe lesions were observed in 23.3% of shoulders and characterized by a severe lesion in the ligament tissue extending to the inferior surface of the acromion as well as eburnation and bone erosion. Calcification of the ligament fibers was noted partially in the moderate stage and largely in the severe stage. The current study classification and description is comparable to that of Ogata and Uhthoff (1990), except that in the current study the gross morphology is also described, whereas Ogata and Uhthoff (1990) described them histologically.

There was no association between CAL lesion and side, sex or age. However, according to the lesion severity, shoulders with severe lesions were older than those with a smooth subacromial surface. This finding is similar to that reported by Ogata and Uhthoff (1990), who reported a significant difference between the ages of grade 3 specimens and normal specimens. CAL parameters, morphology and band number showed no significant difference with respect to subacromial lesion, but there was a significant correlation between the width of the acromial attachment of the CAL and the width of the subacromial lesion. In contrast to Tada *et al*. (1990), the current study found a significant association between subacromial lesions and acromial spur incidence in which lesions were found in 82% of shoulders with acromial spurs and in 52% of shoulders without acromial spurs. Moreover, there was a significant correlation between subacromial lesion and rotator cuff tear incidence, in which CAL lesions were found in 79% of shoulders with rotator cuff tears compared to 56% of shoulders with an intact rotator cuff tendon.

With respect to the size of the CAL lesion, a significant correlation was found between the size and severity of the lesion, in which there were significant difference between lesion types. Severe CAL lesions were larger than moderate and mild lesions, while moderate lesions were larger than mild lesions. Therefore, as the size of the attrition lesion increases, so does the extent of the damage seen. Therefore, the current study suggests that the severity of attrition lesions at the subacromial insertion of the CAL is associated with the severity of shoulder impingement. This was also confirmed by other observations in which significant relationships were found between the severity of the subacromial lesion and the severity of subacromial spurs, subacromial surface appearance and rotator cuff tears. In addition, there was a significant correlation between the size of the subacromial lesion and subacromial spurs. Shoulders with complete and partial rotator cuff tears had larger lesions than shoulders with normal rotator cuff tendons. The parameters of the subacromial lesion were also correlated with the length of the anterior acromion edge and the height of the acromial curvature. In agreement with Ozaki *et al*. (1988), a CAL subacromial lesion appears to result from a bursal side tear. The current study suggests that the formation of a subacromial spur underneath the subacromial insertion of the CAL leads to the formation of a ridge at the anterior third of the acromion. The size of this ridge increases as spur size increases, with the ligament fibers becoming thicker as a result of calcification. This leads to a reduction of the subacromial space thus increasing the chance of attrition and impingement of the rotator cuff and greater tubercle resulting in lesions of both the rotator cuff tendon and the subacromial insertion of the CAL.

4.4.3 Contact Geometry at the Undersurface of the Acromion

Lee *et al*. (2001) evaluated the contact geometry of the subacromial surface of the acromion in relation to a rotator cuff tear. The study involved 40 shoulders, average age 61 years, divided into two groups: rotator cuff tear group (n = 20) and intact rotator cuff group (n = 20). Contact between the rotator cuff and subacromial surface was measured using Fuji Prescale super low-pressure-sensitive film when the shoulder was held at 20° of abduction with an applied axial compressive force of 25 kg. Gross inspection of the subacromial surface in the intact group revealed a smooth surface with a prominence in the anterolateral area of the CAL insertion. In contrast, the subacromial area in the tear group showed excrescences at the anterior acromion and CAL insertion, which was frayed and hypertrophied, showing a broader prominent area than in the other group (Lee *et al*., 2001). Contact imprints were mostly located in the anterior one third of the subacromial surface in both groups. An intense imprint area in the intact group was located anterolaterally at the CAL insertion, whereas it was over the excrescence on the undersurface of the anterior acromion in the tear group. Analysis of the contact geometry showed no difference in the anteroposterior dimension, however a difference was observed in the mediolateral dimension (Lee *et al*., 2001).

Lee *et al*. (2001) reported that the anteroposterior imprint suggests that a relation between different acromion shapes in the supraspinatus view and either the congruence of the acromial undersurface with the rotator cuff or a rotator cuff tear do not necessarily exist. In contrast, the results of the mediolateral imprint were more congruent in shoulders with rotator cuff tears between the subacromial surface and the bursal surface of the rotator cuff than in shoulders with an intact rotator cuff. This agrees with the gross findings which showed that broader acromial spurs develop more medially in tear shoulders than in intact shoulders. Lee *et al*. (2001) support the view that the primary pathology of rotator cuff tendinopathy leads to secondary changes in the subacromial surface. They also suggest that rotator cuff tears are caused by factors other than acromial shape.

The current study found that attrition lesions were mainly formed in 68% of specimens (n= 41) at the anterior third of the subacromial surface underneath the subacromial insertion of the CAL. The lesions were localized in the anterolateral portion of subacromial surface in 61% of specimens (n = 25), extending onto the anterior acromion edge in 29% specimens (n = 12) and to the medial acromion edge in 10% specimens (n = 4) with larger sized lesions and in severe cases. There was a significant association between the severity of attrition lesions and the site of the lesion as the attrition extended medially. In addition, the site of the lesion was significantly correlated with spur site, i.e. attrition lesions follow expansion of the spur. Thus, an attrition lesion increases at the site where the spur has reached. There were also correlations between the site of the attrition lesions and spur severity and rotator cuff tears, as well as the subacromial surface appearance. Therefore, the severity of the subacromial attrition lesion increases as the lesion extended medially.

In relation to rotator cuff tears, these observations support Lee *et al*. (2001) who reported a significant difference in the mediolateral imprint of the attrition lesion but not in the anteroposterior imprint. However, the current study found significant differences in both the anteroposterior and mediolateral dimensions of attrition lesions. This difference may be attributed to the methodology used by Lee *et al*. (2001), in which they studied contact imprints between the head of the humerus and the subacromial surface at a specific abduction angle (20˚), while the current study inspected the attrition lesion themselves. In addition, the current study disagrees with Lee *et al*. (2001), in which a positive correlation between the attrition lesion and acromial curvature height was observed. Therefore, the acromial curvature may play a role in subacromial impingement in shoulders with acromial spurs.

4.4.4 Other Degenerative Changes of Coracoacromial Arch

4.4.4.1 Coracoid spurs

Tada *et al*. (1990) reported some spur formation on the coracoid process (13.5%) along the CAL, which is not usually a site of impingement, yet suggested that spur formation is associated with impingement. In contrast, Edelson and Taitz (1992) reported no degenerative changes associated with the coracoid process, believing that the broad coracoid attachment of the CAL distributes the tensile forces transmitted through the ligament thus preventing spur formation. However, the narrow acromial attachment of the CAL concentrates these tensile forces on the acromion thus influencing spur formation.

The current study detected coracoid spurs in 55% of specimens, which is greater than that reported by Tada *et al*. (1990). The spurs formed along the CAL attachment mainly at the tip and base of the coracoid. These spurs were smaller in comparison to those on the acromion. There were no associations between coracoid spur incidence and side, sex, CAL morphology or band number. Statistical analysis showed no difference in spurs regarding age. However, shoulders with coracoid spurs had a wider acromial attachment than those without coracoid spurs, while the coracoid attachment of the CAL showed no difference. Coracoid spurs also had significant relationships with the incidence and severity of acromial spurs, subacromial surface appearance and the type of severity of CAL degeneration. In addition, shoulders with complete rotator cuff tears showed a significant incidence of coracoid spurs compared to shoulders with intact rotator cuffs and partial tears. Therefore, the current study supports Tada *et al*. (1990) in that the formation of coracoid spurs is associated with shoulder impingement, specifically the advanced stages of shoulder impingement. In contrast to Edelson and Taitz (1992), the current study found no difference in width of the coracoid attachment of the CAL with respect to coracoid spur formation. However, an increase in CAL acromial attachment may increase tensile forces in the ligament leading to spur formation on the coracoid process in advanced stages of shoulder impingement.

4.4.4.2 Degeneration of the acromioclavicular joint (ACJ)

Two degenerative changes have been reported at the ACJ in shoulders with impingement syndrome, namely osteoarthritis and osteophyte formation. Previous studies have reported degenerative changes in the acromial articular facet of the ACJ in an average of 38% (6.7% to 95%) of specimens, while osteophytes have been reported in 31.6% (11% to 58%) of specimens (Table 4.7). Most studies reported more degenerative changes in the acromial facet than osteophyte formation (Hardy *et al*., 1986; Gohlke *et al*., 1993; Nicholson *et al*., 1996), except that of Edelson and Taitz (1992) who reported more osteophytes than degenerative changes.

Table 4.7 Incidence of ACJ degenerative signs in previous studies compared to the observations of the current study: (*) no data found.

Studies	Sample N	Age	ACJ Osteophytes	Degenerative Changes
Cone ***et al***. (1984)	103	52		28 (27.2%)
Nasca ***et al***. (1984)	60	*		4 (6.7%)
Hardy ***et al***. (1986)	36	56 (22-81)	12 (32%)	25 (66%)
Postachani (1989)	18	44 (21-67)	2 (11%)	
Tada ***et al***. (1990)	69	76.8 (44-93)	20 (29%)	
Edelson and Taitz (1992)	200	30-70	116 (58%)	76 (38%)
Gohlke ***et al***. (1993)	57	75(47-90)	12 (21.1%)	54 (95%)
Farley ***et al***. (1994)	45	*	18 (40%)	
Getz ***et al***. (1996)	394	20-89	164 (41.6%)	
Nicholson ***et al***. (1996)	396	21-70	43 (11%)	128 (32.3%)
Cuomo ***et al***. (1998)	123	65.6 (25-95)	13 (17.1%)	
Mahakkanukrauh and Surin (2003)	692	15-100	242 (35%)	
Vassalou ***et al***. (2012)	284	18-89		117 (41.2 %)
The Current Study	**60**	**82 (62-101)**	**35 (58.3%)**	**42 (70%)**

The current study observed ACJ degenerative changes in 70% of specimens, and osteophytes in 58.3%. Both features were greater than the mean values of previous studies. Degenerative changes were greater than reported by Cone *et al*. (1984), Nasca *et al*. (1984), Edelson and Taitz (1992), Nicholson *et al*. (1996) and Vassalou *et al*. (2012), but not to Hardy *et al*. (1986) and Gohlke *et al*. (1993). Osteophyte incidence was greater than reported by Hardy *et al*. (1986), Postachani (1989), Tada *et al*. (1990), Gohlke *et al*. (1993), Nicholson *et al*. (1996), Cuomo *et al*. (1998) and Mahakkanukrauh and Surin (2003), but comparable to Edelson and Taitz (1992), Farley *et al*. (1994) and Getz *et al*. (1996). These differences may be due to the age and type of specimens. The current study found a significant association between ACJ degenerative changes and osteophytes, in which osteophytes were seen in 76.2% of shoulders with ACJ degeneration compared to 16.7% in shoulders with a normal ACJ. Therefore, these observations disagree with previous studies (Hardy *et al*., 1986; Edelson and Taitz, 1992; Gohlke *et al*., 1993; Nicholson *et al*., 1996) which reported a difference in the incidence of ACJ degenerative changes and osteophytes.

Shoulders with acromial spurs had a greater incidence of degenerative changes and osteophyte formation at the acromioclavicular joint (Cone *et al*., 1984; Tada *et al*., 1990; Mahakkanukrauh and Surin, 2003). Degenerative changes were seen in 46% of shoulders with a subacromial spur compared to 20.8% of shoulders without spurs (Cone *et al*., 1984). Tada *et al*. (1990) observed acromioclavicular osteoarthritis in 28.9% of cadaveric shoulders with an average age of 76.8 years (range 44-93 years). Shoulders with acromial spurs showed greater degenerative changes in acromioclavicular joints (40.6%) than shoulders without spurs (18.9%). Mahakkanukrauh and Surin (2003) observed spurs at the acromial facet in 35% of specimens and at the anterior edge of the acromion in 82%. The presence of combined spurs on the subacromial surface and at the acromial facet of the acromioclavicular joint was observed more frequently in older individuals, suggesting a more severe degenerative process.

A significant relationship between degenerative changes in the acromioclavicular joint and both age and rotator cuff tears has been reported (Graves, 1922; Hardy *et al*., 1986; Postacchini, 1989; Gohlke *et al*., 1993; Farley *et al*., 1994; Nicholson *et al*., 1996; Vassalou *et al*., 2012). With respect to age, Graves (1922) described ossification at the articular margins of the acromioclavicular joint facet, as well as in the inter-articular cartilage and joint capsule. Furthermore, in some cases a uniform lipping (spur) was seen around the entire margin of the joint. Severe degeneration of the articular surface of the acromioclavicular joint was also observed in older specimens, suggesting an osteoarthritic process. These degenerative changes were associated with age changes in the scapula. Hardy *et al*. (1986) observed osteophytes at the inferior acromioclavicular joint in 12 patients (32%) with acute subacromial impingement syndrome, while degenerative changes in the acromioclavicular joint were seen in 25 patients (66%): most of the osteophytes and degenerative changes were mild. Acromioclavicular osteophytes have been observed on the anterior and lower aspect of the joint in 2 (11%) patients with subacromial impingement syndrome (Postacchini, 1989). With regard to the type of rotator cuff tear, osteophytes have been reported in 33.3% of shoulders with partial tears and in 50% with full thickness tears (Gohlke *et al*., 1993). The caudal/inferior surface of the acromioclavicular joint was worn in 86% of shoulders with full thickness tears. MRI evaluation of the coracoacromial arch revealed that rotator cuff tears were significantly associated with acromioclavicular enthesophytes (40%), (Farley *et al*., 1994). Degenerative changes in the acromial facet were observed significantly more in specimens older than 50 years (70%) compared to younger specimens (9%) (Nicholson *et al*., 1996). Furthermore, Vassalou *et al*. (2012) found that degeneration of the acromioclavicular joint and formation of a subacromial spur were the most prevalent findings related to age, with degeneration of the joint being observed more frequently in older patients (46-89 years) with impingement syndrome than in younger patients (18-37 years) without impingement syndrome, being 52% and 6% respectively.

The current study found no relationship between ACJ degenerative changes and osteophytes and factors including side, sex and CAL morphology and band number. In addition, there was no relationship between ACJ degenerative changes and osteophytes and the CAL regarding acromial attachment extending to the ACJ. However, shoulders showing both signs were older than shoulders without. This result suggests a degenerative process in the formation of these signs as described by Mahakkanukrauh and Surin (2003). With respect to acromial spur incidence in the current study, there were significant associations between degenerative signs in the ACJ and acromial spur incidence as reported previously (Cone *et al*., 1984; Tada *et al*., 1990; Mahakkanukrauh and Surin, 2003). This result also supports Chen and Bohrer (1990) and Noda and Mizuno (1998) who suggested that CAL calcification and the formation of acromial spurs may be due to systematic disorders such as renal failure and systemic hyperostosis. However, the current study found that the degenerative signs in the ACJ were significantly correlated with severe types of subacromial spurs, roughed and eburnated appearance on the undersurface of the acromion, severe attrition lesions on the insertion of the CAL and the complete rotator cuff tears, in which these types were more likely to be due to biomechanical dysfunction rather than a systematic disorder. Therefore, the current observations suggest that two factors play a role in ACJ degenerative changes and osteophyte formation: age and subacromial impingement.

More and larger osteophytes form on the acromial facet than on the clavicular facet of the acromioclavicular joint (Cuomo *et al*., 1988; Mahakkanukrauh and Surin, 2003). Cuomo *et al*. (1988) observed both a larger size and greater number of osteophytes on both sides of the acromioclavicular joint in shoulders with rotator cuff tears. However, comparing the two groups with respect to the size of downward pointing osteophytes a significant difference was seen in those formed on the acromial side (1.23 mm versus 0.6 mm) compared to the clavicular side (1.61 mm versus 1.21 mm), respectively. Mahakkanukrauh and Surin (2003) observed more osteophytes on the acromial facet (35%) than on the lateral end of the clavicle (11.6%), from which they assumed that acromial facet spurs might form as a result of transmission of forces from the humeral head through the acromion to the acromioclavicular joint. Spurs found on the clavicular facet were fewer and smaller than those on the acromion (Mahakkanukrauh and Surin, 2003).

The current study investigated osteophyte formation only on the acromial side. They formed on all edges of the acromial facet, however mainly on the inferior edge (77%). The mean downward length of osteophytes on the inferior edge of the acromial facet was 3.20 ± 1.1 mm. With respect to rotator cuff tears, the current study disagrees with Cuomo *et al*. (1988) as there was no difference in osteophyte length between the two groups. Furthermore, there was no difference in osteophyte length in relation to the presence of acromial spurs or CAL degenerative changes, and no correlation with age. Therefore, the results of the current study suggest that the size of osteophytes may be controlled by factors other than age or subacromial impingement.

Previous studies have reported no relationship between acromial morphology and osteophyte formation at the lower edge of the acromial facet of the ACJ (Getz *et al*., 1996; Pearsall *et al*., 2003). Getz *et al*. (1996) identified osteophytes in 164 of 394 cadaveric shoulders, with the incidence of osteophytes according to acromial morphology being as follows: 39 in the flat type (43%), 111 in the curved type (41%) and 14 in the hooked type (41%). Pearsall *et al*. (2003) agreed with Getz *et al*. (1996) since they found no association between acromial morphology and degenerative changes in the acromioclavicular joint with rotator cuff tears. In contrast, the current study found that shoulders with ACJ degenerative signs had a greater acromial curvature than those without degenerative signs. Therefore, the results of the current study suggest that increased acromial curvature may lead to greater shoulder impingement, which in turn may cause more degenerative changes in the acromion and ACJ.

5 Conclusion

5.1 Anatomical Variations of the CAL

In conclusion, the current study investigated the anatomical variations and degenerative changes of the CAL in shoulders with rotator cuff tears. Observed anatomical variations of the CAL include a variable morphology, band number and attachment sites.

Morphologically, four shapes of CAL were identified: 6% broad band (n = 14), 10% quadrangular band (n = 21), 38% Y-shaped (n = 84), and 46% multiple banded (n = 101). A V-shaped ligament was not observed in the study as the CAL usually originated as an undivided ligament at the anterior edge and undersurface of the acromion.

With respect to the number of bands of the CAL, it may consist of between one and six bands. The distribution of CALs according to the number of bands was as follows: 16% one band (n = 35), 38% two bands (n = 84) and 46% three or more bands (n = 101). CALs with multiple banded ligaments were the most common type in the current study, which has not been the case in previous reports.

A diaphanous membrane was usually present between the various bands of the ligament with blood vessels piercing the membrane. These blood vessels were branches from the suprascapular vessels. No association was found between the shape or band number of the CAL and factors such as side, sex and age. However, male specimens showed larger CALs than females. Geometric parameters of the CAL showed significant differences and correlations according to the ligament band number. The acromial and coracoid attachment widths of the CAL were positively correlated with the number of bands of the ligament, as well as the length of the corresponding aspects of the acromion and coracoid processes. The anatomical variations of the CAL observed in the study, including its shape and the number of bands. The division criteria, support the view that the bands are primarily determined during gestation, whereas the final shape of the CAL appears to be related to growth changes in the coracoid process.

With respect to the attachment sites, the CAL mainly originates posteriorly from the anterior edge of the acromion, underneath the attachment of the middle fibers of deltoid, with the subacromial insertion covering nearly 46% of the total length of the undersurface of the acromion. The size of the subacromial insertion was significantly correlated with CAL morphology and band number. Anteriorly, the CAL inserted into the posterior lateral aspect of the coracoid process extending from the tip to the medial end. The medial fibers of the CAL were attached underneath the acromial facet of the acromioclavicular joint in nearly 50% of specimens, and to the root of the coracoid in 10% of specimens. CALs with one band had a significant attachment to the anterior edge of the acromion and the lateral aspect of the coracoid, while ligaments with three or more bands tended to be hidden underneath the clavicle attaching to the acromial facet of the acromioclavicular joint and the medial end of the coracoid process. These variations in CAL attachment sites may be related to the size of the ligament or bony processes.

In addition, the CAL was found to have interconnections with other tissues associated with the shoulder joint: deltoid, the coracohumeral ligament, the joint insertion of the short head of biceps and coracobrachialis, the coracoclavicular ligament and the inferior capsule of the acromioclavicular joint. The mode of attachment may increase CAL stability and improve its biomechanical function. Identifying the anatomical variations of the CAL attachments may help in successful surgical release or reattachment of the ligament.

5.2 Rotator Cuff Tears

Rotator cuff tears were observed in 50% of specimens: 48% were partial tears (n= 37), 43% complete tears (n=33) and 9% massive tears (n= 7): the tears were mainly in the supraspinatus tendon. The current study found a significant association between rotator cuff tears and CALs composed of three or more bands. However, there was no association between rotator cuff tears and the shape of the CAL. A significant association between age and rotator cuff tears was also observed, specimens with rotator cuff tears were older than those without. Significant differences in the geometric parameters of the CAL in relation to rotator cuff tears were also found. Shoulders with rotator cuff tears had wider acromial and coracoid attachment widths, larger cross sectional areas and thicker acromial attachments. Geometric differences were observed in both the medial and lateral bands of the CAL. However, the length of the CAL did not show any difference in relation to rotator cuff tears. Moreover, medially placed fibres of the CAL underneath the clavicle were associated with rotator cuff tears. Therefore, it is suggested that increasing band number or the dimensions of the CAL attachment may lead to further subacromial impingement.

5.3 Acromial Spurs

The current study observed acromial spurs in 43% of cadaveric shoulders and in 55% of dry scapulae. Acromial spurs formed within the acromial attachment of the CAL, mainly in the lateral half. There was no relationship between acromial spurs and CAL morphology and/or band number. Shoulders with acromial spurs had wider and thicker CALs than shoulders without spurs. However, there was no difference in CAL length with respect to the presence of acromial spurs. Thus, the width of the CAL may influence spur growth, while its thickness may be influenced by spur growth. The length of the CAL did not affect and was not affected by spur growth. Medially placed fibres of the CAL underneath the clavicle were associated with acromial spurs.

With respect to spur size, there was a significant correlation between the size of the spur and both the acromial attachment width and size of the CAL subacromial insertion. Furthermore, a significant relationship was identified between rotator cuff tears and acromial spur incidence. A significant relationship between the type of rotator cuff tear and acromial spur was observed. Moreover, there were significant associations between the severity of rotator cuff tears and each of the severity types and sizes of acromial spurs.

Individuals with acromial spurs were older than those without acromial spurs. A significant correlation was identified between age and length of anterior acromial spurs. However, there was no association between the incidence of acromial spurs and the factors of side and sex.

Furthermore, a significant relationship was found between degenerative changes on the undersurface of the acromion and spur size, in which the degenerative changes may represent the severity of impingement. The formation of an acromial spur at the anterior edge of the acromion was found to play a role in the curvature and morphology of the acromion. However, there was no relationship between acromial curvature and rotator cuff tears. Finally, the current study suggests that three factors control the size of the spur: (i) the severity of the impingement, (ii) the size of the CAL (mainly the subacromial insertion), and (iii) age. In turn, the size of the acromial spur may increase (i) the size of acromial coverage over the humeral head, (ii) acromial curvature, and (iii) the severity of rotator cuff tears.

5.4 Coracoacromial Arch Degenerative Changes

The current study inspected degenerative changes in the coracoacromial arch in relation to rotator cuff tears. The observed degenerative changes involved changes in the appearance of the acromion, attrition lesions on the subacromial insertion of the CAL, degenerative changes and osteophytes formation in the acromioclavicular joint, and coracoid spur formation. These degenerative changes were associated with the formation of the severe type of acromial spurs and rotator cuff tears, which suggests that these changes are related to advanced stages of shoulder impingement.

Changes in the undersurface of the acromion involved rough and eburnated surfaces. Changes in the subacromial insertion of the CAL involved attrition lesions or marks resulting from contact between the humeral head and the subacromial surface. Attrition lesions significantly extended as the subacromial spur developed. The size of the subacromial insertion of the CAL was significantly correlated with degenerative changes in the subacromial surface, in which large size ligaments showed more severe degenerative changes compared to those in small size ligaments. Therefore, an increase in the size or band number of the CAL may play a role in shoulder impingement causing severe degenerative changes on the subacromial surface. Furthermore, acromioclavicular joint degenerative changes and coracoid spurs had no relation to CAL morphology or band number; however shoulders with coracoid spurs had a wider acromial attachment.

There was a significant difference in the age of shoulders with ACJ degenerative changes, but not for shoulders with coracoid spurs. Therefore, age may play a role in ACJ degenerative signs, while coracoid spurs may form as a result of increased tensile forces transmitted through the CAL. Shoulders with ACJ degenerative signs had a greater acromial curvature than shoulders without degenerative changes, suggesting greater shoulder impingement. Thus, age and shoulder impingement may both play a role in the formation of osteophytes and degenerative changes in the ACJ.

In summary, the anatomical variations of the CAL showed a relationship to rotator cuff tears. Shoulders with rotator cuff tears had larger CALs composed of three or more bands, wider attachments ends and larger subacromial insertions. Shoulders with rotator cuff tears also showed a significant incidence of acromial spurs as a result of calcification of the CAL. The size of acromial spurs correlated with the size of the CAL. Furthermore, CALs in shoulders with rotator cuff tears were thicker, and with subacromial spurs forming a ridge on the undersurface of the acromion causing further impingement on the rotator cuff tendons and greater tubercle. Further impingement results in rotator cuff tears and attrition lesions on the subacromial insertion of the CAL. Finally, degenerative changes in the CAL are extrinsic factors which may lead to rotator cuff tears; however these changes may result from repeated shoulder impingements primarily caused by intrinsic factors.

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