Anatomy of the Shoulder

1

Enrico Bellato, Davide Blonna, and Filippo Castoldi

When we study arthroscopic anatomy of the shoulder, we must not focus solely on structures visible from inside the joint. Whatever encloses the glenohumeral joint is important, in particular with reference to surgical approaches and portals. Moreover, we have to know the structures to be avoided so that we do not cause damages and complications.

Anatomical Landmarks

Before starting arthroscopy, we have to identify the acromioclavicular joint, the acromion, the scapular spine, and the coracoid process.

Acromioclavicular Joint

This is a diarthrodial joint with an articular disc, usually perforated at its center [1]. It is the only articulation between the clavicle and the scapula. However, 1 % of people have a coracoclavicular joint [2], and about 30 % have articular cartilage on the coracoid and clavicular surfaces without a real joint [3].

Articular surfaces of the acromioclavicular joint are on the medial edge of the acromion and the distal aspect of the clavicle. Superior aspect of the distal clavicle is covered by insertion of the deltoid and trapezius muscles; inferiorly, it is characterized by the coracoclavicular processes where the coracoclavicular ligaments originate: the conoid tubercle medially and the trapezoid line laterally.

The acromioclavicular joint is enveloped by the articular capsule that is thinner inferiorly and by ligaments. The *acromioclavicular ligaments* (capsular ligaments) are responsible for controlling posterior translation of the clavicle, and there are two of them: the superior (which blends with trapezius and deltoid fibers) and inferior (thinner than the superior and sometimes absent) [4]. The coracoclavicular ligaments (Fig. 1.1), on the other hand, control vertical stability [4]. We can distinguish two coracoclavicular ligaments:

- The *conoid ligament* originates from the conoid tubercle, characterized by an inverted cone shape, with a base wider than the surface where the ligament inserts. Variations of the insertion on the coracoid process have been described [5]:
  1. It inserts on the most posterior part of the dorsal aspect of the coracoid process, behind the insertion of the trapezoid ligament; it runs posteriorly up to the highest point of the vertical part of the coracoid, where we can find the "Testut tubercle" (52 %) [6].

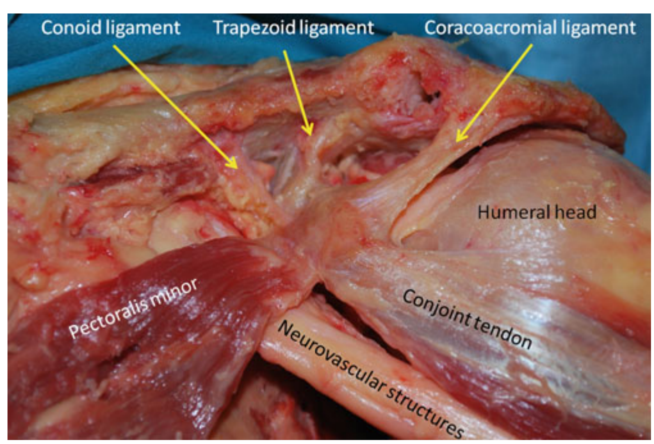

Fig. 1.1 The coracoid origin of the conjoint tendon and of the pectoralis minor tendon; medial to the coracoid, there are important neurovascular structures

E. Bellato, MD (✉) • F. Castoldi, MD
Department of Orthopaedics and Traumatology, Mauriziano-Umberto I Hospital – University of Turin Medical School, Largo Turati 62, Torino 10128, Italy
e-mail: bellatoenrico@gmail.com; filippo.castoldi@unito.it

D. Blonna, MD
Department of Orthopaedics and Traumatology, Mauriziano-Umberto I hospital, Largo Turati 62, Torino 10128, Italy
e-mail: davide.blonna@virgilio.it

G. Milano, A. Grasso (eds.), *Shoulder Arthroscopy*,
DOI 10.1007/978-1-4471-5427-3_1, © Springer-Verlag London 2014

2. It runs posteriorly to join the transverse scapular ligament (33 %).
3. A well-defined accessory conoid ligament, which originates at the base of the coracoid, runs superolaterally and inserts on the clavicle, just lateral to the trapezoid ligament.

- The *trapezoid ligament* originates from the trapezoid line of the clavicle which is three times thicker than the ligament insertion surface on the most posterior aspect of the horizontal part of the coracoid; it takes 15.3 mm from this ligament and the lateral edge of the clavicle [5].

Blood supply to the acromioclavicular joint derives mainly from the acromial artery; innervation is supplied by the pectoral, axillary, and suprascapular nerves [7].

Acromion

It translates as the "highest point of the shoulder," even though the highest point is actually the lateral edge of the clavicle. It is the rectangular extension of the scapular spine.

According to Bigliani et al., the slope of the acromion can present in three different ways [8, 9]: type I "flat," type II "curved," and type III "hooked"; the last one is supposed to be associated with a rotator cuff lesion in 70 % of cases [8, 9]. Recently, an anatomical study found type I in 10.2 % of cases and type II in 89.8 % of cases; the absence of type III may indicate that it is a misinterpretation of the so-called acromial spur [10]. After Bigliani, the acromion was also classified as "cobra shaped" (associated with degenerative changes in 26 % of cases), "square-tipped," and "intermediate" type [11]. The mean distance between acromion and humerus is 9–10 mm (6.6–13.8 mm for males and 7.1–11.9 for females) [12].

Ossification nuclei of the acromion may be not fused by the age of 25, so we can see the so-called os acromiale. This variation was first described by the anatomist Cruveilhier [13] and by the radiologist Lilienfeld [14]. Its frequency is approximately 7–15 % [15, 16], and there are several possible shapes in anterior-posterior order: pre-acromion, meso-acromion, meta-acromion, and basi-acromion. Meso-acromion and meta-acromion are thought to be the most frequent [17].

Moreover, Lilienfeld drew a distinction between "typical" and "atypical" (also known as "secundarium") os acromiale, a term that should be used for displaced acromial ossification centers [14]. This condition is rare (if it really exists) and must not be confused with calcifications due to degenerative or post-traumatic events.

The acromion and the coracoacromial ligaments define the supraspinatus outlet, also called "fornix humeri." The coracoacromial ligament (Fig. 1.1) runs from the coracoid to the acromion edge. It has several different parts: the principal one consists of fibers of the conjoint tendon, the clavipectoral fascia, and the rotator interval. The most lateral aspect originates at the lateral edge of the rotator interval and inserts on the conjoint tendon forming a structure called "falx." Biomechanical studies have shown a tension-band wiring function of the coracoacromial ligament: after a complete lesion of this ligament, the acromion experiences a ten times higher bending force [18].

Spine of the Scapula

It is an oblique process that runs from the medial margin to the upper lateral part of the scapula and becomes gradually thicker; it ends at the acromion process. It is the boundary between the infraspinatus fossa and the supraspinatus fossa and functions as part of insertion of the trapezius and the posterior deltoid. Size and shape of the scapular spine are quite steady, varying less than 1.5 cm from the mean in any dimension [19].

Coracoid Process

The name comes from its similarity to a "crow bill." It comes off the base of the glenoid anteriorly and it hooks laterally; its smooth apex is the insertion surface of the conjoint tendon anteriorly (footprint: 15.5 ± 1.8 mm in width) and of the pectoralis minor tendon medially (footprint: 11.8 ± 2.8 mm in width) [20] (Fig. 1.1). Its dimensions and relationships with ligaments and tendons are fundamental to coracoid osteotomy and transfer, which nowadays can be carried out arthroscopically [21–25]. Coracoid length is about 45.6 mm; width and height in the mid-portion are about 16.1 mm and 13.5 mm, respectively. The mean distance between the tip of the coracoid and the coracoclavicular ligaments insertion is about 28.5 mm. The mean distance from the posterior extent of coracoacromial ligament footprint to the anterior extent of the coracoclavicular ligament footprint is about 2.8 mm, while the mean distance from the posterior extent of pectoralis minor tendon footprint to the anterior extent of the coracoclavicular ligament footprint is about 3.7 mm [20].

Vascularization is also very important: some authors believe that the coracoid process receives blood supply from its apical muscular insertions, and the bony fragment ischemia is held responsible for postoperative complications after coracoid transfer procedures, such as nonunion and bone resorption [26–28]. In a recent study, no vessels were identified at the osteotendinous junction and a complete ischemia of the coracoid follows the osteotomy. The vertical portion of the coracoid is supplied by a branch of the suprascapular artery [29, 30]; the horizontal portion is supplied by a branch of the acromial branch of the thoracoacromial artery, which runs beneath the coracoacromial ligament and enters next to the insertion of this ligament [29]. A direct branch from the second portion of the axillary artery, behind the pectoralis minor muscle, can seldom be found [29].

The coracoid process is a fundamental landmark for shoulder arthroscopy since the arthroscopic instruments must not go beyond it. In fact just medial to the coracoid, under the pectoralis minor tendon, there are important neurovascular structures such as the axillary artery and the cords of the brachial plexus (Fig. 1.1).

Muscles

Deltoid

This is the most important and largest among the shoulder muscles. Its external boundary is the subcutaneous fat, while the bursa and fascial spaces bound the deep side. The thick and deep fascia hosts vessels and nerves supplying the deltoid. Three portions are identified [31]:

- The anterior deltoid: it originates from the lateral third of the clavicle and from the anterior edge of the acromion.
- The middle third: it originates from the lateral acromion.
- The posterior deltoid: it originates at the posterior edge of the acromion and the spine of the scapula.

These portions differ in structure [32]: the anterior and posterior thirds have parallel fibers, while the middle third is multipennate and stronger. Three collagenous raphae divide these sections. One is anterior and originates from the anterolateral corner of the acromion, between the anterior and middle third of the deltoid. The other two are posterior: one is between the middle and posterior portion of the muscle, about 16 mm medial to the posterolateral corner of the acromion; the second ("mid-deltoid") originates from the posterolateral corner of the acromion and lies within the most posterior aspect of the middle third of the deltoid [33]. These three "classical" portions have been reassessed by different authors [34–37]. Recently, Sakoma et al. [38] identified seven segments, each one characterized by an intramuscular tendon: three posterior, three anterior, and a middle one. Each one is proximally separated from the others by precise landmarks. The middle segment and the second posterior one are bounded by the two acromial corners; within this section of the acromion, we can find two little bony tubercula which divide the lateral border of the acromion into three facets, called anterior, middle, and posterior facets: their widths are 19.5, 14.2, and 17.9 mm, respectively. Thanks to a PET study, the seven segments also seem to represent the functional units of the deltoid [38].

Innervation is supplied by the axillary nerve. Its anterior branch supplies in 100 % of cases the middle and the anterior third of the deltoid and in 18 % of cases also the posterior third; the posterior branch supplies the posterior third in 90 % of cases and the middle third in 38 % of cases. As a consequence, the middle and the posterior portions are doubly supplied in 38 and 18 % of cases, respectively [39]. Vascular supply is mainly derived from the posterior humeral circumflex artery and from the deltoid branch of the thoracoacromial artery [40].

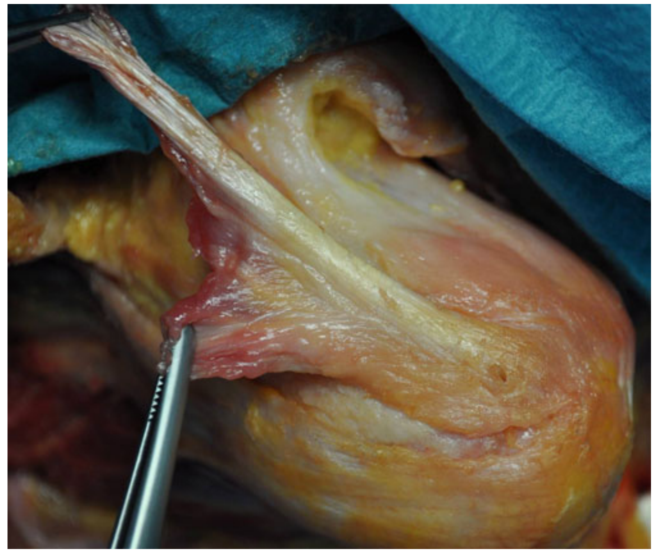

Fig. 1.2 The supraspinatus muscle has an internal tendon within its anterior portion

Rotator Cuff

Supraspinatus

This lies on the superior portion of the scapula and has a fleshy origin from the supraspinatus fossa. Two portions are described [41]:

- Anterior (40 % of the tendon width): it is fusiform and entirely originates at the supraspinatus fossa; within the center of the muscle belly, we find an internal tendon onto which the larger anterior muscle mass inserts (Fig. 1.2) [42, 43].
- Posterior (60 % of the tendon width): it is smaller than the anterior and originates from the spine of the scapula and the glenoid neck; it does not show an internal tendon.

Both of these portions are again divided into superficial, middle, and deep sections, based on fiber orientation and insertion [43].

The tendon runs beneath the coracoacromial arch and inserts into the superior facet of the greater tuberosity of the humerus (Fig. 1.3). It may have an asymptomatic calcium deposit in as many as 2.5 % of shoulders [44]. Inferiorly, the tendon is quite difficult to distinguish from the articular capsule; it is provided with a synovial sheath, which merges into the capsule of the shoulder joint (Fig. 1.4) [45]. The

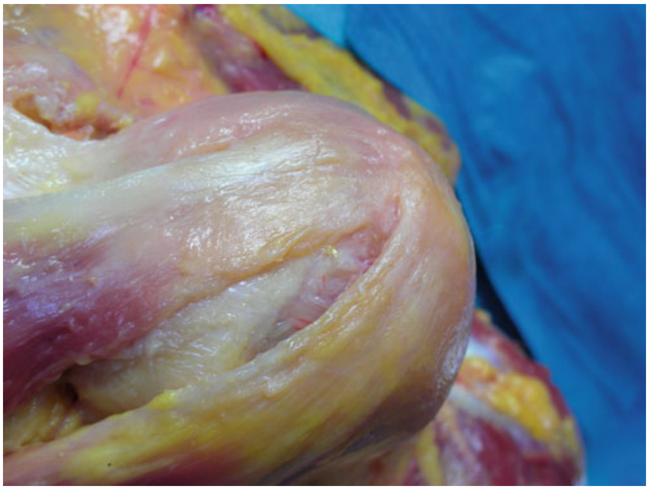

Fig. 1.3 The supraspinatus and infraspinatus tendons

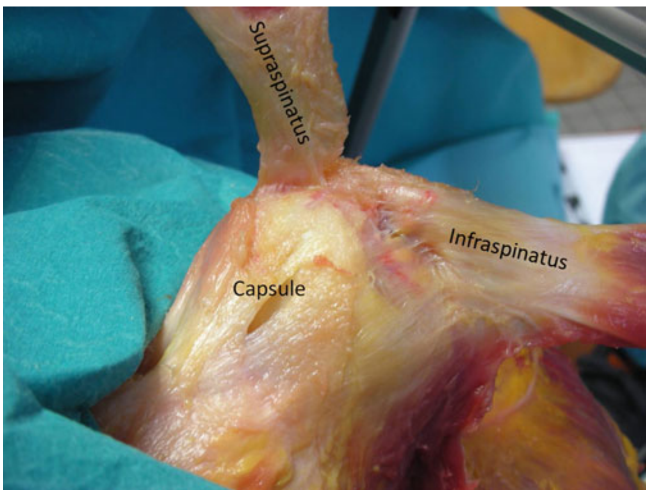

Fig. 1.4 Both the supraspinatus and the infraspinatus tendons are covered by a synovial sheath which merges into the capsule of the shoulder joint

insertional footprint has a trapezoidal or triangular shape with a major proximal base; its average length is 6.9–23 mm and its average width is 12.6–16 mm [46, 47]. The insertional portion of the tendon is characterized by two peculiar structures [48]:

- Crescent: the most distal aspect of the tendon; it is a crescent-shaped sheet of rotator cuff comprising the distal portions of the supraspinatus and infraspinatus insertions; it is very thin, avascular, and so prone to lesions.
- Cable: it is a thick pre-insertional portion (partially involving also the other tendons of the rotator cuff) acting as a suspension bridge capable of stress transfer to protect the crescent; its outer border extends anteriorly to the long head of the biceps and posteriorly to the inferior border of the infraspinatus; some authors stated that it could be an extension of the coracohumeral ligament [49].

Mean tendon width and thickness are 25 mm and 10–12 mm, respectively [50, 51]. It is important to remember the distance between articular cartilage of the humeral head and supraspinatus footprint is about 0.9–1.9 mm [46, 50]: this bare area, which we can calculate during arthroscopy, seems to correlate with partial tendon lesions [46]. Microscopic studies have illustrated a more or less defined layered appearance [46, 52].

Infraspinatus

This is the main external rotator muscle and accounts for 55–60 % of external rotation force [53]. It is a pinnate muscle with a median raphe (often confused with the boundary between infraspinatus and teres minor muscles). It is characterized by three pennate origins in 80 % of cases, bipennate or monopennate origins in 20 % of cases [45]. It has a fleshy origin from the medial aspect of the spine of the scapula and from the infraspinatus fossa. It is sheathed with a dense fascia along with the teres minor; this fascia reflects anteriorly to blend with the fascia of the long head of the triceps. Above the glenohumeral joint, it is 29 mm in width (in neutral rotation) and is characterized by its raphe [33]. As a consequence, this could be considered for the posterior portal as much more suitable and safer than the infraspinatus/teres minor interval (Fig. 1.5) [54]. In fact this interval is often difficult to find, crosses the most inferior margin of the joint, and can host a venous plexus [33]. It has a tendinous insertion into the middle impression of the greater tuberosity, more distal than the supraspinatus footprint (Figs. 1.3 and 1.4). It has a trapezoidal shape with an average maximum length of 10–29 mm and width of 19–32.7 mm [46, 47]. As the supraspinatus muscle, it is sheathed with a synovial sheath which merges into the capsule of the shoulder joint (Fig. 1.4) [45]. During arthroscopy it is difficult to draw a distinction between supraspinatus and infraspinatus muscles. Codman described an area lacking in cartilage, called "rim rent," on the uppermost margin of the anatomic humeral neck: this landmark could be useful to identify the infraspinatus/supraspinatus interval [55]. Minagawa et al. stated that the interval is about 4.3 mm posterior [47].

Both tendons display a layered structure (from the most superficial to the deepest) [46]:

- Superficial fibers of the coracohumeral ligament
- Tendinous fibers parallel to the muscle fibers
- Rare fibers with orientation not well defined
- Flat connective tissue
- Articular capsule

Teres Minor

This is the smallest of the rotator cuff muscles (Fig. 1.5). It originates on the middle portion of the lateral border of the scapula and rarely overlies the infraspinatus as far as the medial border of the scapula [56]. Some fibers originate

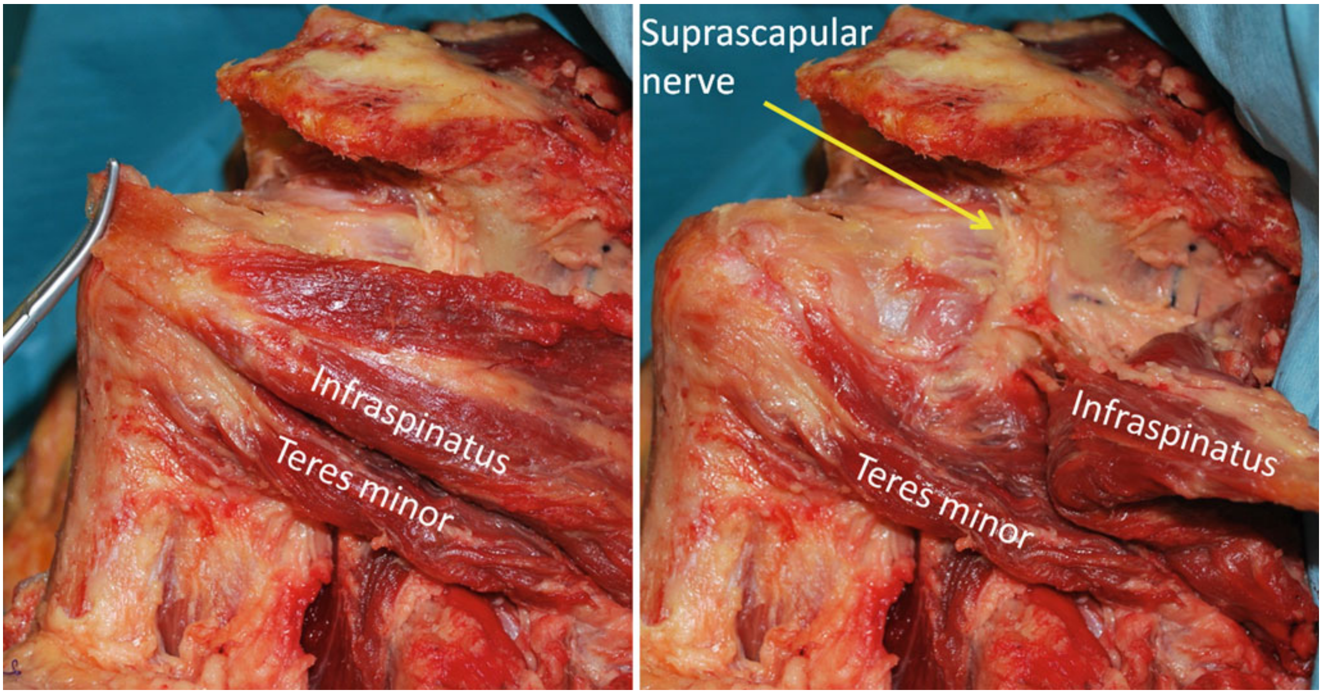

Fig. 1.5 The infraspinatus/teres minor interval crosses the most inferior margin of the joint. The suprascapular nerve is about 1.5–2 cm from the posterior border of the glenoid

from the connective tissue in the infraspinatus/teres minor interval. The tendon inserts into the inferior impression of the greater tuberosity, which displays a triangular shape (average maximum length, 29 mm; average width, 21 mm). It quickly becomes thinner and is characterized by few tendinous fibers superiorly and a fleshy portion inferiorly. The mean distance between the footprint and the articular cartilage is 10 mm [46].

Subscapularis

This is a triangular-shaped multipennate muscle. It has a fleshy origin from the subscapularis fossa. The superior portion (60 %) inserts into the lesser tuberosity with a tendinous insertion, while the inferior portion (40 %) is mainly fleshy and inserts under the lesser tuberosity enclosing humeral head and neck [57].

The subscapularis tendon is 155 mm in length and about 31 mm in width [58]. However, the portion we can see during arthroscopy represents only 26–36 % of the entire tendon (Fig. 1.6) [58, 59].

Many anatomical variations have been described [60–63]. Recently, Staniek and Brenner [64] described the so-called infraglenoid muscle. They identified this structure in 64 % of cadavers: it originates from the upper/lateral third of the lateral border of the scapula and inserts at the crest of the lesser tuberosity (86 %), at the lesser tubercle itself (12 %) or at both anatomical structures (2 %).

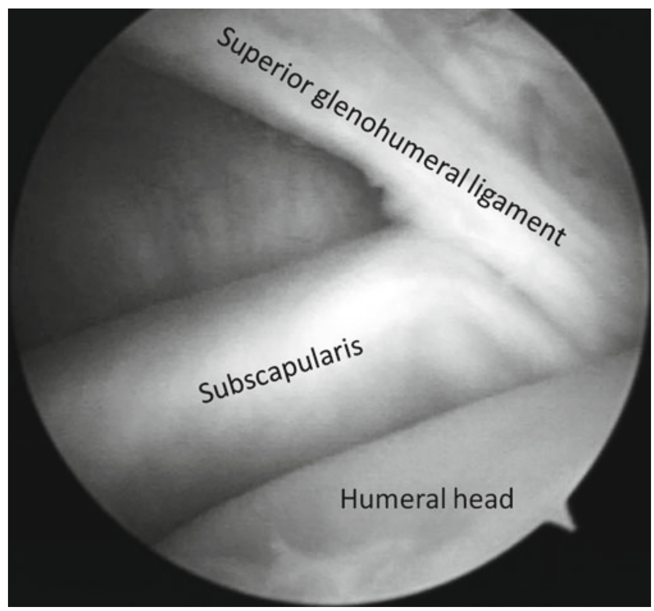

Fig. 1.6 During arthroscopy we can see only 26–36 % of the entire subscapularis tendon. The subscapular recess is between the subscapularis tendon and the superior glenohumeral ligament

Biceps Brachii

Even though it is considered mainly an elbow muscle, the biceps brachii is often involved in shoulder pathologic processes. It has a short head originating from the coracoid tip (laterally to the coracobrachialis muscle) and a

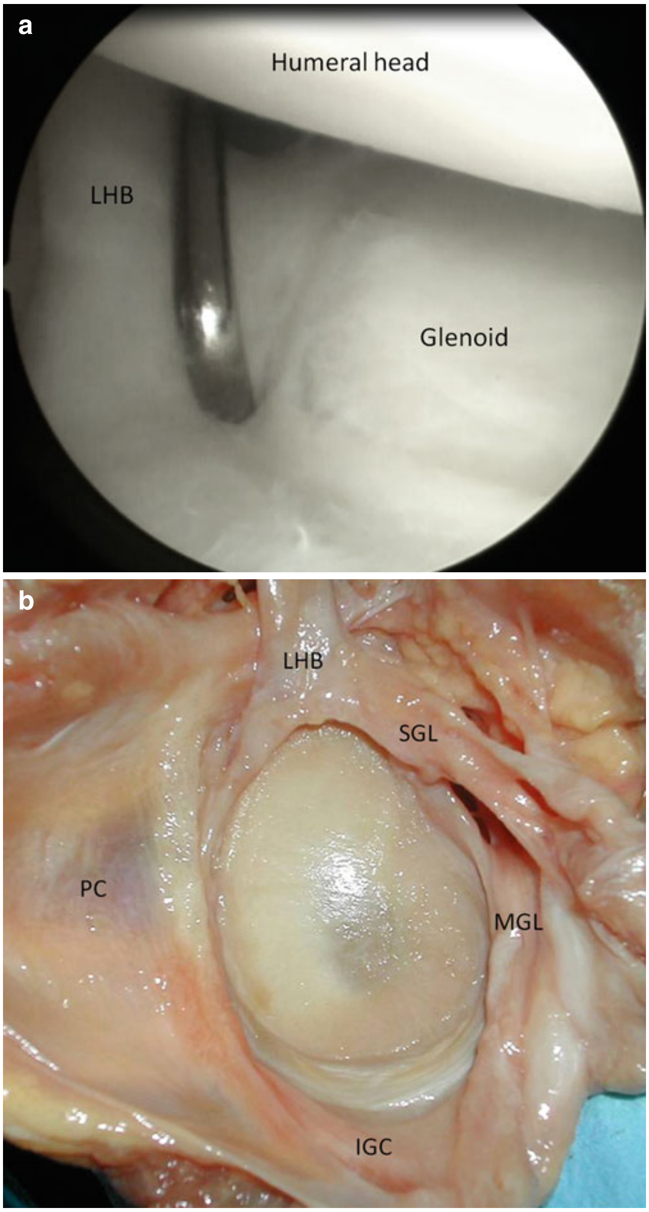

Fig. 1.7 (**a**) The long head of the biceps (*LHB*) originates from both the supraglenoid tubercle and the superior labrum. (**b**) *LHB* long head of the biceps brachii, *SGL* superior glenohumeral ligament, *MGL* middle glenohumeral ligament, *IGC* inferior glenohumeral complex, *PC* posterior capsule

long head (LHB) which originates from both the supraglenoid tubercle and the superior labrum (Fig. 1.7) [65]. Anterior labral attachment is observed in 33 % of cases, posterior labral attachment is seen in 100 % of cases, and isolated posterior labral attachment is seen in 67 % of shoulder joints [66]. Four types of LHB origin have been described [65]:

- Type I: the entire LHB attaches to the posterior labrum.
- Type II: most of the LHB fibers attach to the posterior labrum, but a small portion attaches to the anterior labrum.

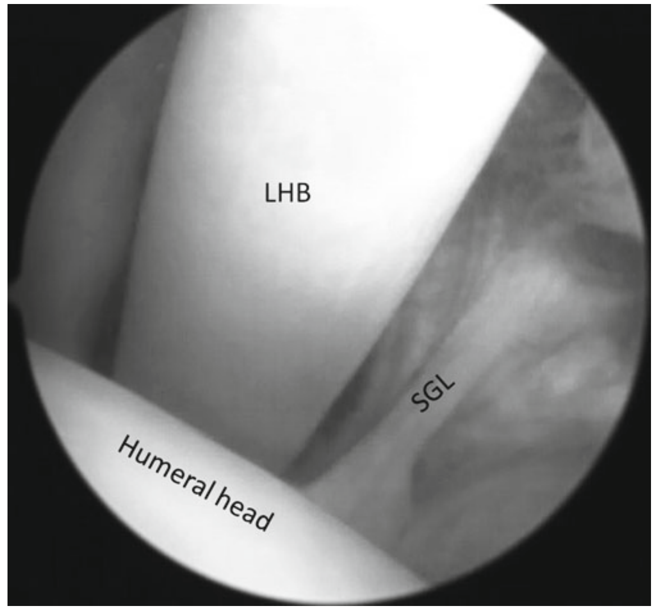

Fig. 1.8 The superior glenohumeral ligament (*SGL*) is one of the four structures forming the "pulley" which stabilizes the long head of the biceps (*LHB*)

- Type III: the LHB attaches equally to the anterior and posterior part of the labrum.
- Type IV: most of the LHB fibers attach to the anterior labrum, but a small portion attaches to the posterior labrum.

Sometimes (25 % of cases, particularly among young patients) we can see small fibrovascular bands of synovium that run from the LHB to the surrounding synovium and capsule; these anatomical variants have been called "vincula biceps" [67].

The intra-articular portion of the LHB (Fig. 1.8) is stabilized by a structure called "pulley" which is medial to the tendon and just above the bicipital groove [68–71]. It consists of four principal structures:

- Coracohumeral ligament: it is characterized by an anterior and posterior portion.
- Superior glenohumeral ligament (Fig. 1.8): it originates from the supraglenoid tubercle; its medial aspect forms a fold parallel to the LHB and laterally it becomes a U-shaped sling; it blends into the coracohumeral ligament, just before the insertion on the lesser tuberosity, forming a sling similar to the ring bends of a finger flexor tendon.
- Fibers of the supraspinatus and subscapularis tendons: these tendon fibers arise from the "fasciculus obliquus," a thin connective structure which runs from the supraspinatus to the subscapularis tendon and helps to build the roof of the rotator cuff interval. The uppermost aspect of the subscapularis tendon is considered by some authors the most important structure to stabilize the LHB [72].

Vascular supply of the tendon has been an interesting object of investigation as particular areas of the LHB are supposed to be prone to rupture because of mechanical or vascular factors. The LHB seems to be characterized by double/triple vascularization:

- One vessel at the osteotendinous junction (the acromial branch of the thoracoacromial artery)
- One vessel at the musculotendinous junction (the most important; a branch of the brachial artery)
- One intermediate mesotendon-derived vessel (rare; a branch of the anterior humeral circumflex artery)

As a consequence, we can see two regions of poor blood supply: the proximal being as much as 1.2–3 cm from the supraglenoid tubercle [73].

Bursae

Many bursae are described in the shoulder. They are totally avascular hollow spaces. The most important are:

1. *Subacromial bursa*: lubricates motion between the rotator cuff and the acromion; it does not usually connect with the glenohumeral joint [74] and has a capacity of 5–10 ml [75].
2. *Subdeltoid bursa*: usually fused with the subacromial bursa.
3. *Subscapularis bursa*: lubricates motion between the subscapularis tendon and the coracoid. It is located between the upper portion of the subscapularis tendon and the glenoid neck and should be more correctly considered a recess of the joint as it actually connects with the glenohumeral joint (Fig. 1.6). Free bodies or inflammatory synovial processes can be found in this recess.
4. *Coracobrachialis bursa*: not always detachable; in 20 % of cases, it is an extension of the subacromial bursa [75].

We can also find other bursae:

- Between the infraspinatus and the capsule
- Between the supraspinatus and the capsule
- Between the coracoid and the capsule
- Between the teres minor and the capsule
- Between the trapezius and the spine of the scapula
- Between the latissimus dorsi and the teres major

Articular Surfaces

The glenohumeral joint is formed by the humeral head and the glenoid fossa. The glenohumeral surfaces have been classified into three types [76]:

- Type A: the humeral surface has a radius of curvature smaller than that of the glenoid → small circular contact area.
- Type B: the humeral and glenoid surfaces have similar radii of curvature → larger circular contact area.
- Type C: the humeral surface has a radius of curvature larger than that of the glenoid → peripheral ring-shaped contact.

Glenoid

The glenoid cavity is slightly concave and measures about 6–8 cm^2 [77]. It is pear-shaped (Fig. 1.7) because of the so-called glenoid notch, well expressed in 55 % of the population [78]. It is covered with hyaline cartilage and displays a thinner central circular portion known as a “bare area.” The cartilage is thickest at the periphery (3.81 mm) and thinnest at the center (1.14 mm) [79]. Beneath this thin area of cartilage is an area of subchondral bone thickening termed “Asskay tubercle” [80].

Glenoid vertical axis measures 39 mm, while the horizontal one is about 23–29 mm. Its vertical radius of curvature is usually 2.3 mm larger than the humeral [81]. The glenoid could be either anteverted or retroverted: it is retroverted about 7.5° in 75 % of the population and anteverted about 2–10° in 25 % of cases. It is angled at an average of 15° medially with regard to the scapular plane [76, 82, 83].

The glenoid is completely rounded by the labrum, a circular rim which slightly increases glenoid concavity (Fig. 1.7). It is commonly triangular, but it may also be round, crescent in shape, or blunted [84]. It consists of dense fibrous tissue with a few elastic fibers: we can find fibrocartilage only in a small transitional zone between the labrum and the glenoid bone [85]. Detrisac and Johnson described two anatomical variants [86]:

- Meniscal-shaped: it inserts on the glenoid through a transitional fibrocartilaginous part and is centrally lifted off.
- The labrum inserts centrally and peripherally on all sides.

Cooper et al. [87] stated that the labrum is meniscal-shaped only apparently in its upper portion; in fact this portion inserts directly into the biceps tendon distal to the insertion of the tendon to the supraglenoid tubercle, and the collagen fibers of the labrum and biceps tendon intermingle in this area. Two other important anatomical variants of labrum insertion have been described:

- *Buford complex*: it is detected in 1.5 % of cases; the absence of the anterosuperior labrum is associated with a cord-like middle glenohumeral ligament originating anteriorly to the LHB and running over the subscapularis tendon. It should not be confused with a labrum tear or a SLAP lesion [88].
- *Sublabral hole*: it is detected in 12 % of cases; in the anterosuperior area, there is a hole beneath the labrum insertion [70].

Humeral Head

The humeral head has a wide, almost hemispheric articular surface. It is medially and proximally bent with an inclination angle of about 137° [89]. It is covered with articular cartilage 1.5–2 mm thick, which is usually thicker in the upper portion [90]. The humeral head is characterized by two "bare areas": one is located in the posterior aspect of the head, between the posterior insertion of the rotator cuff and articular surface; it is 2–3 cm long and usually cannot be seen in young patients; it is probably associated with age-related degenerative processes and must not be confused with Hill-Sachs lesion [91]. The second one is anterior, between the subscapularis footprint and the articular surface, and has a trapezoidal shape [92].

The average radius of curvature of the humeral head is 24 mm in the coronal plane and 22 mm in the axial plane [81]. Articular surface diameter is about 43.3 mm [93]. Humeral head retroversion may be calculated between a line perpendicular to the articular margin plane and the transepicondylar (about 18°) or the tangent elbow axes (about 21–23°) [89, 93].

The anatomical neck of the humeral head is the boundary between the articular surface and the tuberosities. These display different impressions hosting the footprints of the rotator cuff tendons and ligaments [46]. The tuberosities distally continue as the two lips of the bicipital groove. The groove, in its central portion, is about 6.2 mm wide and 5 mm deep [94]. The roof of the groove is formed by:

- Some fibers of the supraspinatus and subscapularis tendon; they form a sheath 7 mm long which envelops and stabilizes the LHB in its middle portion; this sheath is also strengthened by some fibers of the coracohumeral ligament.
- Superior glenohumeral ligament.
- Transverse humeral ligament.
- Falciform ligament: it is the main distal stabilizer, but is not always present; it is a tendinous expansion from the insertion of the sternocostal portion of the pectoralis major tendon.

Shoulder Capsule

The capsule is large: it has twice the surface area of the humeral head. Its normal capacity is 10–15 ml, but this can decrease to 5 ml or less in cases of adhesive capsulitis and increase to 30 ml or more in cases of laxity [95]. It normally extends from the glenoid neck to the anatomical humeral neck. However, its anterior insertion is quite variable and we can see three main types [96]:

- I: the capsule inserts in or next to the labrum
- II: the insertion is at the level of the scapular neck
- III: the insertion is more medial

It is mainly made of types I, III, and V collagen [97] and is strengthened around 360° by the rotator cuff. The tendons blend 2.5 mm into the capsule, especially the subscapularis, and form the so-called musculotendinous/capsulotendinous cuff [95]. Capsule thickness is not uniform, the inferior glenohumeral ligament being the thickest portion and the posterior capsule the thinnest portion (Fig. 1.7). The thickness is mainly determined by the middle collagen layer and ranges from 1.32 to 4.47 mm. The thickest portion is next to the axillary nerve [98].

Ligaments

The ligaments are thickenings of the shoulder capsule.

Coracohumeral Ligament

The coracohumeral ligament (CHL) is believed to represent phylogenetically the old insertion of the pectoralis major, since in 15 % of the population, part of this muscle crosses the coracoid process to insert on the humeral head [99]. It originates from the proximal third of the horizontal part of the coracoid, under the insertion area of the coracoclavicular ligament, and has a variable insertion:

- Superficial fibers insert into the greater tuberosity; only 15–50 % of the fibers insert into the lesser tuberosity; they blend into muscular fibers of the supraspinatus and subscapularis tendons.
- Deep fibers blend into expansions of the subscapularis tendon; only a few fibers run over the LHB and insert into the lesser tuberosity [100, 101].

Anterior border of the CHL is well defined medially, while it blends into the capsule laterally. The posterior border is normally difficult to distinguish. Although it is considered a ligament, its histological features are more similar to capsular tissue [72, 100, 102].

Several authors showed that the CHL is the key ligament which keeps the LHB aligned within the bicipital groove [72, 103–105]. Its contribution to the stability of the joint is very small, best demonstrated with the arm at the side, and consists of a triple function: support of the arm, restraint of external rotation below 60° of abduction, and stabilization of the LHB [103].

Glenohumeral Ligaments

Glenohumeral ligaments are collagenous reinforcements of the capsule (Fig. 1.7).

Superior Glenohumeral Ligament

Superior glenohumeral ligament (SGL) is a fairly constant structure, missing in 5–10 % of the population [91, 106]. However, there is a wide variability in its dimensions and consistency. The SGL (also called Flood ligament) arises from the superior tubercle of the glenoid, displaying three possible origins [71, 107]: along with the LHB, just anterior to the LHB, and along with the middle glenohumeral ligament. It inserts into the fovea capitis of the humerus, just above the lesser tuberosity. The gap between the superior and the middle glenohumeral ligament is called the Weitbrecht foramen.

SGL contributes very little to static stability of the joint; it develops the most strain at 0° of abduction. It is considered one of the most important stabilizers of the LHB in the bicipital groove [72, 104].

Middle Glenohumeral Ligament

Middle glenohumeral ligament (MGL) is missing in 8–30 % of the population and shows the greatest variations among the glenohumeral ligaments: it can be very thin or as thick as the LHB [106, 108, 109]. MGL originates just beneath or just medial to the SGL and inserts just medial to the lesser tuberosity, under the subscapularis tendon which blends into. Morgan et al. [110] showed the following anatomic variants for MGL:

- Normal (66 %).
- Cord-like (19 %): it is separated from the inferior glenohumeral ligament by a recess or by the so-called Rouviere foramen.
- Fan-like (5 %): it is often associated with a thickening of the anterior band of the inferior glenohumeral ligament.
- Missing (10 %).

MGL stabilizes the joint in a 45° abducted position; additionally, it is tightened over the anterior aspect of the humeral head when a position of extension and 45° of external rotation is held as the arm is abducted from 0° to 90°[71, 103].

Inferior Glenohumeral Ligament

Inferior glenohumeral ligament (IGL) is missing in 7–25 % of population and is the main static stabilizer of the abducted arm [107, 111].

IGL is a hammock-like structure which originates on the inferior aspect of the glenoid and consists of two different structures: the anterior and posterior bands. The anterior band originates on various portions from 2 to 4 o'clock [106, 108]; the posterior band (generally thinner than the anterior one) originates from various portions from 7 to 9 o'clock [108]. Between them there is the axillary pouch or recess. All together these structures identify the so-called inferior glenohumeral complex (IGC) (Fig. 1.9), which inserts on the humeral head in two possible ways:

- "Collar-like" attachment, just under the articular margin
- "V-shaped" attachment, with the anterior and posterior band attaching close to the articular surface and the axillary recess inserting further from the articular edge [95]

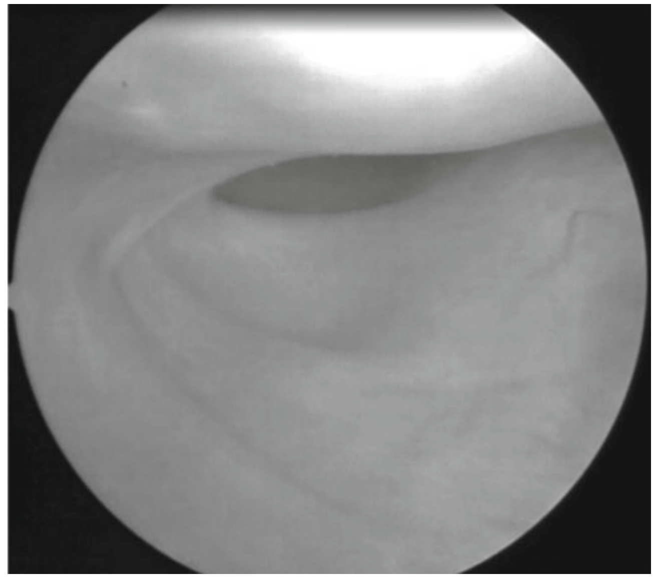

Fig. 1.9 The inferior glenohumeral complex

Rotator Interval

The space between the upper border of the subscapularis tendon and the anterior margin of the supraspinatus tendon is called the rotator interval (RI). It has a triangular shape with its apex above the bicipital groove. The rotator interval consists of four layers [112]:

- The superficial layer of the CHL
- Supraspinatus and subscapularis fibers
- The deep layer of the CHL ligament
- The SGL

The RI is believed to perform different roles. Jost et al. distinguished two regions: a medial one, from the coracoid to the cartilage boundary, controlling the inferior translation with the arm at the side and a lateral one, which covers the humeral head up to the greater tuberosity, controlling the external rotation with the arm at the side [112]. Harryman et al. showed how it stabilizes the shoulder posteroinferiorly and anteroinferiorly in a 60° abducted position [101]. Slatis and Alto underlined its role in the medial stabilization of the LHB [105].

Neurovascular Structures

Axillary Nerve

The axillary nerve runs from the anterior to the posterior aspect of the shoulder through the quadrangular space. Here the nerve is medial to the posterior circumflex humeral artery [33] and can suffer from impingement lesions [113]. It splits into the anterior and posterior branches either within the quadrangular space (65–66 %) or within the posterior deltoid (33–35 %) [39, 114]. The anterior branch gives off one branch to the joint capsule, one to the anterior portion of the deltoid, one to the middle portion of the deltoid, and one to the posterior third of the deltoid [39]. The posterior branch pierces the deep fascia and develops into different branches:

- One branch to the teres minor (the nearest branch to the glenoid rim) [115]
- The superior lateral brachial cutaneous nerve
- One branch to the posterior portion of the deltoid (78–90 %) [39, 116]
- One branch to the middle portion of the deltoid (38 %) [39]
- One branch to the posterior joint capsule [117]

Some anatomical studies have evaluated the axillary nerve position relative to specific anatomical landmarks:

- Wright et al. stated that it is 32.8 ± 6 mm from the most inferior arthroscopically detectable aspect of the subscapularis tendon [59].
- Lin et al. showed it to be about 45.5 mm from the tip of the greater tuberosity [118].
- Kamineni et al. measured the distance between the nerve and the lateral border of the acromion, both laterally (about 57 mm) and anteriorly (about 51 mm) [119].
- The inferior glenohumeral ligament is on average 2.5 mm from the axillary nerve [115]; moreover, the nerve is closer to the humeral than the glenoid insertion of the capsule and is probably closest in the neutral position and during internal rotation [120].
- The nearest aspect of the glenoid border to the nerve is from 4:30 to 7:00 o'clock [115, 120, 121].

Suprascapular Nerve

Suprascapular nerve is a mixed motor and sensory nerve which typically stems from the fifth and sixth cervical roots [122], even though a contribution from the fourth cervical root has been described [123]. The nerve enters the supraspinatus fossa passing through the suprascapular notch, under the superior transverse scapular ligament (STLS) (Fig. 1.10). This ligament has a variable relationship with the origin of the omohyoid muscle, which is adjacent medial to the ligament in 44 % of cases or partly located on the ligament in 18 % of cases [124]. The suprascapular notch is about 6 mm high and about 8 mm wide [124]. At least five subtypes have been described [125] and type I (U-shaped) is the most common (43.7 %) [126]. The STLS is about 9–11.5 mm long and about 3.5 mm thick [124, 127]. The ligament is missing in 1.5–9.5 % of cases and is substituted by a bony bridge in 3–12.5 % of cases [5, 124, 128, 129]. In 5.7 % of cases, it consists of two distinct parts [130]. Normally the nerve runs under the ligament while the suprascapular artery and vein run over the ligament. However, some anatomical variations

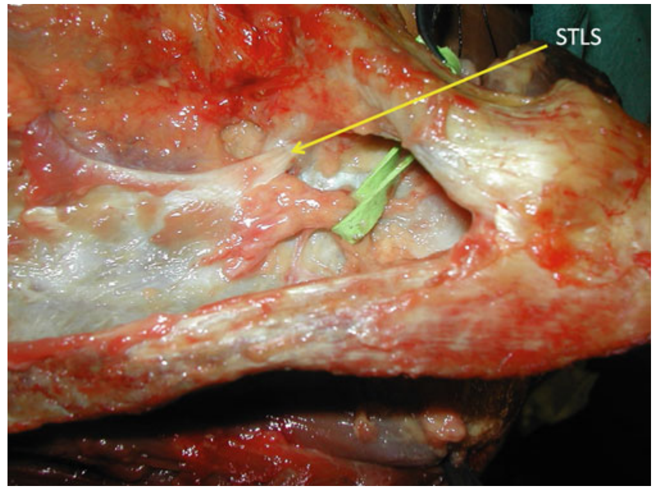

Fig. 1.10 The suprascapular nerve passes under the superior transverse scapular ligament (*STLS*)

are described: in type I (59.4 %) all suprascapular vessels run over the STSL; in type II (29.7 %) the vessels run over and under the STSL simultaneously; in type III (10.9 %) all vessels run under the STSL [124].

After passing through the suprascapular notch, the nerve gives off a motor branch to the infraspinatus muscles and sensory branches to the glenohumeral joint and to the coracoacromial and coracoclavicular ligaments. Then, it runs over the spinoglenoid ligament and enters the infraspinatus fossa. At the spinoglenoid notch, it is about 1.5 cm from the posterior border of the glenoid [33]. The nerve splits into various branches (from four to six) which pierce the infraspinatus muscle generally 2 cm from the articular surface [33] (Fig. 1.5). It does not usually supply the skin; however, some rare branches are described supplying the posterior aspect of the shoulder [131–134].

Musculocutaneous Nerve

It is one of the two terminal branches of the lateral cord of the brachial plexus. It pierces the coracobrachialis muscle as much as 1.5–9 cm from the tip of the coracoid [135–137]. It runs inferiorly supplying the biceps brachii and the brachialis muscle, whose nerves are about 14 cm from the musculocutaneous nerve [138]. We find it again at the elbow as the lateral cutaneous nerve of the forearm.

There are many possible anatomical variations: there can be communications between the musculocutaneous and the median nerve (10–53 %) [139–142]; the nerve can be missing (1.4–5 %) [142–145] or may not pierce the coracobrachialis muscle (7.5–11 %) [142, 143]. Many different ways to classify these anatomical variations have been proposed [143, 146, 147]. Recently, Guerri-Guttenberg and

Ingolotti published a new classification according to four items [142]:

- Presence/absence of the nerve
- Perforation or not of the coracobrachialis muscle
- Presence of communications/fusion or not
- Relationships between the communication and the point of entry of the nerve into the coracobrachialis muscle

Anterior Humeral Circumflex Artery

Anterior humeral circumflex artery originates from the third portion of the axillary artery and runs lateral and parallel to the inferior border of the subscapularis muscle, beneath the LHB, and partially supplies the infraspinatus and subscapularis muscles. It gives off an important branch to the humeral head: the anterolateral ascending artery, which runs along the lateral border of the bicipital groove and pierces the greater tuberosity. The terminal intraosseous portion is called "arcuate artery" because of its shape and gives off many branches supplying the humeral head [148, 149].

Brooks et al. [150] described three intraosseous anastomoses between the arcuate artery and:

- Three to four posteromedial vessels coming from the posterior humeral circumflex artery (These vessels can supply the humeral head despite a lesion of the anterior humeral circumflex artery)
- Metaphyseal vessels
- Vessels of the greater and lesser tuberosities

The authors showed that the arcuate artery alone can supply the whole humeral head. However, after a four-part fracture, blood is mainly supplied by posteromedial vessels [150]. This theory was later confirmed by Hertel [151].

Posterior Humeral Circumflex Artery

Posterior humeral circumflex artery is greater than anterior humeral circumflex artery. It runs lateral to the axillary nerve within the quadrangular space [33] and then splits into two branches:

- Anterior branch: it runs about 5 cm from the acromion and communicates with the acromial branch of the thoracoacromial artery and with the deltoid branch of the brachial artery; moreover, it gives off branches for the glenohumeral joint and for the skin above the middle third of the deltoid.
- Posterior branch: it provides a higher blood supply to the bone than the anterior branch (Fig. 1.11).

Some studies showed that the posterior humeral circumflex artery only supplied the posterior aspect of the greater tuberosity and a tiny posteroinferior portion of the humeral head [148, 149]. More recently, Duparc et al. showed that this is the main vessel supplying the subchondral bone of the humeral head and the greater tuberosity [152].

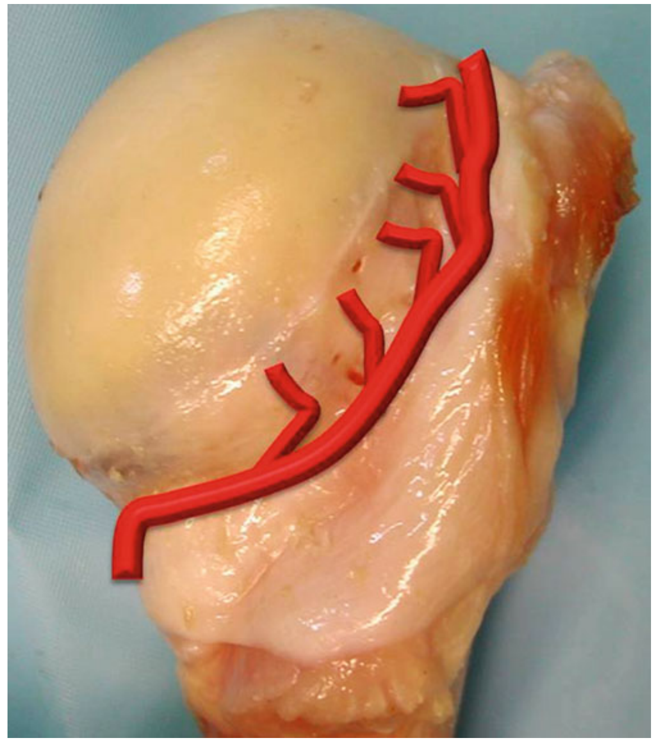

Fig. 1.11 The posterior humeral circumflex artery

References

1. DePalma A. Surgical anatomy of acromioclavicular and sternoclavicular joints. Surg Clin North Am. 1963;43:1541–50.
2. Nutter P. Coracoclavicular articulations. J Bone Joint Surg. 1941;23A:177–9.
3. Lewis O. The coraco-clavicular joint. J Anat. 1959;93:296–303.
4. Urist M. Complete dislocation of the acromioclavicular joint. J Bone Joint Surg. 1963;45A:1750–3.
5. Rengachary SS, Burr D, Lucas S, Hassanein KM, Mohn MP, Matzke H. Suprascapular entrapment neuropathy: a clinical, anatomical, and comparative study. Part 2: anatomical study. Neurosurgery. 1979;5:447–51.
6. Testut L. Traite d'anatomie humaine. Paris: Octave dion; 1904.
7. Hollinshead W. Anatomy for surgeons, vol. III. 3rd ed. Philadelphia: Harper & Row; 1982.
8. Bigliani LU, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC. The relationship of acromial architecture to rotator cuff disease. Clin Sports Med. 1991;10:823–38.
9. Bigliani L, Morrison D, April EW. The morphology of the acromion in its relationship to rotator cuff tears. Orthop Trans. 1986; 10:228.
10. Freese A. Anatomische untersuchungen zur ossaren morphologie und stellung des akromions und deren bedeutung fur die atiologie des Impingement-Syndroms. Aachen: Diss; 1998.
11. Edelson JG, Taitz C. Anatomy of the coraco-acromial arch. Relation to degeneration of the acromion. J Bone Joint Surg. 1992; 74B:589–94.

12. Petersson CJ, Redlund-Johnell I. The subacromial space in normal shoulder radiographs. Acta Orthop Scand. 1984;55:57–8.
13. Cruveilhier J. Traité d'anatomie descriptive. Paris: Asselin; 1833.
14. Lilienfeld A. Uber das Os acromiale und seine beziehungen zu den affektionen der schultergegend. Fortschr Rontgenstr. 1914; 21:198–205.
15. Symington J. Separate acromion process. J Anat Physiol. 1900; 34:287–94.
16. Pfitzner W. Beitrage zur kenntnis des menschlichen extremitaten-skelets. VIII: die morphologischen elemente des menschlichen handskelets. Morphol Anthropol. 1900;2:77–157.
17. Liberson F. Os acromiale – a contested anomaly. J Bone Joint Surg. 1937;19A:683–9.
18. Putz R, Liebermann J, Reichelt A. The function of the coracoacromial ligament. Acta Anat (Basel). 1988;131:140–5.
19. Jobe M. Gross anatomy of the shoulder. In: Rockwood CA, Matsen FA, editors. The shoulder. Philadelphia: Saunders; 1990.
20. Dolan CM, Hariri S, Hart ND, McAdams TR. An anatomic study of the coracoid process as it relates to bone transfer procedures. J Shoulder Elbow Surg. 2011;20:497–501.
21. Boileau P, Mercier N, Old J. Arthroscopic Bankart-Bristow-Latarjet (2B3) procedure: how to do it and tricks to make it easier and safe. Orthop Clin North Am. 2010;41:381–92.
22. Boileau P, Mercier N, Roussanne Y, Thélu CÉ, Old J. Arthroscopic Bankart-Bristow-Latarjet procedure: the development and early results of a safe and reproducible technique. Arthroscopy. 2010; 26:1434–50.
23. Lafosse L, Boyle S, Gutierrez-Aramberri M, Shah A, Meller R. Arthroscopic latarjet procedure. Orthop Clin North Am. 2010;41: 393–405.
24. Lafosse L, Boyle S. Arthroscopic Latarjet procedure. J Shoulder Elbow Surg. 2010;19:2–12.
25. Lafosse L, Lejeune E, Bouchard A, Kakuda C, Gobezie R, Kochhar T. The arthroscopic Latarjet procedure for the treatment of anterior shoulder instability. Arthroscopy. 2007;23:1242.
26. Haddad N, Khemiri C, Khorbi A, Ben Dali N, Filali Z, Kanoun ML, et al. Facteurs d'échec du traitement de l'instabilité antérieure de l'épaule par l'intervention de Latarjet. Tunis Orthop. 2008;1:150–5.
27. Hovelius L, Körner L, Lundberg B, Akermark C, Herberts P, Wredmark T, et al. The coracoid transfer for recurrent dislocation of the shoulder. Technical aspects of the Bristow-Latarjet procedure. J Bone Joint Surg. 1983;65A:926–34.
28. Vander Maren C, Geulette B, Lewalle J, Mullier J, Autrique JC, Thiery J, et al. Coracoid process abutment according to Latarjet versus the Bankart operation. A comparative study of the results in 50 cases. Acta Orthop Belg. 1993;59:147–55.
29. Hamel A, Hamel O, Ploteau S, Robert R, Rogez JM, Malinge M. The arterial supply of the coracoid process. Surg Radiol Anat. 2012;34:599–607.
30. Abrassart S, Stern R, Hoffmeyer P. Arterial supply of the glenoid: an anatomic study. J Shoulder Elbow Surg. 2006;15:232–8.
31. Abbott L, Lucas D. The tripartite deltoid and its surgical significance in exposure of the scapulohumeral joint. Ann Surg. 1952;136:392–403.
32. Perry J. Biomechanics of the shoulder. In: Rowe C, editor. The shoulder. New York: Churchill Livingstone; 1988.
33. Bailie DS, Moseley B, Lowe WR. Surgical anatomy of the posterior shoulder: effects of arm position and anterior-inferior capsular shift. J Shoulder Elbow Surg. 1999;8:307–13.
34. Brown JM, Wickham JB, McAndrew DJ, Huang XF. Muscles within muscles: coordination of 19 muscle segments within three shoulder muscles during isometric motor tasks. J Electromyogr Kinesiol. 2007;17:57–73.
35. Lorne E, Gagey O, Quillard J, Hue E, Gagey N. The fibrous frame of the deltoid muscle. Its functional and surgical relevance. Clin Orthop Relat Res. 2001;386:222–5.
36. Kumar VP, Satku K, Liu J, Shen Y. The anatomy of the anterior origin of the deltoid. J Bone Joint Surg. 1997;79B:680–3.
37. Leijnse JN, Han SH, Kwon YH. Morphology of deltoid origin and end tendons-a generic model. J Anat. 2008;213:733–42.
38. Sakoma Y, Sano H, Shinozaki N, Itoigawa Y, Yamamoto N, Ozaki T, et al. Anatomical and functional segments of the deltoid muscle. J Anat. 2011;218:185–90.
39. Loukas M, Grabska J, Tubbs RS, Apaydin N, Jordan R. Mapping the axillary nerve within the deltoid muscle. Surg Radiol Anat. 2009;31:43–7.
40. Salmon M, Dor J. Les artères des muscles des membres et du tronc. Paris: Masson et Cie; 1933.
41. Vahlensieck M, Pollack M, Lang P, Grampp S, Genant HK. Two segments of the supraspinous muscle: cause of high signal intensity at MR imaging? Radiology. 1993;186:449–54.
42. Roh MS, Wang VM, April EW, Pollock RG, Bigliani LU, Flatow EL. Anterior and posterior musculotendinous anatomy of the supraspinatus. J Shoulder Elbow Surg. 2000;9:436–40.
43. Kim SY, Boynton EL, Ravichandiran K, Fung LY, Bleakney R, Agur AM. Three-dimensional study of the musculotendinous architecture of supraspinatus and its functional correlations. Clin Anat. 2007;20:648–55.
44. McLaughlin HL. Lesions of the musculotendinous cuff of the shoulder: III. Observations on the pathology, course and treatment of calcific deposits. Ann Surg. 1946;124:354–62.
45. Holibka R, Holibková A, Laichman S, Růzicková K. Some peculiarities of the rotator cuff muscles. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub. 2003;147:233–7.
46. Curtis AS, Burbank KM, Tierney JJ, Scheller AD, Curran AR. The insertional footprint of the rotator cuff: an anatomic study. Arthroscopy. 2006;22:603–9.
47. Minagawa H, Itoi E, Konno N, Kido T, Sano A, Urayama M, et al. Humeral attachment of the supraspinatus and infraspinatus tendons: an anatomic study. Arthroscopy. 1998;14:302–6.
48. Burkhart SS, Esch JC, Jolson RS. The rotator crescent and rotator cable: an anatomic description of the shoulder's "suspension bridge". Arthroscopy. 1993;9:611–6.
49. Clark J, Sidles JA, Matsen FA. The relationship of the glenohumeral joint capsule to the rotator cuff. Clin Orthop Relat Res. 1990;254:29–34.
50. Ruotolo C, Fow JE, Nottage WM. The supraspinatus footprint: an anatomic study of the supraspinatus insertion. Arthroscopy. 2004;20:246–9.
51. Ellman H. Diagnosis and treatment of incomplete rotator cuff tears. Clin Orthop Relat Res. 1990;254:64–74.
52. Clark JM, Harryman DT. Tendons, ligaments, and capsule of the rotator cuff. Gross and microscopic anatomy. J Bone Joint Surg. 1992;74A:713–25.
53. Colachis SC, Strohm BR, Brechner VL. Effects of axillary nerve block on muscle force in the upper extremity. Arch Phys Med Rehabil. 1969;50:647–54.
54. Shaffer BS, Conway J, Jobe FW, Kvitne RS, Tibone JE. Infraspinatus muscle-splitting incision in posterior shoulder surgery. An anatomic and electromyographic study. Am J Sports Med. 1994;22:113–20.
55. Codman E. The shoulder. Boston: Thomas Todd; 1934.
56. Waterston D. Variations in the teres minor muscle. Anat Anz. 1908;32:331–3.
57. Hinton MA, Parker AW, Drez Jr D, Altcheck D. An anatomic study of the subscapularis tendon and myotendinous junction. J Shoulder Elbow Surg. 1994;3:224–9.
58. Pearsall AW, Holovacs TF, Speer KP. The intra-articular component of the subscapularis tendon: anatomic and histological correlation in reference to surgical release in patients with frozen-shoulder syndrome. Arthroscopy. 2000;16:236–42.
59. Wright JM, Heavrin B, Hawkins RJ, Noonan T. Arthroscopic visualization of the subscapularis tendon. Arthroscopy. 2001;17:677–84.

60. Macalister A. Additional observation on muscular anomalies in human anatomy. Trans R Ir Acad Sci. 1875;25:1–130.
61. Kameda Y. An anomalous muscle (accessory subscapularis-teres-latissimus muscle) in the axilla penetrating the brachial plexus in man. Acta Anat (Basel). 1976;96:513–33.
62. Breisch EA. A rare human variation: the relationship of the axillary and inferior subscapular nerves to an accessory subscapularis muscle. Anat Rec. 1986;216:440–2.
63. Yoshinaga K, Kawai K, Tanii I, Imaizumi K, Kodama K. Nerve fiber analysis on the so-called accessory subscapularis muscle and its morphological significance. Anat Sci Int. 2008;83:55–9.
64. Staniek M, Brenner E. Variations in the anatomy of the anterior-inferior rotator cuff: the "infraglenoid muscle". Ann Anat. 2012;194:373–80.
65. Vangsness CT, Jorgenson SS, Watson T, Johnson DL. The origin of the long head of the biceps from the scapula and glenoid labrum. An anatomical study of 100 shoulders. J Bone Joint Surg. 1994;76B:951–4.
66. Paul S, Sehgal R, Khatri K. Anatomical variations in the labral attachment of the long head of biceps brachii. J Anat Soc India. 2004;53:49–51.
67. Johnson LL, Bays BM, Eda van Dyk G. Vincula of the biceps tendon in the glenohumeral joint: an arthroscopic and anatomic study. J Shoulder Elbow Surg. 1992;1:162–6.
68. Nakata W, Katou S, Fujita A, Nakata M, Lefor AT, Sugimoto H. Biceps pulley: normal anatomy and associated lesions at MR arthrography. Radiographics. 2011;31:791–810.
69. Johnson LL. Arthroscopic surgical anatomy. In: Johnson LL, editor. Diagnostic and surgical arthroscopy of the shoulder. St Louis: Mosby; 1993.
70. Snyder S. Shoulder arthroscopy. New York: McGraw Hill; 1994.
71. Turkel SJ, Panio MW, Marshall JL, Girgis FG. Stabilizing mechanisms preventing anterior dislocation of the glenohumeral joint. J Bone Joint Surg. 1981;63A:1208–17.
72. Arai R, Mochizuki T, Yamaguchi K, Sugaya H, Kobayashi M, Nakamura T, et al. Functional anatomy of the superior glenohumeral and coracohumeral ligaments and the subscapularis tendon in view of stabilization of the long head of the biceps tendon. J Shoulder Elbow Surg. 2010;19:58–64.
73. Cheng NM, Pan WR, Vally F, Le Roux CM, Richardson MD. The arterial supply of the long head of biceps tendon: anatomical study with implications for tendon rupture. Clin Anat. 2010;23:683–92.
74. Ellis V. The diagnosis of shoulder lesions due to injuries of the rotator cuff. J Bone Joint Surg. 1953;35B:72–4.
75. Strizak AM, Danzig L, Jackson DW, Resnick D, Staple T. Subacromial bursography. An anatomical and clinical study. J Bone Joint Surg. 1982;64A:196–201.
76. Saha A. Theory of the shoulder mechanism: descriptive and applied. Springfield: Charles C Thomas; 1961.
77. Prescher A, Klümpen T. Does the area of the glenoid cavity of the scapula show sexual dimorphism? J Anat. 1995;186:223–6.
78. Prescher A, Klümpen T. The glenoid notch and its relation to the shape of the glenoid cavity of the scapula. J Anat. 1997;190:457–60.
79. Soslowsky LJ, Flatow EL, Bigliani LU, Mow VC. Articular geometry of the glenohumeral joint. Clin Orthop Relat Res. 1992;285:181–90.
80. Warner JJ, Bowen MK, Deng XH, Hannafin JA, Arnoczky SP, Warren RF. Articular contact patterns of the normal glenohumeral joint. J Shoulder Elbow Surg. 1998;7:381–8.
81. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. J Bone Joint Surg. 1992;74A:491–500.
82. Saha AK. Dynamic stability of the glenohumeral joint. Acta Orthop Scand. 1971;42:491–505.
83. Saha AK. The classic. Mechanism of shoulder movements and a plea for the recognition of "zero position" of glenohumeral joint. Clin Orthop Relat Res. 1983;173:3–10.
84. De Maeseneer M, Van Roy F, Lenchik L, Shahabpour M, Jacobson J, Ryu KN, et al. CT and MR arthrography of the normal and pathologic anterosuperior labrum and labral-bicipital complex. Radiographics. 2000;20 Spec No:S67–81
85. Moseley H, Overgaard B. The anterior capsular mechanism in recurrent anterior dislocation of the shoulder. JBone Joint Surg. 1962;44A:913–27.
86. Detrisac D, Johnson L. Arthroscopic shoulder anatomy: pathological and surgical implications. New Jersey: Slack; 1986.
87. Cooper DE, Arnoczky SP, O'Brien SJ, Warren RF, DiCarlo E, Allen AA. Anatomy, histology, and vascularity of the glenoid labrum. An anatomical study. J Bone Joint Surg. 1992; 74A:46–52.
88. Williams MM, Snyder SJ, Buford Jr D. The Buford complex – the "cord-like" middle glenohumeral ligament and absent anterosuperior labrum complex: a normal anatomic capsulolabral variant. Arthroscopy. 1994;10:241–7.
89. Hertel R, Knothe U, Ballmer FT. Geometry of the proximal humerus and implications for prosthetic design. J Shoulder Elbow Surg. 2002;11:331–8.
90. Di Giacomo G, Di Giacomo S, Silvestrini MG, Costantini A. L'artroscopia di spalla. Roma: Verduci; 2003.
91. DePalma A, Callery G, Bennet G. Variational anatomy and degenerative lesions of the shoulder joint. Am Acad Orthop Surg Instr Course Lect. 1949;6:255–80.
92. Ide J, Tokiyoshi A, Hirose J, Mizuta H. An anatomic study of the subscapularis insertion to the humerus: the subscapularis footprint. Arthroscopy. 2008;24:749–53.
93. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg. 1997;79B:857–65.
94. Habermeyer P. Zur funktionellen anatomie und biomechanik der langen bizepssehene. Unfallchirurg. 1991;90:319–29.
95. O'Brien S, Arnoczky S, Warren R, et al. Chapter 1. Developmental anatomy of the shoulder and anatomy of the glenohumeral joint. In: Rockwood CA, Matsen FA, editors. The shoulder, vol. I. 1st ed. Philadelphia: Saunders; 1990. p. 1–32.
96. Kummel BM. Spectrum of lesions of the anterior capsular mechanism of the shoulder. Am J Sports Med. 1979;7:111–20.
97. Kaltsas DS. Comparative study of the properties of the shoulder joint capsule with those of other joint capsules. Clin Orthop Relat Res. 1983;173:20–6.
98. Cone RO, Danzig L, Resnick D, Goldman AB. The bicipital groove: radiographic, anatomic, and pathologic study. AJR Am J Roentgenol. 1983;141:781–8.
99. Williams P, Warwick R. Gray's anatomy. 36th ed. Philadeplhia: WB Saunders; 1980.
100. Yang HF, Tang KL, Chen W, Dong SW, Jin T, Gong JC, et al. An anatomic and histologic study of the coracohumeral ligament. J Shoulder Elbow Surg. 2009;18:305–10.
101. Harryman 2nd DT, Sidles JA, Harris SL, Matsen 3rd FA. The role of the rotator interval capsule in passive motion and stability of the shoulder. J Bone Joint Surg. 1992;74A:53–66.
102. Gohlke F, Essigkrug B, Schmitz F. The pattern of the collagen fiber bundles of the capsule of the glenohumeral joint. J Shoulder Elbow Surg. 1994;3:111–28.
103. Ferrari DA. Capsular ligaments of the shoulder. Anatomical and functional study of the anterior superior capsule. Am J Sports Med. 1990;18:20–4.
104. Gambill ML, Mologne TS, Provencher MT. Dislocation of the long head of the biceps tendon with intact subscapularis and supraspinatus tendons. J Shoulder Elbow Surg. 2006;15:20–2.

105. Slätis P, Aalto K. Medial dislocation of the tendon of the long head of the biceps brachii. Acta Orthop Scand. 1979;50:73–7.
106. Ide J, Maeda S, Takagi K. Normal variations of the glenohumeral ligament complex: an anatomic study for arthroscopic Bankart repair. Arthroscopy. 2004;20:164–8.
107. DePalma A. Surgery of the shoulder. 3rd ed. Philadelphia: Lippincott; 1973.
108. O'Brien SJ, Neves MC, Arnoczky SP, Rozbruck SR, Dicarlo EF, Warren RF, et al. The anatomy and histology of the inferior glenohumeral ligament complex of the shoulder. Am J Sports Med. 1990;18:449–56.
109. Warner JJ, Deng XH, Warren RF, Torzilli PA. Static capsuloligamentous restraints to superior-inferior translation of the glenohumeral joint. Am J Sports Med. 1992;20:675–85.
110. Morgan C, Rames R, Snyder S. Arthroscopic assessment of anatomic variations of the glenohumeral ligaments associated with recurrent shoulder instability. Orthop Trans. 1992;16:727–8.
111. Steinbeck J, Liljenqvist U, Jerosch J. The anatomy of the glenohumeral ligamentous complex and its contribution to anterior shoulder stability. J Shoulder Elbow Surg. 1998;7:122–6.
112. Jost B, Koch PP, Gerber C. Anatomy and functional aspects of the rotator interval. J Shoulder Elbow Surg. 2000;9:336–41.
113. Cahill BR, Palmer RE. Quadrilateral space syndrome. J Hand Surg Am. 1983;8:65–9.
114. Tubbs RS, Tyler-Kabara EC, Aikens AC, Martin JP, Weed LL, Salter EG, et al. Surgical anatomy of the axillary nerve within the quadrangular space. J Neurosurg. 2005;102:912–4.
115. Price MR, Tillett ED, Acland RD, Nettleton GS. Determining the relationship of the axillary nerve to the shoulder joint capsule from an arthroscopic perspective. J Bone Joint Surg. 2004;86A:2135–42.
116. Ball CM, Steger T, Galatz LM, Yamaguchi K. The posterior branch of the axillary nerve: an anatomic study. J Bone Joint Surg. 2003;85A:1497–501.
117. Gardner E. The innervation of the shoulder joint. Anat Rec. 1948;102:1–18.
118. Lin J, Hou SM, Inoue N, Chao EY, Hang YS. Anatomic considerations of locked humeral nailing. Clin Orthop Relat Res. 1999;368:247–54.
119. Kamineni S, Ankem H, Sanghavi S. Anatomical considerations for percutaneous proximal humeral fracture fixation. Injury. 2004;35:1133–6.
120. Jerosch J, Filler TJ, Peuker ET. Which joint position puts the axillary nerve at lowest risk when performing arthroscopic capsular release in patients with adhesive capsulitis of the shoulder? Knee Surg Sports Traumatol Arthrosc. 2002;10:126–9.
121. Eakin CL, Dvirnak P, Miller CM, Hawkins RJ. The relationship of the axillary nerve to arthroscopically placed capsulolabral sutures. An anatomic study. Am J Sports Med. 1998;26:505–9.
122. Cummins CA, Messer TM, Nuber GW. Suprascapular nerve entrapment. J Bone Joint Surg. 2000;82A:415–24.
123. Lee HY, Chung IH, Sir WS, Kang HS, Lee HS, Ko JS, et al. Variations of the ventral rami of the brachial plexus. J Korean Med Sci. 1992;7:19–24.
124. Yang HJ, Gil YC, Jin JD, Ahn SV, Lee HY. Topographical anatomy of the suprascapular nerve and vessels at the suprascapular notch. Clin Anat. 2012;25:359–65.
125. Hrdlicka A. The scapula: visual observations. Am J Phys Anthropol. 1942;29:73–94.
126. Edelson JG. Bony bridges and other variations of the suprascapular notch. J Bone Joint Surg. 1995;77B:505–6.
127. Duparc F, Coquerel D, Ozeel J, Noyon M, Gerometta A, Michot C. Anatomical basis of the suprascapular nerve entrapment, and clinical relevance of the supraspinatus fascia. Surg Radiol Anat. 2010;32:277–84.
128. Natsis K, Totlis T, Tsikaras P, Appell HJ, Skandalakis P, Koebke J. Proposal for classification of the suprascapular notch: a study on 423 dried scapulas. Clin Anat. 2007;20:135–9.
129. Wang HJ, Chen C, Wu LP, Pan CQ, Zhang WJ, Li YK. Variable morphology of the suprascapular notch: an investigation and quantitative measurements in Chinese population. Clin Anat. 2011;24:47–55.
130. Grundlagen M. Moglichkeiten und grenzen der sonographie osteofibroser kanale im schulterbereich teil 1. Ann Anat. 1997;179:355–73.
131. Ajmani ML. The cutaneous branch of the human suprascapular nerve. J Anat. 1994;185:439–42.
132. Harbaugh KS, Swenson R, Saunders RL. Shoulder numbness in a patient with suprascapular nerve entrapment syndrome: cutaneous branch of the suprascapular nerve: case report. Neurosurgery. 2000;47:1452–5.
133. Vastamäki M, Göransson H. Suprascapular nerve entrapment. Clin Orthop Relat Res. 1993;297:135–43.
134. Ludig T, Walter F, Chapuis D, Molé D, Roland J, Blum A. MR imaging evaluation of suprascapular nerve entrapment. Eur Radiol. 2001;11:2161–9.
135. Flatow EL, Bigliani LU, April EW. An anatomic study of the musculocutaneous nerve and its relationship to the coracoid process. Clin Orthop Relat Res. 1989;244:166–71.
136. Linell EA. The distribution of nerves in the upper limb, with reference to variabilities and their clinical significance. J Anat. 1921;55:79–112.
137. Bach BR, O'Brien SJ, Warren RF, Leighton M. An unusual neurological complication of the Bristow procedure. A case report. J Bone Joint Surg. 1988;70A:458–60.
138. Macchi V, Tiengo C, Porzionato A, Parenti A, Stecco C, Bassetto F, et al. Musculocutaneous nerve: histotopographic study and clinical implications. Clin Anat. 2007;20:400–6.
139. Uysal II, Karabulut AK, Büyükmumcu M, UnverDogan N, Salbacak A. The course and variations of the branches of the musculocutaneous nerve in human fetuses. Clin Anat. 2009;22:337–45.
140. Krishnamurthy A, Nayak SR, Venkatraya Prabhu L, Hegde RP, Surendran S, Kumar M, et al. The branching pattern and communications of the musculocutaneous nerve. J Hand Surg Eur Vol. 2007;32:560–2.
141. Prasada Rao PV, Chaudhary SC. Communication of the musculocutaneous nerve with the median nerve. East Afr Med J. 2000;77:498–503.
142. Guerri-Guttenberg RA, Ingolotti M. Classifying musculocutaneous nerve variations. Clin Anat. 2009;22:671–83.
143. Choi D, Rodríguez-Niedenführ M, Vázquez T, Parkin I, Sañudo JR. Patterns of connections between the musculocutaneous and median nerves in the axilla and arm. Clin Anat. 2002;15:11–7.
144. Buch-Hansen K. Variations of the median nerve and the musculocutaneous nerve and their connections. Anat Anz. 1955;102:187–203.
145. Prasada Rao PV, Chaudhary SC. Absence of musculocutaneous nerve: two case reports. Clin Anat. 2001;14:31–5.
146. Loukas M, Aqueelah H. Musculocutaneous and median nerve connections within, proximal and distal to the coracobrachialis muscle. Folia Morphol. 2005;64:101–8.
147. Venieratos D, Anagnostopoulou S. Classification of communications between the musculocutaneous and median nerves. Clin Anat. 1998;11:327–31.
148. Laing PG. The arterial supply of the adult humerus. J Bone Joint Surg. 1956;38A:1105–16.
149. Gerber C, Schneeberger AG, Vinh TS. The arterial vascularization of the humeral head. An anatomical study. J Bone Joint Surg. 1990;72A:1486–94.
150. Brooks CH, Revell WJ, Heatley FW. Vascularity of the humeral head after proximal humeral fractures. An anatomical cadaver study. J Bone Joint Surg. 1993;75B:132–6.
151. Hertel R. Fractures of the proximal humerus in osteoporotic bone. Osteoporos Int. 2005;16:65–72.
152. Duparc F, Muller JM, Fréger P. Arterial blood supply of the proximal humeral epiphysis. Surg Radiol Anat. 2001;23:185–90.