Normal Shoulder MRI and MR Arthrography: Anatomy and Technique

Eva Llopis, MD[1] Pau Montesinos, MD[1] M. Teresa Guedez, MD[2] Luis Aguilella, PhD[1] Luis Cerezal, MD[3]

[1] Department of Radiology, Hospital de la Ribera, Valencia, Spain
[2] Centro Diagnostico Scanner, Malaga, Spain
[3] DMC, Diagnostico Medico Cantabria, Santander, Spain

Address for correspondence Eva Llopis, MD, Department of Radiology, Hospital de la Ribera, Carretera de Corbera km1, Alcira, Valencia 46600, Spain (e-mail: evallopis@gmail.com).

Semin Musculoskelet Radiol 2015;19:212–230.

Abstract

The use of MR for the diagnosis of shoulder lesions is well established, as well as MR arthrography for the diagnosis for shoulder instability and microinstability. For an accurate evaluation is essential to know the normal anatomy and variants to avoid the misdiagnosis of a pitfall as pathological condition. In addition we will discuss which variants might be clinically relevant. We will review the classical frequent variants such as intraarticular structures, especially glenohumeral ligaments and labrum but also bone, cartilage and rotator cuff variants and pitfalls. Both static and dynamic structures play an important role providing stability at different positions and with different range of motion.

Keywords
- shoulder
- anatomy
- MR arthrography
- CT arthrography
- abduction and external rotation

The combination of a bony discrepancy between the glenoid and the humeral head allowing a large range of motion makes the shoulder joint susceptible to instability and dislocation.[1] Shoulder biomechanics are based on the interaction of static and dynamic stabilizing systems. The glenoid, humeral head, glenoid labrum, and capsule including the glenohumeral ligaments are static structures; the rotator cuff and the other muscular structures surrounding the shoulder joint are the dynamic stabilizing structures.[2,3] For educational purposes we have divided them into bone, labrum, ligaments, and muscles, which we describe in the course of this article after a short introduction on technique.

Technique

MRI

Although this article is mainly based on MRI, we should not forget the relevance of radiographs for the evaluation of bone and joint structures (►**Fig. 1**). Normally we start an MRI study after radiographs have been evaluated. MR images should be obtained with a dedicated shoulder coil; the patient is placed in a supine position in a neutral or slightly external rotation. Axial images should cover the area from the top of the acromioclavicular (AC) joint to below the glenohumeral inferior capsular insertion. Oblique coronal images are oriented on the axial images and should follow the longitudinal plane of the scapula.[4] Oblique sagittal plane is perpendicular to the coronal one and ranges from the deltoid muscle to the neck of the scapula. A sagittal T1-weighted fast spin-echo sequence is recommended to evaluate fat infiltration of the rotator muscles and bone marrow and to rule out hemorrhage. A combination of different pulse sequences should be used including fluid-sensitive sequences with long TR and moderate to long TE (proton density or T2) preferably with fat saturation (►**Figs. 2–4**).[3]

Shoulder Arthrography

Shoulder arthrography indications are the evaluation of the labrum, glenohumeral ligaments, long head of the biceps (LHB) including rotator cuff interval, some partial articular rotator cuff tears, and in some exceptional cases to outline the extent of a rotator cuff tear.

Injection

Shoulder arthrography starts with the injection of contrast material into the joint. Depending on the hospital environment, the injection can be done under fluoroscopic, computed tomography, or ultrasound (US) guidance. Both anterior and posterior approaches are used. For the anterior approach the patient is placed in a supine position with the shoulder in

Issue Theme The Shoulder: Back to Basics; Guest Editors, Andrew Grainger, MRCP, FRCR and Philip Robinson, MB ChB (Honours), MRCP, FRCR

DOI http://dx.doi.org/10.1055/s-0035-1549316.
ISSN 1089-7860.

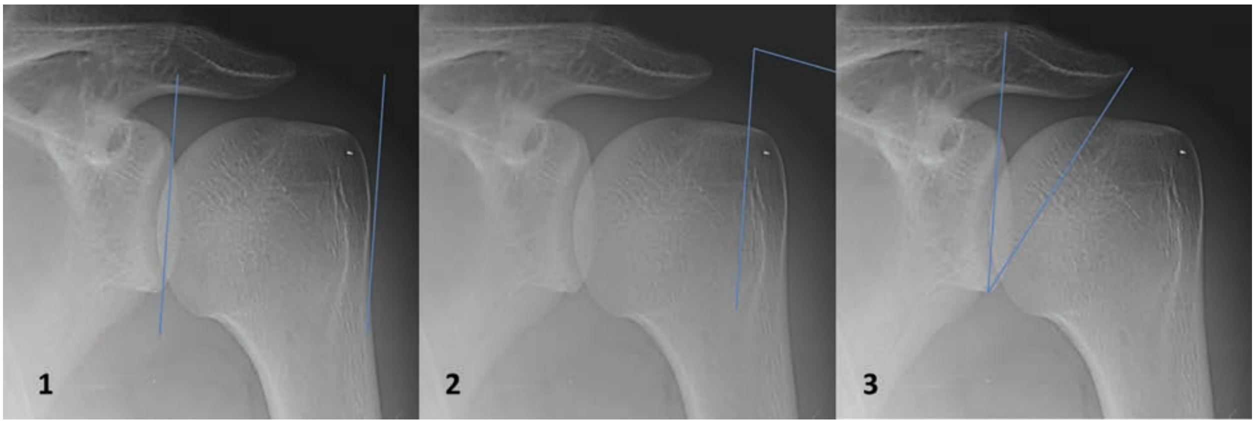


Fig. 1 Radiograph measurements.[17] 1. The acromion index is the ratio between the distance from the glenoid plane to the acromion and the distance from the glenoid plane to the lateral aspect of the humeral head. This should be > 0.68. 2. The lateral acromion angle is the angle between a line drawn parallel to the sclerotic line of the acromion undersurface and a line between the superior and inferior glenoid fossa. This should be < 83 degrees. 3. The critical shoulder angle (CSA) is the angle between the first line connecting the inferolateral point of the acromion and a second line connecting the inferior border of the glenoid to the most inferolateral point of the acromion. This should be > 35 degrees. CSA reflects the lateral extension of the acromion and the glenoid inclination with only one radiologic parameter and has been found to be the most powerful predictor for rotator cuff disease.

a slightly external rotation. External rotation allows the anterior border of the glenoid to be medial to the humeral head, thereby decreasing the risk of penetrating the anterior labrum. The humeral head cartilage becomes exposed. Normally the needle is aimed at the inferior medial quadrant.[4–7] Once the humeral head has been reached, a slightly oblique medially angled direction is recommended to make the injection easier (►**Fig. 4**).

Some authors recommend a posterior approach to avoid traversing the anterior stabilizer structures such as the anterior labrum, inferior glenohumeral ligament (IGHL), or subscapularis.[8] The patient is placed in a prone position with the shoulder in slightly internal rotation. Alternatively, blind injections using anatomical bone landmarks have also been described.[9]

We use a 20- to 22-gauge 9-cm stylet spinal needle. Fluoroscopic guidance has the advantage that proper location of the needle can be checked by a small test injection allowing easy readjustment if contrast fails to flow from the needle indicating an extra-articular location. With proper intra-articular positioning, the contrast agent flows easily between the glenoid and humeral head into the axillary recess, biceps sheath, and subscapular recess. During intra-articular shoulder injection, there should always be low resistance (►**Fig. 4**).

The type of contrast agent mixture depends on whether computed tomography arthrography (CTA), magnetic resonance arthrography (MRA), or combined CTA-MRA will subsequently be performed. In our department we perform combined CTA-MRA. The mixture is made with 10 mL dilution of gadolinium (Gd)-chelate 0.5 to 2 mmol diluted in sterile saline, 7 mL nonionic iodine agent (340 mg/mL), and local anesthetic, 2 mL 2% lidocaine.[10] Epinephrine is only added if delay is envisaged. Decreased signal intensity of T1-weighted images has been reported if the concentration of iodine is > 25%, but in our experience up to 30 to 40% iodine solution allows high-resolution MRA and CTA images after only one intra-articular injection. The injection volume ranges from 10 to 15 mL. Occasionally the volume may go up to 20 mL, but an injection > 15 mL carries an increased risk of extra-articular leakage that may be mistaken for rotator cuff tear and postprocedure pain.

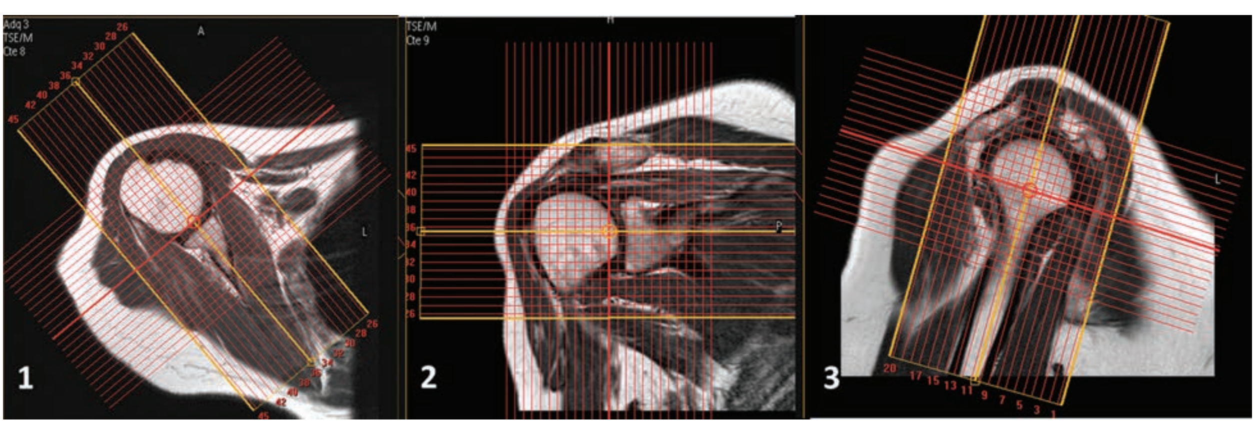
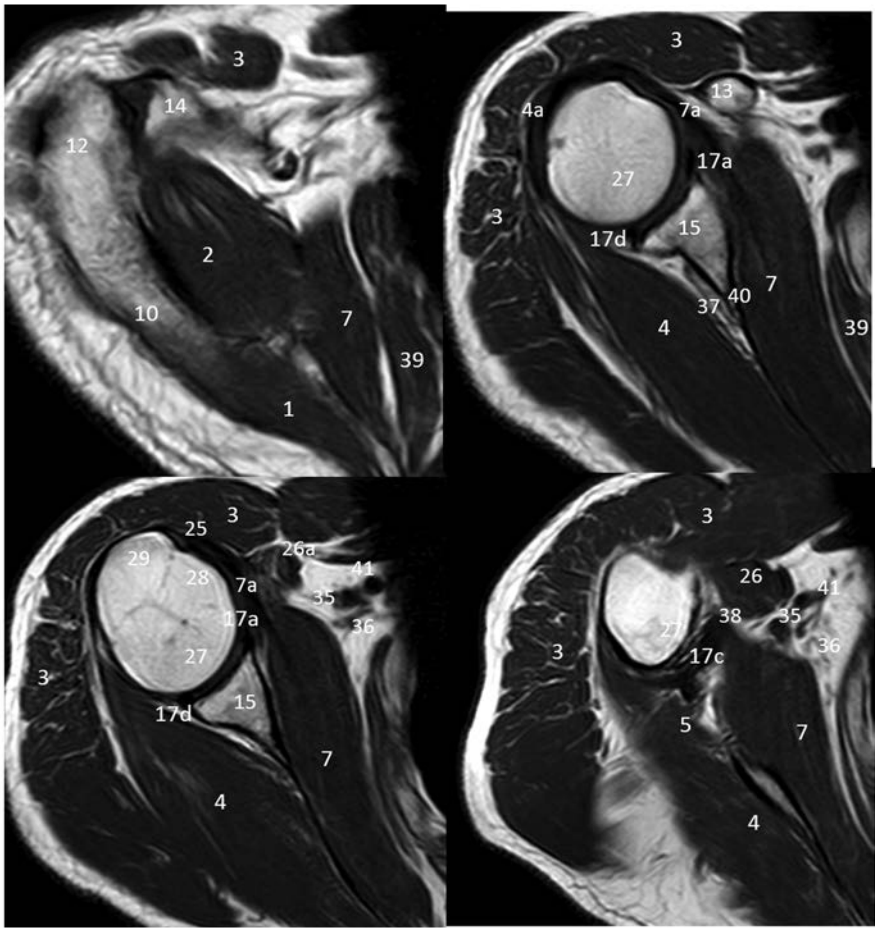
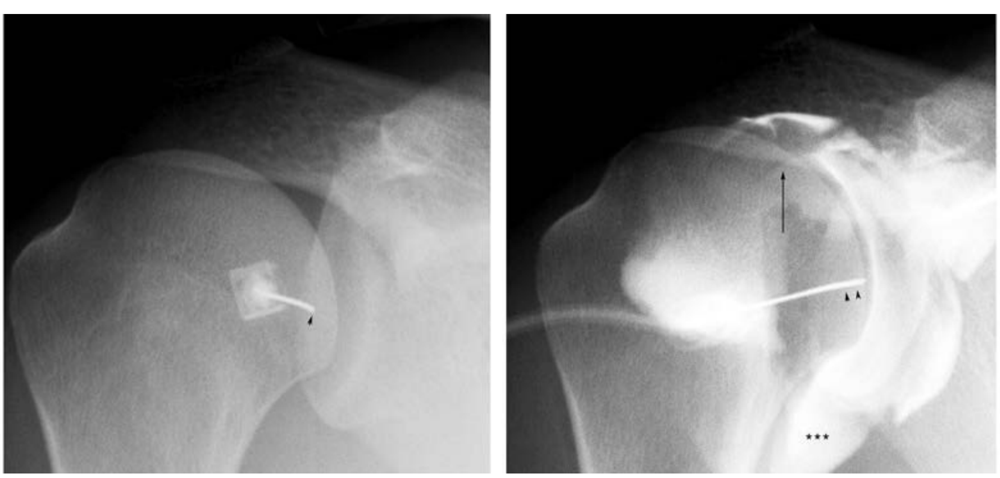


Fig. 2 MR planes showing how to plane an adequate shoulder MR.



a

Fig. 3 MRI anatomy. (**a**) Axial. (**b**) Coronal. (**c**) Sagittal. 1. Trapezius muscle. 2. Supraspinatus muscle; 2a. supraspinatus tendon. 3. Deltoid muscle. 4. Infraspinatus muscle; 4a. infraspinatus tendon., 5. Teres minor muscle; 5a. teres minor tendon. 6. Teres major muscle. 7. Subscapularis muscle; 7a. subscapularis tendon. 8. Suprascapular fossa. 9. Infrascapular fossa. 10. Spine of scapula. 11. Body of the scapula. 12. Acromion. 13. Coracoid process. 14. Clavicle. 15. Glenoid. 16. Glenoid tuberosity. 17a. Anterior labrum; 17b. superior labrum; 17c. inferior labrum; 17d. posterior labrum. 18. Coracohumeral ligament. 19. Coracoclavicular ligament. 20. Triceps long portion. 21. Coracobrachial. 22. Pectoralis minor tendon. 23. Pectoralis major. 24. Coracoacromial ligament. 25. Long head of biceps tendon. 26. Biceps brachii muscle; 26a. short head of the biceps tendon. 27. Humeral head. 28. Lesser tubercle. 29. Greater tubercle. 30. Surgical neck. 31.Humeral shaft. 32. Bicipital groove. 33. Posterior circumflex humeral artery and axillary nerve. 34. Circumflex scapular artery. 35. Axillary artery. 36. Brachial plexus. 37. Suprascapular artery and nerve. 38. Inferior glenohumeral ligament/capsule. 39. Serrato. 40. Scapular notch. 41. Axillary vein.



a b

Fig. 4 (**a**) Anterior shoulder arthrography approach; needle is oblique oriented (arrowheads). (**b**) Contrast dilution extends onto the axillary recess (asterisks) and the biceps tendon (arrow).

MRA should be performed when necessary but undertaken with thin needles and by an experienced radiologist. Contraindications for MRA are infection of the skin, soft tissue, or joint next to the needle path, and reflex sympathetic dystrophy because this might be reactivated after joint injection. MRA is controversial when an anticoagulant is taken or if there is a risk of developing an allergic reaction. There is no clear proof of MRA initiating allergic reactions, and if these occur they are mainly related to the local anesthetic or the iodine solution rather than the Gd-chelate solution. However, caution should be observed if a history of allergic reaction to contrast agent is reported.[5]

Complications are similar to other joint injections. Severe but very rare is infection. Its risk is increased in elderly patients and in patients with diabetes mellitus, rheumatoid arthritis, or skin infection. Antibiotic prophylaxis is not necessary, but patients should be informed about the possibility and signs of infection. They should be instructed how to respond when symptoms do occur to allow timely treatment and thereby avoid serious problems.

The most frequent issue is pain during the injection; to decrease it, injection of a local anesthetic during the injection is recommended. Some intra-articular pain probably related to chemical synovitis is a self-limited process and treated with painkillers.

MRA Positioning

The shoulder is placed in a neutral position or in slightly external rotation (►**Fig. 5**). MR protocols vary but always includeT1-weighted fat saturation high-resolution images in axial, oblique coronal, and oblique sagittal planes perpendicular and parallel to the glenoid fossa. T2-weighted fat saturation images are essential to rule out extra-articular injuries and T1-weighted images are used to evaluate for fatty atrophy. An option is to position the patient in abduction and external rotation (ABER) following normal shoulder MRA using a flexible coil. The total additional time is 5 minutes. In a study performed by Saleem et al, 95% of the patients were able to do this.[11] After a coronal localizer, images are taken following the long axis of the humerus.

The ABER position is described for the evaluation of the rotator cuff. The insertion of the supraspinatus is relaxed, and therefore the intra-articular fluid enters more easily, improving the delineation of the extent of the lesion (►**Fig. 6**). A normal variant consisting of a small fold at the level of the scapular spine should not be mistaken for a tear. At the same time it increases the tension on the anteroinferior capsulolabral complex and therefore is optimal for the evaluation of the IGHL and inferior capsule. It also improves visualization of some Bankart lesions, especially the periosteal attachment of the labrum, because it separates the base of the labrum from the periosteum, helping to diagnose Perthes lesions (►**Fig. 7**). ABER has been reported to improve the visualization of the biceps-labral complex and helps rule out superior labrum anterior and posterior (SLAP) injuries. However, in our experience, due to the orientation of the bicipital-labral junction, it is not well depicted and is better seen with extreme external rotation. ABER might be useful in postsurgical patients where it is difficult to diagnose re-tears.

In our experience, adding coronal and axial sequences with the patient in forced external rotation is the best way to visualize the bicipital-labral complex (►**Fig. 8**). Forced external rotation facilitates the differentiation of normal variants from SLAP and increases the confidence of radiologic diagnosis for SLAP, rotator interval, and subtle lesions of the subscapularis tendon. In our series in 19% of the cases external rotation

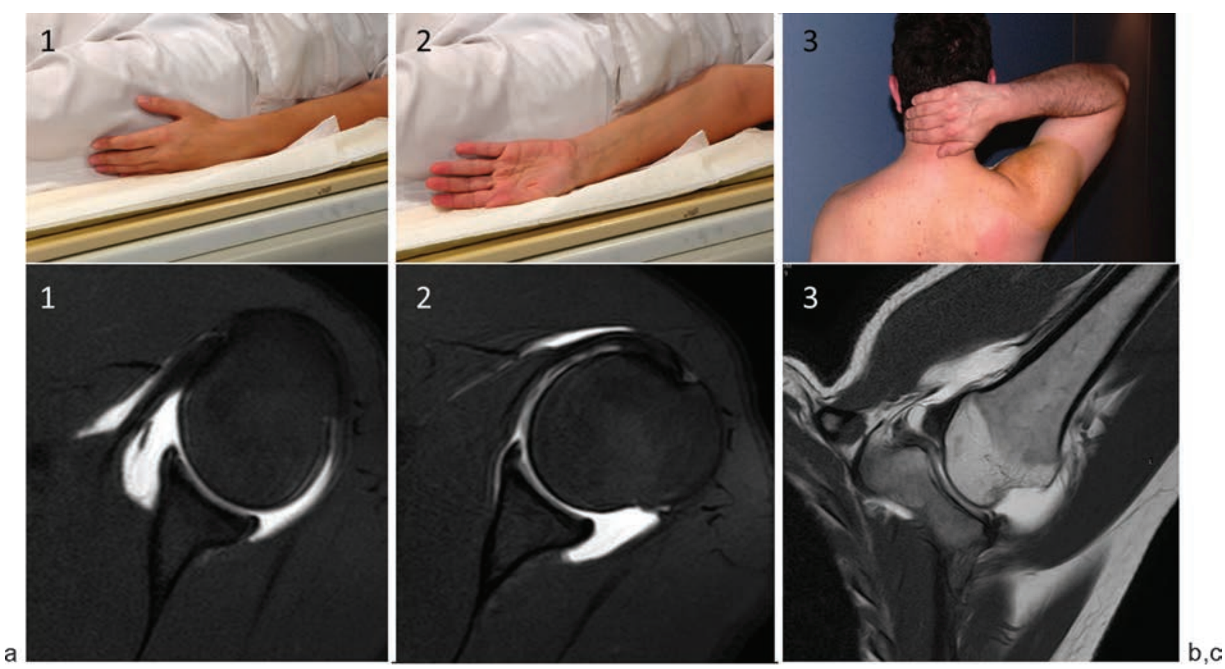


Fig. 5 Different positions on MRI. (**a**) Neutral-internal rotation position. (**b**) Forced external rotation. (**c**) ABER. 1–3. Corresponding MR images.

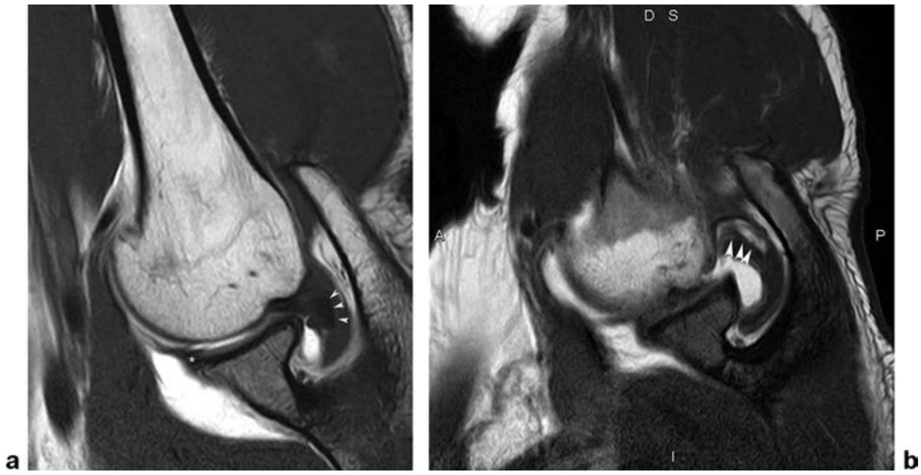


Fig. 6 Different patients MRA in ABER position. (**a**) Normal supraspinatus insertion, inferior glenohumeral ligament (asterisk). (**b**) Partial supraspinatus tear. The contrast nicely delineates the tear extension (arrowhead).

Fig. 7 ABER position improves the visualization of anterior labral detachment with a sleeve periosteum, Perthes lesion (arrow).

allowed diagnosis of SLAP lesions not seen on conventional internal rotation.[12] Forced external rotation can be slightly painful, but it is more comfortable than the ABER position and results in fewer motion artifacts (►**Fig. 9**).

Anatomy of Static Stabilizers (Osseous and Joint Anatomy)

The Clavicle

The clavicle is a short tubular S-shaped bone that articulates medially with the sternoclavicular joint and laterally with the AC joint. It varies in appearance from flat to curved, and its morphology changes with activity.[12–14] The lateral half of the shaft has irregular osseous ridges for the insertion of the deltoid and trapezoid muscles (►**Figs. 3** and **10**).[15]

The Scapula

The scapula is a large triangular bone divided into three parts: body, spine, and neck. It has three structures to articulate

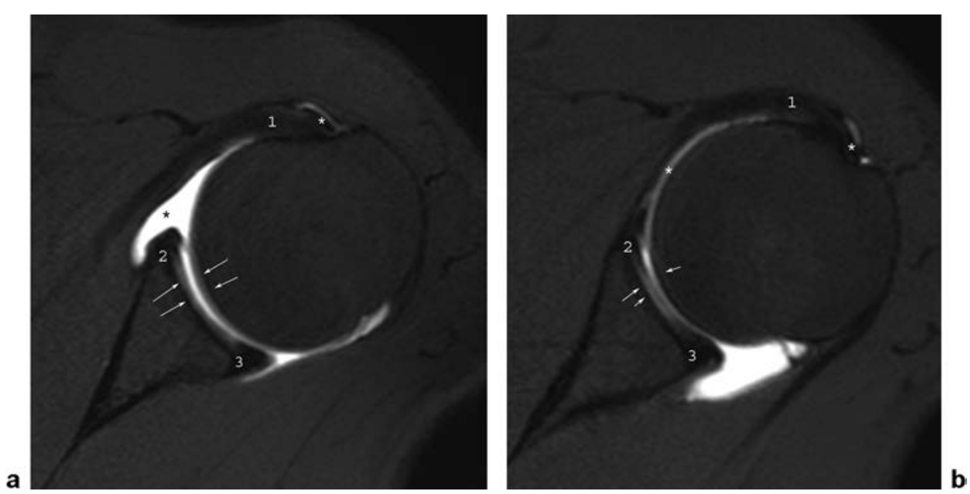


Fig. 8 MRA in (**a**) neutral position and (**b**) forced external rotation shows normal glenoid and humeral cartilage (arrow). 1. Subscapularis. 2. Anterior labrum. 3. Posterior labrum, biceps (asterisk), anterior recess (asterisk).

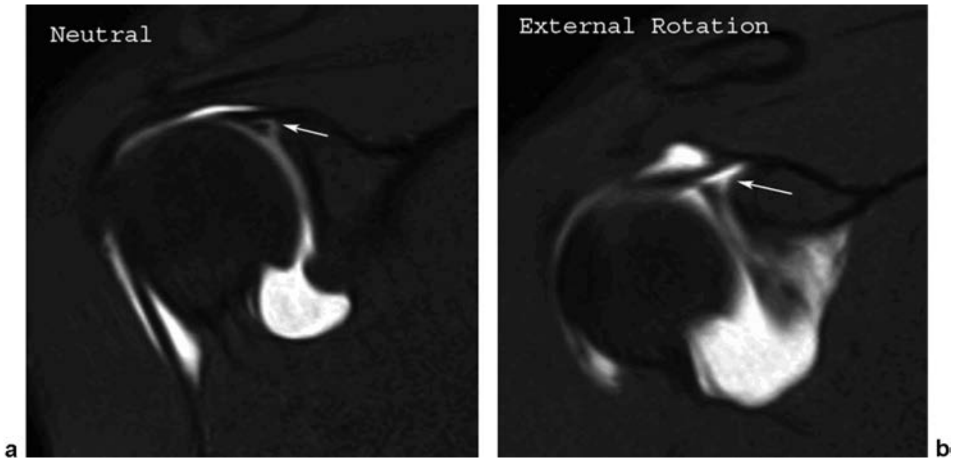


Fig. 9 (**a**) MRA in neutral position. (**b**) Small SLAP lesion. External rotation improves its visualization and determines the extension into the biceps tendon (arrow).

with the humeral head and the clavicle: the acromion, the coracoid process, and the glenoid fossa (►**Fig. 11**).

Acromion

The acromion is a posterolateral extension of the scapular spine that articulates with the clavicle. The acromion is formed by several ossification centers that are completely fused at age 25 years. The absence of fusion occurs in 7 to 15% of individuals and is known as os acromiale (►**Figs. 10** and **12**). It should not be mistaken for a fracture.[15]

The impact of acromion morphology on the pathogenesis of rotator cuff lesions is controversial. Distinct anatomical variants of the acromion that have been associated with degenerative rotator cuff tears are bone spurs on the undersurface of the acromion, different orientations of the acromion, and various shoulder angles. Bigliani classified acromion morphology on radiographs into three types: type I (flat), type II (curved), and type III (hooked). Type III is thought to be an acquired form and not congenital. The relationship between the glenohumeral and AC joints seems to be a more valuable tool. If the acromion index is > 0.68, the lateral acromion angle is < 83 degrees, and especially if the critical shoulder angle is > 35 degrees, there is an increased chance of developing rotator cuff lesions. Its value is limited when extensive rotator cuff disease is present because the superior and medial migration of the humeral might change the accuracy of these parameters (►**Fig. 1**).[16]

Coracoid Process

The coracoid process is an anterior process arising from the anterolateral aspect of the scapula. Its morphology varies. It is the origin of the short head of the biceps and the minor pectoral muscle. The coracoid orientation may have an impact on the subcoracoid space and lead to subcoracoid impingement with tendinosis of the subscapularis.[13]

Glenoid Fossa

The glenoid fossa is the articular surface of the scapula for the glenohumeral joint. The glenoid rim normally develops from two ossification centers. The upper ossification center appears between ages 9 and 15 years, and the lower ossification center appears between ages 12 and 16 years. It has a supraglenoid tubercle that is the origin of the LHB and a infraglenoid tubercle that is the origin of the long head of the triceps.[2]

The glenoid has a distinct pear-shaped morphology and measures ~ 6 to 8 cm^2 (►**Fig. 11**). The anterior glenoid can be concave, flat, or convex. Only the inferior peripheral rim of

Fig. 10 Volume-rendering multidetector computed tomography superior view shows the oblique course of the clavicle. Bilateral os acromiale (arrow) is seen. C, clavicle; Co, coracoid process; S, scapula.

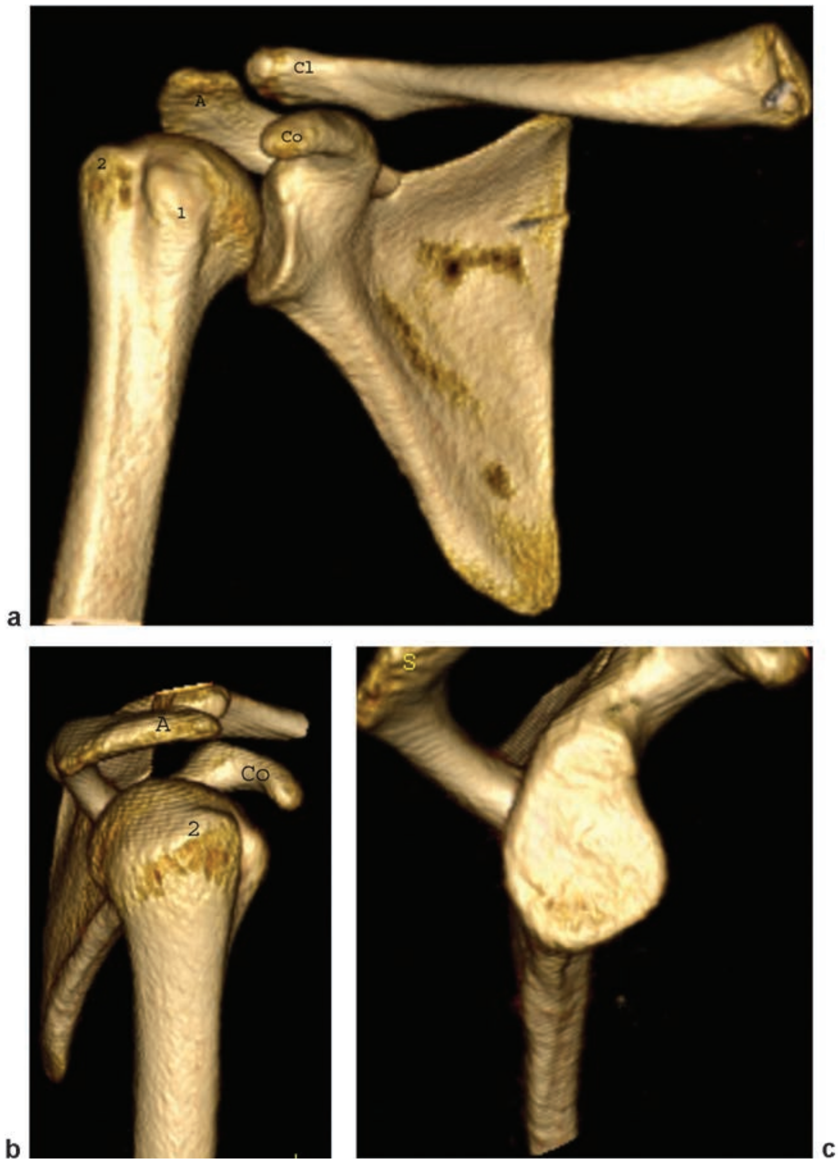


Fig. 11 Volume rendering of the scapula (S) and shoulder joint. (**a**) Anteroposterior view. 1. Lesser trochanter. 2. Greater trochanter. (**b**) Lateral view. (**c**) Glenoid with its characteristic pear shape. CL, clavicle; CO, coracoid process.

the inferior quadrants of the articular surface makes a circle. The glenoid cavity is usually located in retroversion with an average of 7 degrees.[17] To maintain normal shoulder stability, it is essential for it to have this pear-shaped morphology. Anterior bone loss is not infrequent secondary to anterior shoulder dislocation and leads to an inverted pear-shaped appearance. A 30% loss of the inferior glenoid increases the contact area by 41% and increases the contact pressure.[17] Assessment of the morphology of the glenoid rim is essential because bone loss is associated with the failure of surgery.

The posterior rim of the glenoid also has some variants: triangular, delta, or J-shaped (►**Fig. 13**). The last two reflect bone deformity and associated hypertrophied (posterior) labrum or cartilage (►**Fig. 14**). They have been associated with posterior instability and posterior labral tears. They should be differentiated from glenoid dysplasia (►**Fig. 15**) that combines deficiency of the posterior rim with a full spectrum of other signs of hypoplasia in the scapular neck, hyperplasia of the coracoid and acromion, and hypoplasia of the humeral head. Depending on the degree, this can also be associated with multidirectional instability. Three types have been described: mild, moderate, and severe.[18–21] Moderate and mild dysplasia overlap with the variants of posterior bone and are more frequent than previously thought, ranging from 14 to 35%. Glenoid dysplasia is usually detected in late adolescence during the peak of sports activity or between 50 and 60 years of age when degenerative changes begin. The most predictive factor for instability is the size of the defect; the cutoff value reported has been a craniocaudal deficiency length $\geq$ 12 mm, although the clinical relevance of this measurement is not clear.[19]

The hyaline cartilaginous articular surface of the glenoid is thinner in the center and gets thicker on the periphery; the average thickness is 1.8 mm (►**Fig. 8**).[22,23] The glenoid contact area changes with motion. When the arm is raised, the glenoid contact area shifts from the inferomedial to the

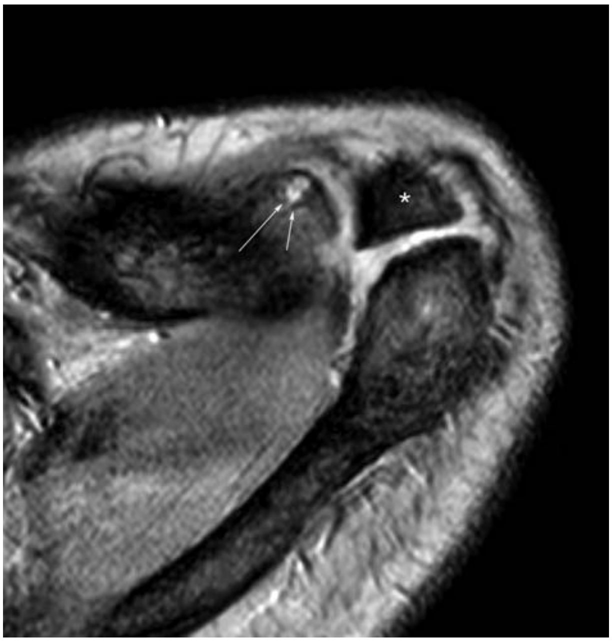


Fig. 12 Os acromiale axial (asterisk) with degenerative changes (arrow).

superolateral portion of the posterior articular surface of the humeral head; this contact zone is called the glenoid track. A maximum of 30% of the articular cartilage of the humeral head articulates with the articular surface of the glenoid at any given time, due to the mismatch between the humeral head and the glenoid. There is a bare area of cartilage covering a thickening of subchondral bone located in the center (but not exactly in the mathematical center) of a circle created between the anterior, posterior, and inferior lower glenoid cavity, the so-called bare spot or tubercle of Assaki (►**Fig. 16**). The lower prevalence in the pediatric population supports the hypothesis that it could be an acquired finding, probably related to increased contact. It should not be confused with a cartilage defect. It has been used as a method for arthroscopic assessment of bone deficiency, but the variability of its location and the high incidence of deficiency of the glenoid notch (45%) means it is not feasible to use to judge bone glenoid deficiency[2,24] (►**Figs. 14** and **15**).

Humerus

The articular surface of the humeral head is normally retroverted by 30 degrees. Morphology of the superior and posterior humeral head is essential to maintain shoulder stability (►**Fig. 11**). The size and morphology of Hill-Sachs fractures are associated with an increased risk of postoperative recurrence of dislocation.[25,26]

The humeral head is covered by cartilage and thinner at the periphery and thicker in the center.[27] Humeral head cartilage is thin, with an average thickness of 1.24 mm.[22,23] There is a posteriorly bare area of the humeral head between the posterior insertion of the joint capsule and synovial membrane and the adjacent articular cartilage. This should not be confused with a Hill-Sachs impaction injury. There is another acquired bare area between the supraspinatus insertion in the greater tuberosity and the adjacent articular cartilage. This might lead to overestimation of a partial articular surface supraspinatus tear, but this bare area is increased in undersurface supraspinatus tears and cartilage lesions (►**Fig. 17**).[7]

The space between the lesser tuberosity and the coracoid process is called the coracohumeral interval. It varies with internal and external rotation, and it is smaller in women. It normally measures between 10 and 11.5 mm. The diagnosis of subcoracoid impingement syndrome is based on clinical symptoms and not on the coracohumeral interval measurement alone.[28]

Acromioclavicular Joint

The AC joint is a synovial joint between the lateral surface of the clavicle and the medial surface of the acromion. Stabilization depends on static structures (ligaments) and dynamic structures (muscles). There is a small fibrocartilage disk between the two bones. The superior and inferior AC ligaments in particular reinforce the AC capsule. The deltoid muscle attaches anteriorly to the lateral border of the clavicle and acromion, the trapezium attaches to the superior and posterior aspect, and the two together provide dynamic stabilization.

The main stabilizer of the AC joint is the coracoclavicular ligament that consists of two parts: the conoid and the trapezoid ligaments that form a V-shaped structure. They

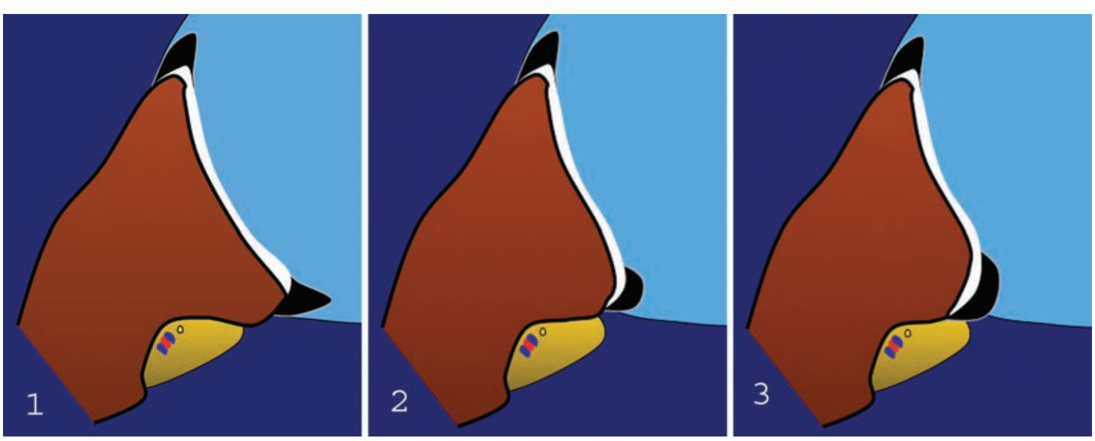


Fig. 13 Schema of the posterior glenoid rim variants. 1. Normal triangular. 2. Rounded or J shape. 3. Delta shape.

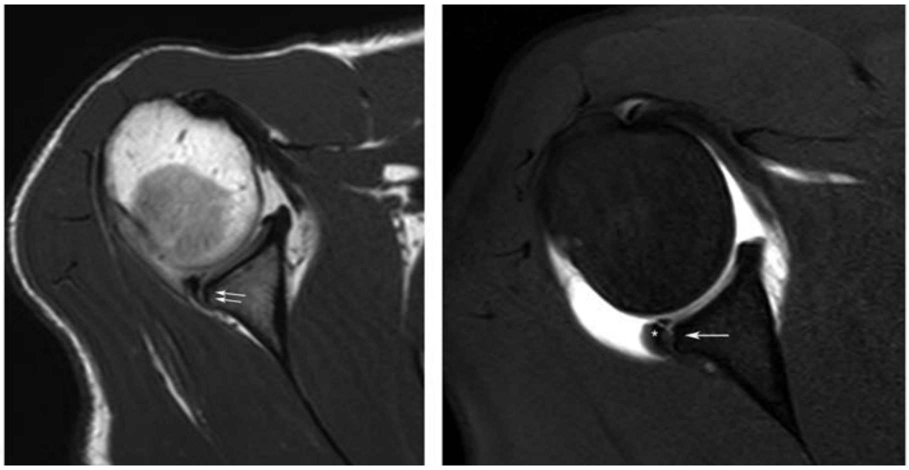


Fig. 14 (**a**) Rounded posterior glenoid rim with posterior labrum hypertrophy (arrows). (**b**) Delta-shaped posterior glenoid rim (arrow) and posterior labrum tear (asterisk).

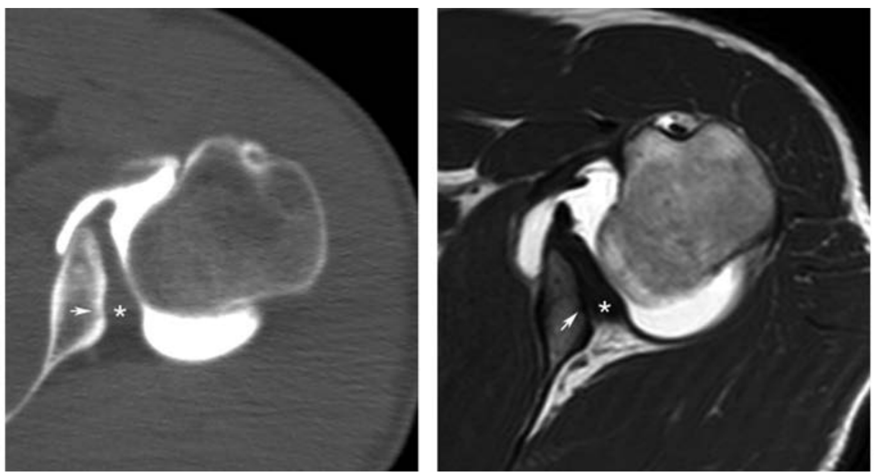


Fig. 15 Glenoid dysplasia, severe posterior glenoid deficiency (arrow) is shown in the (**a**) CTA and (**b**) MRA with marked hypertrophied labrum (asterisk).

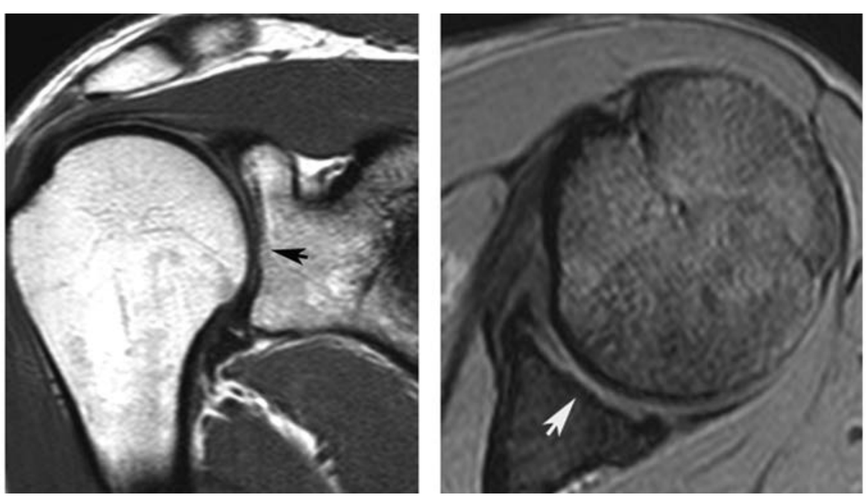


Fig. 16 Tubercle of Assaki (arrow). Centrally located bare area of cartilage in the glenoid fossa. (**a**) CTA and (**b**) MRA.

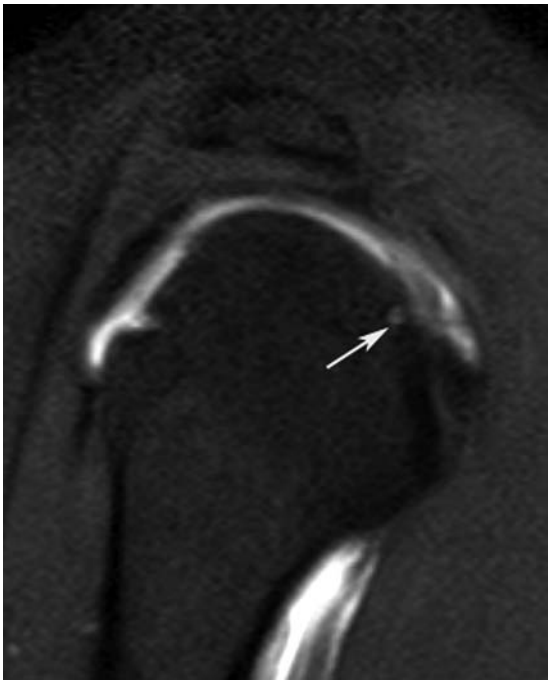


Fig. 17 Sagittal MR showing a bare area of cartilage in the posterior humeral head with small fibrocystic changes.

attach to the undersurface of the clavicle from the junction of the middle and outer thirds of the clavicle to the lateral side. The conoid ligament is located medially and prevents superior and anterior displacement and rotation, and the trapezoid is located laterally and prevents posterior displacement and limits rotation (►**Figs. 3** and **18**).

Fig. 18 Sagittal T1-weighted image shows coracoclavicular ligament. A, acromion; C, coracoid process; Cl, clavicle. Arrow shows conoid of coracoclavicular ligament.

The coracoacromial ligament is a triangular ligament attached by its broad base to the lateral horizontal portion of the coracoid process and inserts on the tip of the acromion in front of the AC joint[29] (►**Fig. 18**).

Labrum

The glenoid labrum adds depth to the glenoid cavity by 50%, thus acting as a passive stabilizer to the glenohumeral joint. It also serves as a primary attachment site for the glenohumeral ligaments, joint capsule, and LHB tendon. The fibrocartilaginous labrum is firmly attached to the posterior and inferior glenoid. Anteriorly the glenoid labrum blends with the anterior band of the IGHL; superiorly it blends with the biceps tendon and the superior glenohumeral ligament (SGHL).[30] There are two types of chondrolabral attachment: an abrupt transition (type A) and a transitional zone (type B) that is shown on MR by a linear band of increased signal intensity between the labrum and the hyaline cartilage (►**Fig. 19**). Its size is variable, but the average width is 4 mm and thickness is 3 mm.

The labrum is usually triangular shaped, especially the anterior part, but other morphologies have been described that are rounded (more frequent), flat, cleaved, notched, or absent. On MR it has overall low signal intensity on all pulse sequences, but minor signal intensity changes are frequently depicted in the normal labrum.

MRA is the preferred method to evaluate the labrum. Although 3T improves the signal-to-noise ratio and spatial resolution, MRA still offers additional value and therefore is still the modality of choice.[31]

Long Head of the Biceps Tendon

The LHB tendon may originate from four structures: the supraglenoid tuberosity, the labrum (anterosuperior and posterosuperior), and the coracoid process. The tendon has an oblique intra-articular course, traverses the rotator interval, and must take a 30- to 45-degree turn along the anterior surface of the humerus before it exits the joint between the lesser and greater tuberosities into the bicipital groove[30,32–35] (►**Figs. 3**, **20**, **21**, and **22**).

The region of attachment of the LHB tendon to the superior labrum is called the bicipital-labral complex or biceps anchor. Three different types of attachment of the biceps tendon on the supraglenoid tubercle have been described. In type I the biceps is firmly attached to the glenoid rim with no free edge. In type II the attachment of the biceps to the glenoid is more medial with a small sulcus between the labral-free edge and cartilage with synovial lining. Type III has a deep recess, and as a consequence the superior labrum projects into the joint (►**Fig. 23**). This large synovial recess in the undersurface of the bicipital-labral junction is called the sublabral recess or sublabral sulcus, and it is located between the 11 and 1 o'clock position. Types II and III are frequent (up to 39%) anatomical variants. These must be differentiated from SLAP type II injuries.[13,27]

The sublabral foramen is a focal detachment of the anterosuperior quadrant of the labrum between 1 and 3 o'clock, present in ~ 10% of normal people. Sublabral foramen should

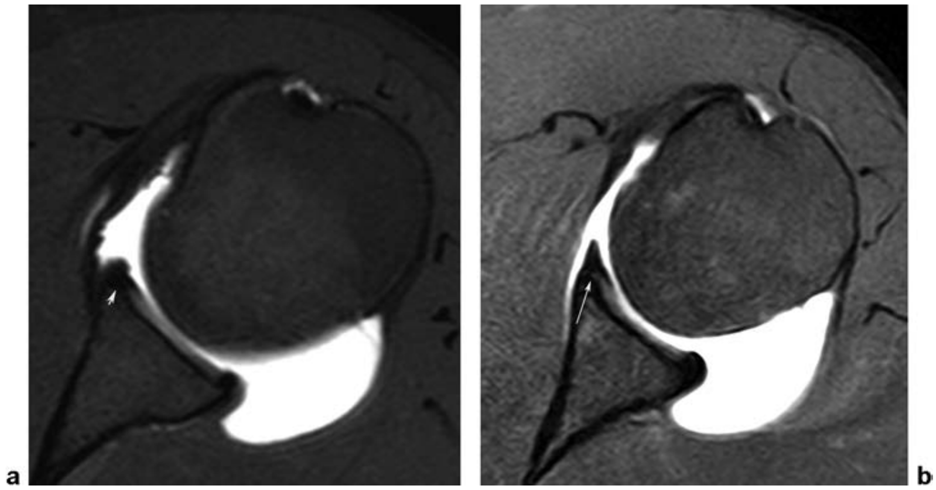


Fig. 19 Axial MRA different patients of chondrolabral junction. (**a**) Abrupt transition (arrow) (type A) and a transitional zone (arrow) (type B) that is shown on MR by a linear band of increased signal intensity between the labrum and the hyaline cartilage.

not be confused with anterior or superior labral tears. Location is the key for the diagnosis. It should not be displaced by more than 1 to 2 mm and has smooth borders. The sublabral foramen represents a normal pathway between the glenohumeral joint and the subscapularis recess. Studies have demonstrated that the presence of these superior labral variants increases the stress on the biceps tendon and therefore increases the risk of developing SLAP-type lesions (►**Fig. 24**).

Variations of the LHB tendon are common and range from complete absence of the intra-articular portion of the tendon, which is very rare, to the presence of one or more supernumerary heads.[36]

An aponeurotic extension of the superficial supraspinatus tendon can be seen anteriorly and laterally to the biceps tendon in half of the shoulders. It is a tendon-like structure extending vertically along the anterior aspect of the LHB at

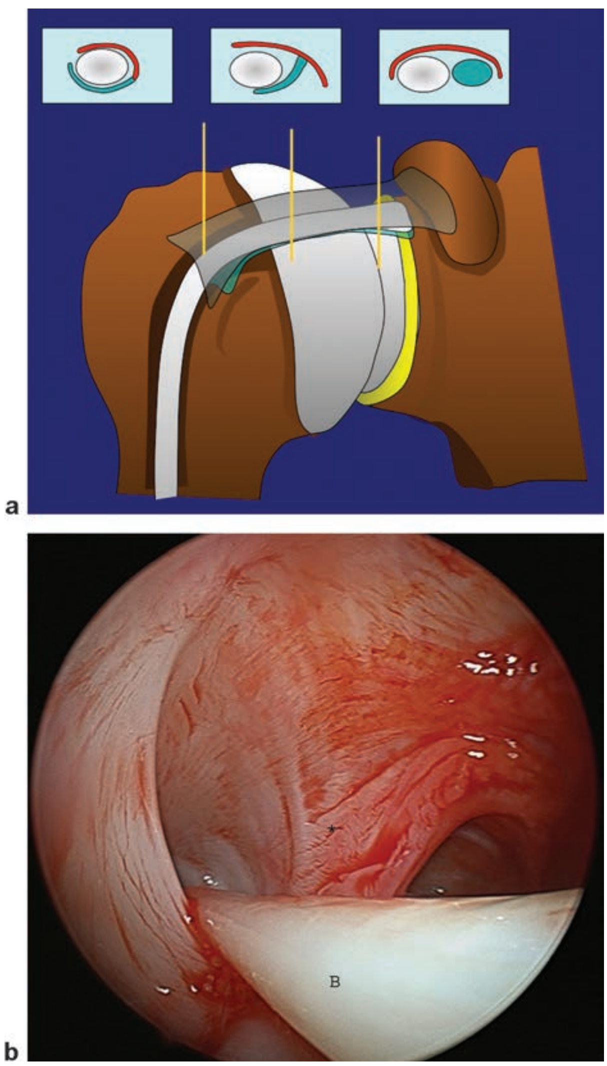


Fig. 20 (**a**) Schema of the biceps and biceps pulley system. Biceps tendon (white), coracohumeral ligament (red), superior glenohumeral ligament (red). (**b**) Arthroscopic view. B, biceps tendon; coracohumeral ligament (asterisk).

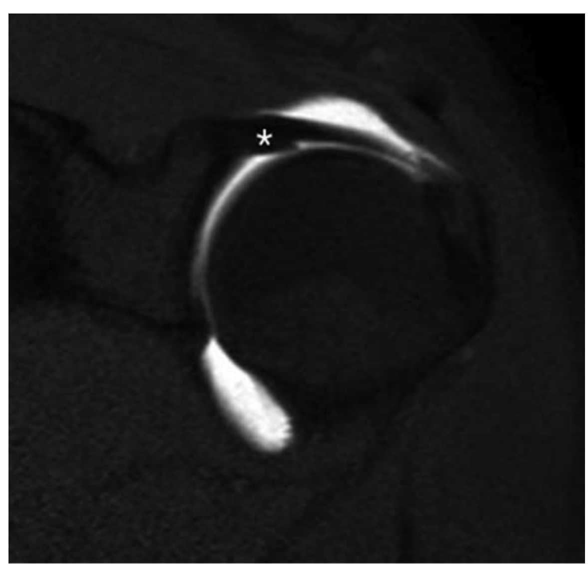


Fig. 21 Coronal MRA shows the entrance of the long head of the biceps tendon into the joint and the biceps-labral anchor (asterisk).

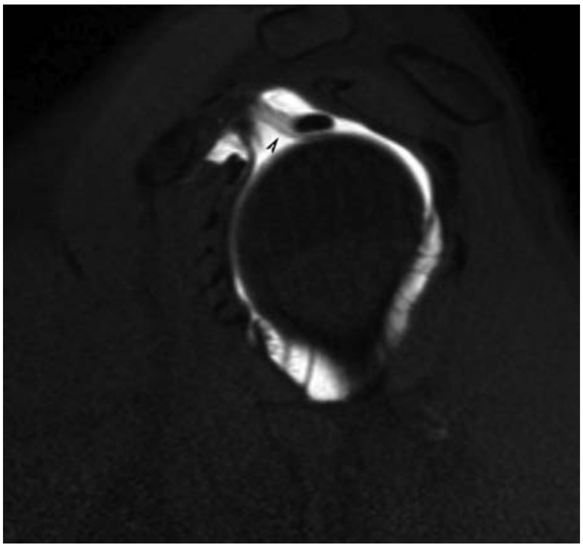


Fig. 22 Sagittal MRA T1 fat saturation image nicely shows the pulley system and its relation with the biceps tendon (arrowhead).

the level of the bicipital groove, and its distal insertion is attached to the pectoralis major tendon. It was thought to be an accessory slip of the biceps tendon, but its structure is different.[37]

Capsule and Ligaments

The glenohumeral joint capsule is composed of three layers: synovial lining on the articular surface, a subsynovial layer with loosely packed collagen, and a relatively thicker bursal surface layer consisting of dense collagen. Bands within the capsule, consisting of collagenous thickening, form the glenohumeral ligaments (►**Fig. 25**). These and the coracohumeral ligament reinforce the thin capsular tissue. They represent static stabilizers of the shoulder.[33] They are best visualized using CTA or MRA.[34] The capsular insertion to the glenoid defines three types of capsular attachments from medial to lateral. Instability has been related with more medial attachment (►**Figs. 26** and **27**).

Fig. 23 Coronal MRA T1 fat-saturated image show a sublabral type II recess variant in the biceps anchor (arrow).

The Superior Glenohumeral Ligament

The SGHL is absent in only 3% of cases. It is variable in origin: supraglenoid tubercle, superior labrum, LHB tendon, middle glenohumeral ligament, or some combination. It extends in a plane nearly perpendicular to the middle glenohumeral ligament and parallel to the coracoid process, close to the biceps tendon. It inserts into a small depression above the lesser tuberosity known as the fovea capitis of the humerus, where it blends with the medial band of the coracohumeral ligament (CHL) within the rotator interval and forms a sling around the LHB[30,34,38] (►**Fig. 28**).

The Middle Glenohumeral Ligament

The middle glenohumeral ligament (MGHL) is the most variable glenohumeral ligament in both size and constancy. It may be attenuated or absent in up to 20 to 30% of shoulders.[35] The absence of the MGHL is often associated with a prominent anterior capsular recess (►**Fig. 29**). The insertion of the MGHL is more often seen at the level of the superior anterior labrum rather than at the level of the scapula, as was suggested arthroscopically. On axial MR images it is seen as a hypointense structure separated from the anterior superior labrum by a small cleft. It runs oblique and posterior to the superior margin of the subscapularis muscle and blends with the anterior capsule. Distally it is attached to the anterior aspect of the proximal humerus, below the insertion of the SGHL.[39]

The Buford complex is a well-recognized variant; it represents a cordlike thickening of the MGHL, with the absence of the anterosuperior portion of the labrum. This variant may easily be mistaken for an anterior labral tear during arthroscopy. It has been described in 1.5% of patients, but the real incidence is unknown (►**Fig. 30**).[40]

A few cases of a longitudinal split or duplicate ligament have been reported. This may represent a true normal variant or is an old longitudinal tear of the MGHL (►**Fig. 31**).

The foramen of Weitbrecht is a normal communication channel between the glenohumeral joint capsule with the subscapularis bursae located between the SGHL and the MGHL. Slightly below it is another communication channel, the foramen of Rouviere, between the MGHL and the IGHL.[27]

Inferior Glenohumeral Ligament

The IGHL consists of the axillary pouch and anterior and posterior bands. The anterior band originates along the inferior two thirds of the anterior glenoid labrum. When redundant, it may overlap the anterior edge of the glenoid cartilage. The anterior band is usually more prominent and thicker than the anterior band.[35] The IGHL inserts in the region of the anatomical neck (►**Fig. 25**).

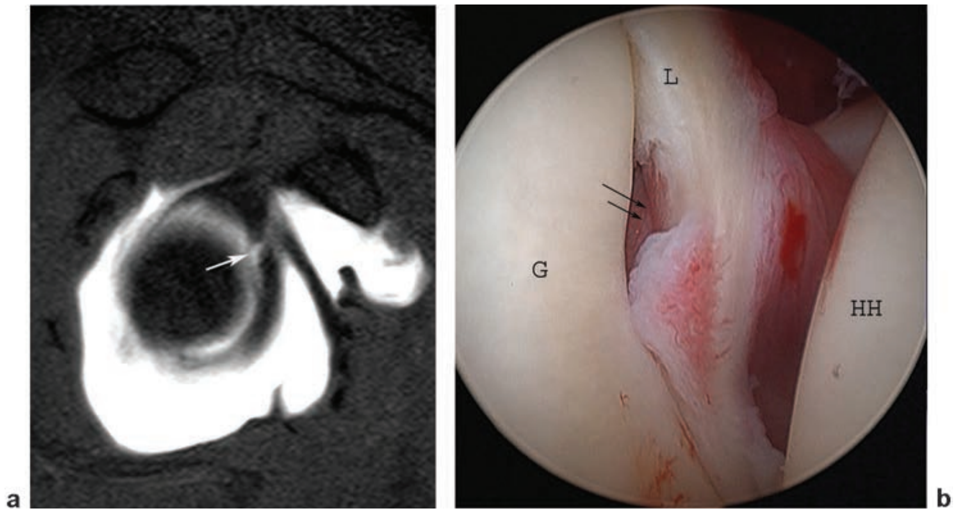


Fig. 24 (**a**) Sagittal MRA T1 fat-saturated image shows a sublabral foramen (arrow). (**b**) Corresponding arthroscopic view. G, glenoid; HH, humeral head; L, labrum; sublabral foramen (arrow).

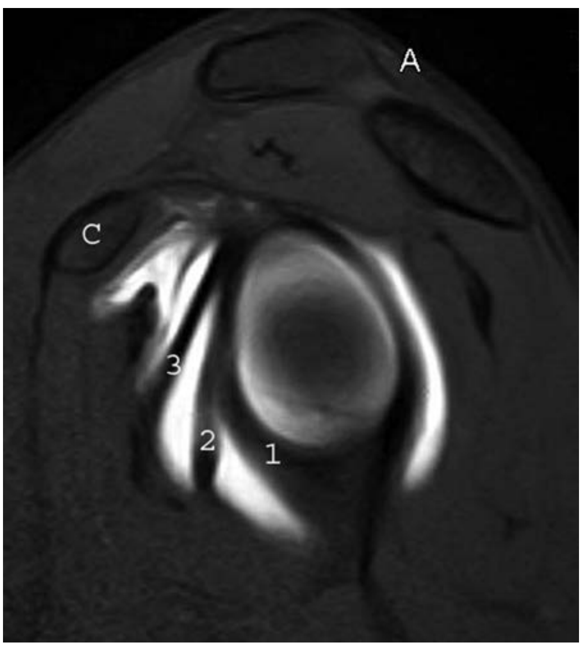


Fig. 25 Glenoid ligaments, labral level. 1. Labrum. 2. Inferior glenohumeral ligament. 3. Middle glenohumeral ligament. C, coracoid process.

The Coracohumeral Ligament

The CHL is an extra-articular structure that extends anterolaterally from the base of the coracoid process and then fans out to insert in the greater tuberosity and biceps sheath.[41] Its distal aspect divides into two major functional (although not always clearly distinct) bands: a smaller medial and a larger lateral band. The medial band of the CHL (MCHL) blends with the fibers of the SGHL to form a ligament (SGHL-MGHL) complex that surrounds the medial and inferior aspect of the intra-articular portion of the LHB tendon before it inserts on the lesser tuberosity of the humerus and merges with the rotator interval capsule along with the superior fibers of the subscapularis tendon. The lateral band of the CHL surrounds the superior and lateral aspect of the intra-articular LHB tendon before inserting on the greater tuberosity of the humerus and on the anterior margin of the supraspinatus tendon.[34] This sling-like band surrounding the long head of the biceps is called the biceps reflection pulley or biceps pulley (►**Figs. 20–22**). The function of the biceps pulley is to limit medial subluxation of the biceps tendon and increase its efficiency during contraction of the biceps.[34] Moreover, the CHL and SGHL are minor contributors to the stability of the abducted glenohumeral joint.

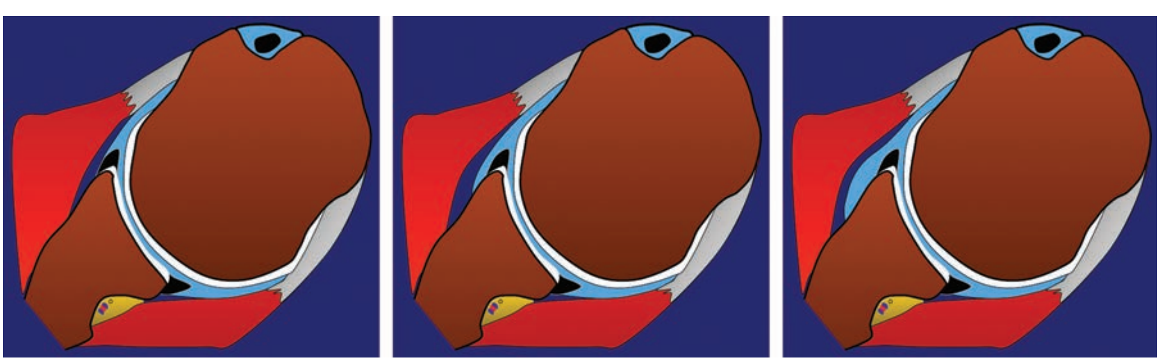


Fig. 26 Anterior glenoid capsular attachments from lateral to medial I, II, and III.

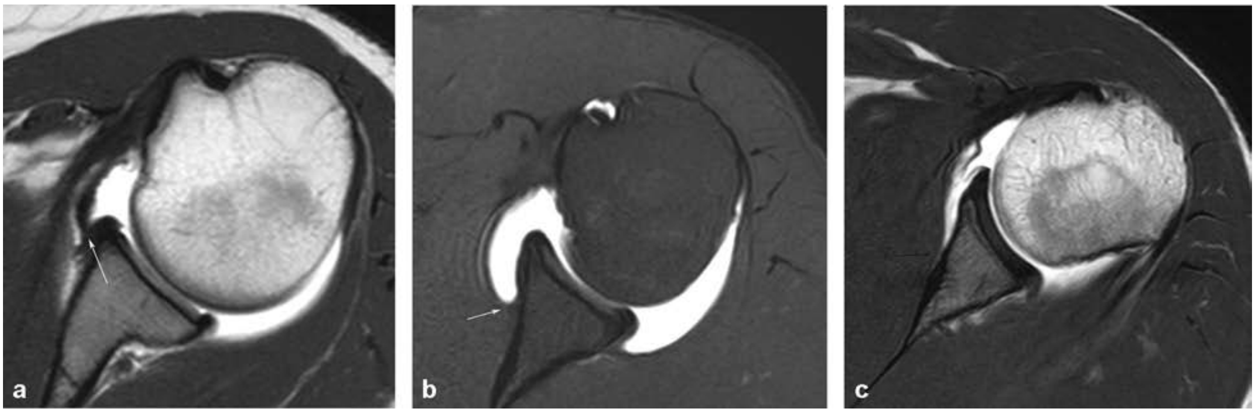


Fig. 27 Anterior glenoid capsular attachment (arrow) with corresponding MRA views from lateral to medial. (**a**) Type I. (**b**) Type II. (**c**) Type III.

These structures are challenging to visualize on shoulder MRI, even when intact. The oblique sagittal plane is thought to provide the best view of the CHL and SGHL and their relationship with the LHB.[36]

The Rotator Interval

The rotator interval is a triangular anatomical area in the anterosuperior aspect of the shoulder defined by the coracoid process at its base, superiorly by the anterior margin of the supraspinatus tendon, and inferiorly by the superior margin of the subscapularis tendon.[33,34] The rotator interval allows the biceps tendon to become intra-articular as it runs to the superior labral insertion. As the biceps tendon enters, it is covered by the biceps pulley. Subscapularis and supraspinatus fibers cross over the rotator interval and merge together with the CHL and SGHL (►**Figs. 6** and **33**). A close look at them should be taken to rule out small undersurface tendon tears[36,41] (►**Figs. 20–22** and **32**).

Active Stabilizers

Muscles and Rotator Cuff

The rotator cuff includes the muscles and tendons of the supraspinatus, infraspinatus, subscapularis, and teres minor (►**Fig. 3**). They originate from the scapula and fuse together on their respective attachment sites. Due to the angulation of its fibers, the supraspinatus insertion site is prone to show the magic angle phenomenon that should not be mistaken with a partial tear. All three were described as running parallel to each other and inserting separately into the greater tuberosity (supraspinatus in the highest, infraspinatus in the middle, and teres minor in the lowest facet of the greater tuberosity). However, it has been demonstrated that the supraspinatus and infraspinatus tendons interdigitate, fuse, and have a partly continuous attachment on the greater tuberosity.[13] This region is microscopically composed of five layers.[42]

Fig. 28 Axial MRA in forced external rotation. 1. Biceps tendon. 2. Superior glenohumeral ligament.

Fig. 29 Sagittal MRA absence of middle glenoid humeral ligament. 1. Inferior glenohumeral ligament.

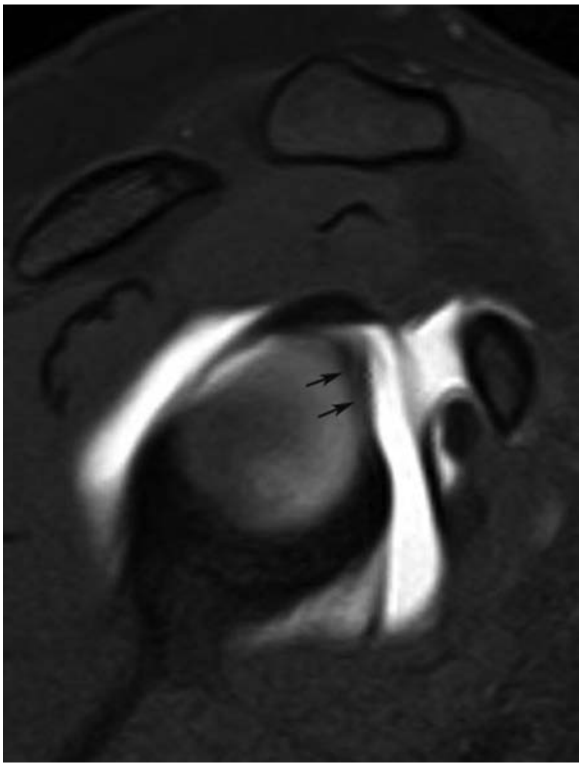


Fig. 30 Sagittal MRA nicely shows a Buford complex with hypoplasia of the anterosuperior labrum (arrows).

The supraspinatus originates from the supraspinatus fossa and the superior surface of the spine of the scapula, runs laterally, and inserts on the highest impression of the greater tuberosity. The supraspinatus tendon has two portions. The anterior half is long and thick; the posterior half is short and thin. The footprint of the supraspinatus insertion takes only the most anterior portion, in the shape of a triangle that is wider anteriorly, and frequently it has an additional extension with fibers crossing over the transverse ligament and bicipital groove with its biceps tendon and inserting into the lesser tuberosity.[43]

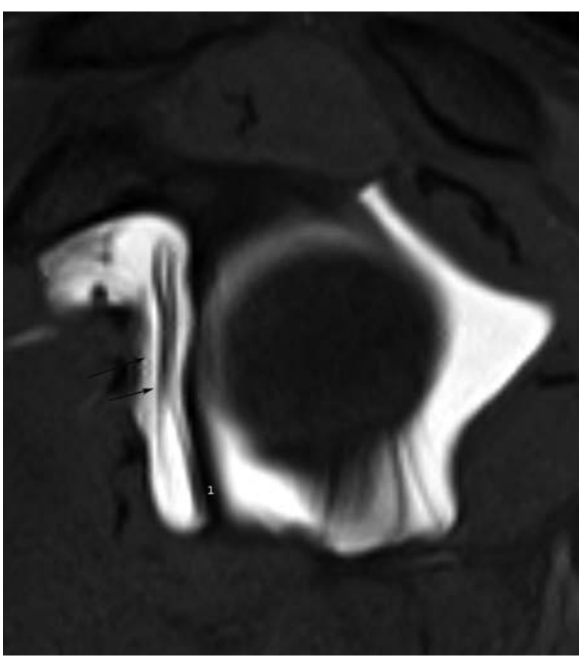


Fig. 31 Split middle glenohumeral ligament (arrows). 1. Inferior glenohumeral ligament.

The infraspinatus originates from both the infraspinatus fossa and the inferior surface of the spine of the scapula, runs superolaterally occupying most of the greater tuberosity, half of the highest portion, and all of the middle. The footprint of the infraspinatus muscle has a trapezoid shape that is wider laterally. The infraspinatus tendon has a fanlike appearance. Its superior half is long and thick; the posterior half is short and thin. The anterior portion of the infraspinatus is slightly more protuberant than the posterior and partially covers the posterolateral part of the supraspinatus. The wider insertion of the infraspinatus muscle on the greater tuberosity could explain the atrophy of the infraspinatus, even with small rotator cuff tears and even without nerve dysfunction.[44,45]

In 1993 Burkhart et al described the arthroscopic vision of the rotator cuff as a crescent configuration that comprises the supraspinatus and infraspinatus distal insertion on the greater tuberosity and on its margin has a bundle of perpendicular fibers that act as a suspension bridge, the rotator cable.[46] These fibers were described by Clark and Harryman and are related with a deep extension of the CHL extending from the biceps' inferior margin to the inferior margin of the infraspinatus spanning the supraspinatus and infraspinatus insertions.[42] With aging there is a transition from a crescent dominant cuff in young people to a cable dominant cuff; the crescent gets thinner, and reliance on the cable increases. The cable acts as a primary stabilizer of the rotator cuff.

The rotator cable has also been described on radiologic images. Morag et al described its appearance on US and reported it as visible in 99% of asymptomatic patients. They described it as a fusiform and flat perpendicular oriented bundle of hyperechogenic fibers on the undersurface of the supraspinatus.[47,48] Gyftopoulos et al, in a cadaveric study with MR and MRA, described it as a low-intensity linear band on the undersurface of the supraspinatus and infraspinatus, continuous with the CHL component of the biceps pulley system.[49] This is visible in 74.3% on coronal and sagittal oblique images. However, previously Sheah et al found it easier and more consistently recognized with the ABER position on MRA[50] (►**Fig. 33**).

The subscapularis is a powerful muscle arising from the anterior scapula. It contains about nine multiple tendinous bands that merge laterally into a flattened tendon in the superior two thirds of the muscle[51] (►**Fig. 3**). Most of the tendinous portion of the subscapularis inserts on the lesser tuberosity, and the superior aspect has continuous tissue consisting of tendon fibers crossing over the bicipital groove covering the entire biceps tendon, extending across to the greater tuberosity and blending with the supraspinatus.[52] Thus it contributes to the rotator interval and blends with the medial portion of the CHL and the SGHL, helping the suspension pulley for the biceps tendon.[53] The inferior third of the subscapularis has a muscular attachment directly onto the

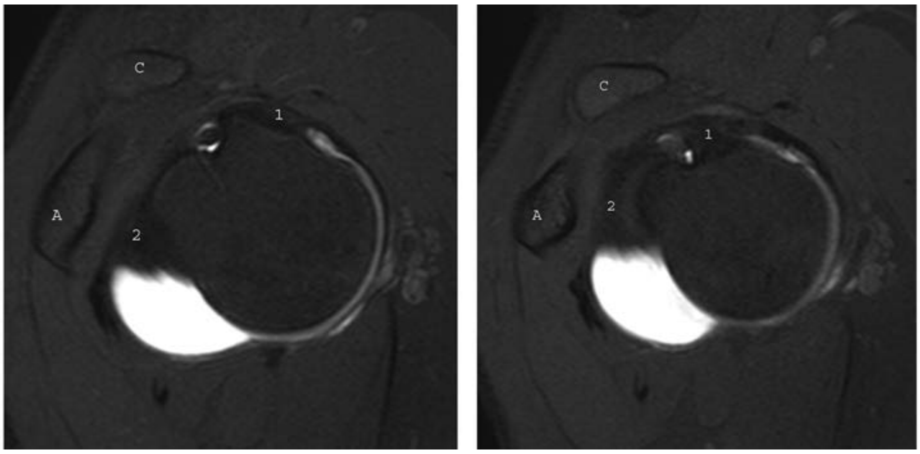


Fig. 32 Axial oblique plane (perpendicular to ABER coronal plane) nicely shows the crossing fibers between the subscapulatis (1) and the supraspinatus (2). A, acromion; C, clavicle.

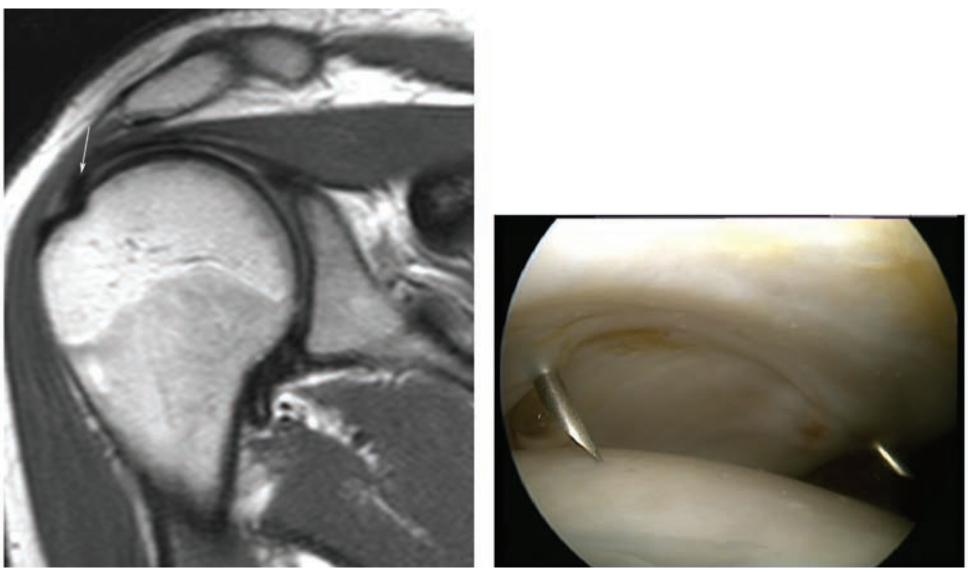


Fig. 33 Rotator cable. Coronal proton-density image shows perpendicular oriented fibers in the undersurface of the supraspinatus (arrow). (**b**) Corresponding arthroscopic view. Rotator cable is marked between the needles.

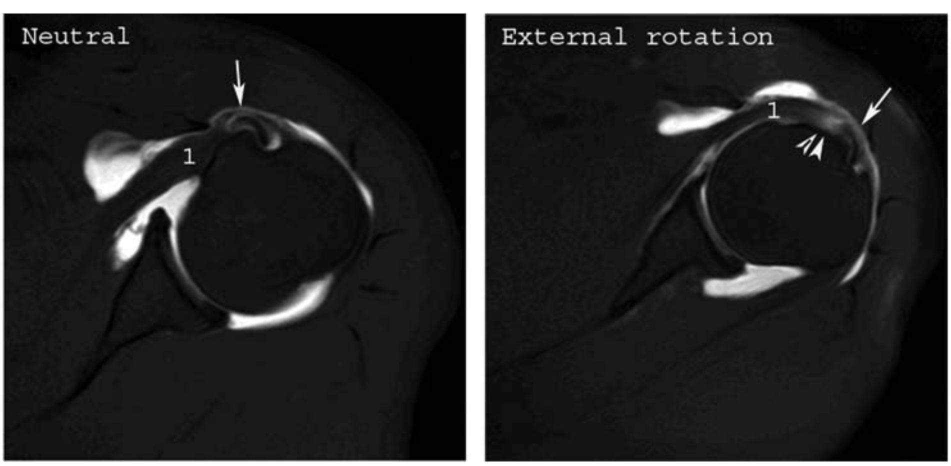


Fig. 34 Small subscapularis partial tear (arrowhead) is better visualized in forced external rotation. 1. Subscapularis, biceps (arrow).

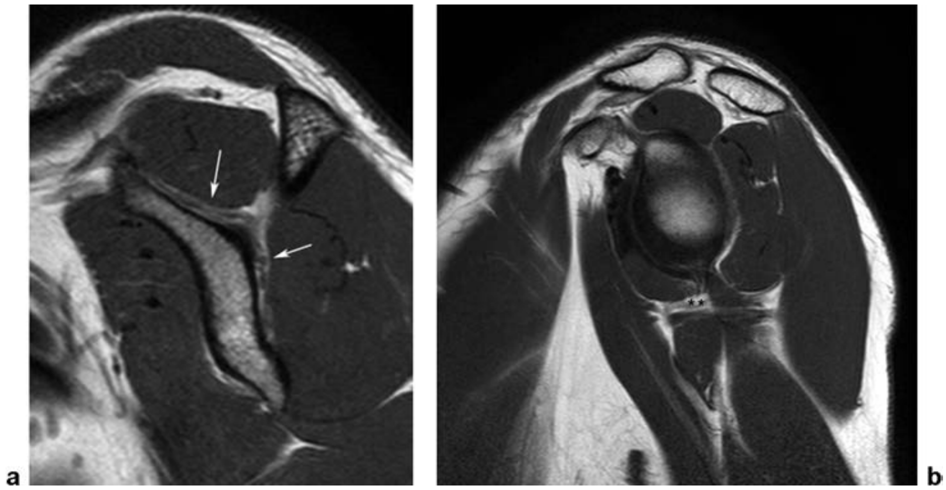


Fig. 35 T1-weighted image in the sagittal plane. (**a**) Suprascapular nerve (arrows). (**b**) Axillary nerve (asterisk).

inferior aspect of the lesser tuberosity and the anterior aspect of the humeral shaft. Superior and inferior subscapularis muscle components are innervated by the upper and lower subscapularis nerves, respectively, and have mechanical differences.

The best technique for the evaluation of the subscapularis tendon is a combination of sagittal and axial planes. External forced rotation helps the evaluation of small undersurface lesions, especially those close to the rotator interval, and to determine the extent of the tear (►**Fig. 34**).

Coracohumeral Interval

The coracohumeral interval is defined as the space between the coracoid process and the humeral head where the subscapularis inserts.

Nerves

Suprascapular Nerve

The suprascapular nerve is a mixed motor and sensory nerve that arises from the upper trunk of the brachial plexus C5 and C6, with variable contribution from C4. The suprascapular nerve enters the supraspinatus fossa through the suprascapular notch, a fibro-osseous tunnel bridged by the transverse scapular ligaments. In the suprascapular fossa, two branches extend to the supraspinatus muscles and the superior aspect of the shoulder joint. The remaining portion of the nerve travels around the lateral margin of the scapular spine through the spinoglenoid notch and into the infraspinatus muscle and posterior aspect of the glenohumeral joint. The pattern of denervation depends on the compression point; if it is within the suprascapular notch it will affect both supraspinatus and infraspinatus muscles, whereas if the compression is distal at the spinoglenoid notch, only the infraspinatus will be denervated.[54] The relatively fixed position of the suprascapular nerve and the fibro-osseous tunnels make it susceptible to entrapment (►**Fig. 35**).

Axillary Nerve

The axillary nerve is formed from the posterior cord of the brachial plexus and descends inferolaterally anterior to the subscapularis. The axillary nerve enters the quadrilateral space with the circumflex humeral artery. It supplies the teres minor, deltoid muscle, and skin. The teres minor, teres major, long head of the triceps, and the neck of the humeral head form the boundaries of the quadrilateral space.[55,56]

Conclusion

The goal of creating a biomechanically complicated wide range of motion and therefore function while maintaining stability makes the shoulder an unique anatomical region. For the sake of brevity, we did not discuss the role of scapular-thoracic motion. We addressed some of the major biomechanical and related anatomical concepts pertinent to using MR in the shoulder from a holistic clinical perspective. A thorough understanding of anatomical structures is key in generating useful MR images and in the interpretation of these images to the benefit of our patients in whom the integrity of these structures is compromised.

Acknowledgments
I would like to thank my friends and colleagues Victoria Higueras and Elena Belloch for their help, my MR technicians for providing the best images our magnets can produce, and to Hans Bloem for editing.

References

1 Tischer T, Vogt S, Kreuz PC, Imhoff AB. Arthroscopic anatomy, variants, and pathologic findings in shoulder instability. Arthroscopy 2011;27(10):1434–1443
2 Lugo R, Kung P, Ma CB. Shoulder biomechanics. Eur J Radiol 2008; 68(1):16–24
3 Chen Q, Miller TT, Padron M, Beltran J. In:Pope T, Bloem JL, Beltran J, Morrison W, Wilson D, eds. Imaging of the Musculoskeletal System. Philadelphia, PA: WB Saunders; 2008:101–125

4 Shortt CP, Morrison WB, Roberts CC, Deely DM, Gopez AG, Zoga AC. Shoulder, hip, and knee arthrography needle placement using fluoroscopic guidance: practice patterns of musculoskeletal radiologists in North America. Skeletal Radiol 2009;38(4): 377–385
5 Hodler J. Technical errors in MR arthrography. Skeletal Radiol 2008;37(1):9–18
6 Jacobson JA, Lin J, Jamadar DA, Hayes CW. Aids to successful shoulder arthrography performed with a fluoroscopically guided anterior approach. Radiographics 2003;23(2):373–378; discussion 379
7 Rhee RB, Chan KK, Lieu JG, Kim BS, Steinbach LS. MR and CT arthrography of the shoulder. Semin Musculoskelet Radiol 2012; 16(1):3–14
8 Farmer KD, Hughes PM. MR arthrography of the shoulder: fluoroscopically guided technique using a posterior approach. AJR Am J Roentgenol 2002;178(2):433–434
9 Catalano OA, Manfredi R, Vanzulli A, et al. MR arthrography of the glenohumeral joint: modified posterior approach without imaging guidance. Radiology 2007;242(2):550–554
10 Llopis E, Fernandez E, Cerezal L. MR and CT arthrography of the hip. Semin Musculoskelet Radiol 2012;16(1):42–56
11 Saleem AM, Lee JK, Novak LM. Usefulness of the abduction and external rotation views in shoulder MR arthrography. AJR Am J Roentgenol 2008;191(4):1024–1030
12 Guedez M, Llopis E, Hernandez E, Cruz A, Higueras V, Cerezal L. External rotation improves diagnostic yield of MR arthrography when added to conventional internal positioning in patients clinically suspected of having SLAP lesions. Poster presented at: Radiological Society of North America conference; November 20, 2008; Chicago, IL. Available at: http://archive.rsna.org/2008/6010842.html. Accessed January 28, 2015
13 Rudez J, Zanetti M. Normal anatomy, variants and pitfalls on shoulder MRI. Eur J Radiol 2008;68(1):25–35
14 Cook TS, Stein JM, Simonson S, Kim W. Normal and variant anatomy of the shoulder on MRI. Magn Reson Imaging Clin N Am 2011;19(3):581–594
15 Prescher A. Anatomical basics, variations, and degenerative changes of the shoulder joint and shoulder girdle. Eur J Radiol 2000;35(2):88–102
16 Moor BK, Wieser K, Slankamenac K, Gerber C, Bouaicha S. Relationship of individual scapular anatomy and degenerative rotator cuff tears. J Shoulder Elbow Surg 2014;23(4):536–541
17 Di Giacomo G, Itoi E, Burkhart SS. Evolving concept of bipolar bone loss and the Hill-Sachs lesion: from “engaging/non-engaging” lesion to “on-track/off-track” lesion. Arthroscopy 2014;30(1): 90–98
18 Weishaupt D, Zanetti M, Nyffeler RW, Gerber C, Hodler J. Posterior glenoid rim deficiency in recurrent (atraumatic) posterior shoulder instability. Skeletal Radiol 2000;29(4):204–210
19 Harper KW, Helms CA, Haystead CM, Higgins LD. Glenoid dysplasia: incidence and association with posterior labral tears as evaluated on MRI. AJR Am J Roentgenol 2005;184(3):984–988
20 Randall T. Glenoid dysplasia. J Athl Train 1995;30(3):259–260
21 Tung GA, Hou DD. MR arthrography of the posterior labrocapsular complex: relationship with glenohumeral joint alignment and clinical posterior instability. AJR Am J Roentgenol 2003;180(2): 369–375
22 Guntern DV, Pfirrmann CW, Schmid MR, et al. Articular cartilage lesions of the glenohumeral joint: diagnostic effectiveness of MR arthrography and prevalence in patients with subacromial impingement syndrome. Radiology 2003;226(1):165–170
23 Yeh LR, Kwak S, Kim YS, et al. Evaluation of articular cartilage thickness of the humeral head and the glenoid fossa by MR arthrography: anatomic correlation in cadavers. Skeletal Radiol 1998;27(9):500–504
24 Kralinger F, Aigner F, Longato S, Rieger M, Wambacher M. Is the bare spot a consistent landmark for shoulder arthroscopy? A study of 20 embalmed glenoids with 3-dimensional computed tomographic reconstruction. Arthroscopy 2006;22(4):428–432
25 Ozaki R, Nakagawa S, Mizuno N, Mae T, Yoneda M. Hill-Sachs lesions in shoulders with traumatic anterior instability: evaluation using computed tomography with 3-dimensional reconstruction. Am J Sports Med 2014;42(11):2597–2605
26 Mascarenhas R, Rusen J, Saltzman BM, et al. Management of humeral and glenoid bone loss in recurrent glenohumeral instability. Adv Orthop 2014;2014:640952
27 Dunham KS, Bencardino JT, Rokito AS. Anatomic variants and pitfalls of the labrum, glenoid cartilage, and glenohumeral ligaments. Magn Reson Imaging Clin N Am 2012;20(2):213–228, x
28 Giaroli EL, Major NM, Lemley DE, Lee J. Coracohumeral interval imaging in subcoracoid impingement syndrome on MRI. AJR Am J Roentgenol 2006;186(1):242–246
29 Alyas F, Curtis M, Speed C, Saifuddin A, Connell D. MR imaging appearances of acromioclavicular joint dislocation. Radiographics 2008;28(2):463–479; quiz 619
30 De Maeseneer M, Van Roy F, Lenchik L, et al. CT and MR arthrography of the normal and pathologic anterosuperior labrum and labral-bicipital complex. Radiographics 2000;20(Spec No.): S67–S81
31 Major NM, Browne J, Domzalski T, Cothran RL, Helms CA. Evaluation of the glenoid labrum with 3-T MRI: is intraarticular contrast necessary? AJR Am J Roentgenol 2011;196(5):1139–1144
32 Schaeffeler C, Waldt S, Holzapfel K, et al. Lesions of the biceps pulley: diagnostic accuracy of MR arthrography of the shoulder and evaluation of previously described and new diagnostic signs. Radiology 2012;264(2):504–513
33 Morag Y, Jacobson JA, Shields G, et al. MR arthrography of rotator interval, long head of the biceps brachii, and biceps pulley of the shoulder. Radiology 2005;235(1):21–30
34 Petchprapa CN, Beltran LS, Jazrawi LM, Kwon YW, Babb JS, Recht MP. The rotator interval: a review of anatomy, function, and normal and abnormal MRI appearance. AJR Am J Roentgenol 2010;195(3):567–576
35 Massengill AD, Seeger LL, Yao L, et al. Labrocapsular ligamentous complex of the shoulder: normal anatomy, anatomic variation, and pitfalls of MR imaging and MR arthrography. Radiographics 1994;14(6):1211–1223
36 Vinson EN, Wittstein J, Garrigues GE, Taylor DC. MRI of selected abnormalities at the anterior superior aspect of the shoulder: potential pitfalls and subtle diagnoses. AJR Am J Roentgenol 2012; 199(3):534–545
37 Moser TP, Cardinal É, Bureau NJ, Guillin R, Lanneville P, Grabs D. The aponeurotic expansion of the supraspinatus tendon: anatomy and prevalence in a series of 150 shoulder MRIs. Skeletal Radiol 2015;44(2):223–231
38 Beltran J, Bencardino J, Mellado J, Rosenberg ZS, Irish RD. MR arthrography of the shoulder: variants and pitfalls. Radiographics 1997;17(6):1403–1412; discussion 1412–1415
39 Beltran J, Bencardino J, Padron M, Shankman S, Beltran L, Ozkarahan G. The middle glenohumeral ligament: normal anatomy, variants and pathology. Skeletal Radiol 2002;31(5):253–262
40 Williams MM, Snyder SJ, Buford D Jr. The Buford complex—the “cord-like” middle glenohumeral ligament and absent anterosuperior labrum complex: a normal anatomic capsulolabral variant. Arthroscopy 1994;10(3):241–247
41 Lee JC, Guy S, Connell D, Saifuddin A, Lambert S. MRI of the rotator interval of the shoulder. Clin Radiol 2007;62(5):416–423
42 Clark JM, Harryman DT II. Tendons, ligaments, and capsule of the rotator cuff. Gross and microscopic anatomy. J Bone Joint Surg Am 1992;74(5):713–725
43 Kolts I. A note on the anatomy of the supraspinatus muscle. Arch Orthop Trauma Surg 1992;111(5):247–249
44 Vad VB, Southern D, Warren RF, Altchek DW, Dines D. Prevalence of peripheral neurologic injuries in rotator cuff tears with atrophy. J Shoulder Elbow Surg 2003;12(4):333–336

45 Mochizuki T, Sugaya H, Uomizu M, et al. Humeral insertion of the supraspinatus and infraspinatus. New anatomical findings regarding the footprint of the rotator cuff. J Bone Joint Surg Am 2008;90(5):962–969
46 Burkhart SS, Esch JC, Jolson RS. The rotator crescent and rotator cable: an anatomic description of the shoulder's "suspension bridge.". Arthroscopy 1993;9(6):611–616
47 Orlandi D, Sconfienza LM, Fabbro E, et al. Preliminary ultrasound evaluation of the rotator cable in asymptomatic volunteers. J Ultrasound 2012;15(1):16–19
48 Morag Y, Jamadar DA, Boon TA, Bedi A, Caoili EM, Jacobson JA. Ultrasound of the rotator cable: prevalence and morphology in asymptomatic shoulders. AJR Am J Roentgenol 2012;198(1):W27–W30
49 Gyftopoulos S, Bencardino J, Nevsky G, et al. Rotator cable: MRI study of its appearance in the intact rotator cuff with anatomic and histologic correlation. AJR Am J Roentgenol 2013;200(5):1101–1105
50 Sheah K, Bredella MA, Warner JJ, Halpern EF, Palmer WE. Transverse thickening along the articular surface of the rotator cuff consistent with the rotator cable: identification with MR arthrography and relevance in rotator cuff evaluation. AJR Am J Roentgenol 2009;193(3):679–686
51 Morag Y, Jamadar DA, Miller B, Dong Q, Jacobson JA. The subscapularis: anatomy, injury, and imaging. Skeletal Radiol 2011;40(3):255–269
52 Boon JM, de Beer MA, Botha D, Maritz NG, Fouche AA. The anatomy of the subscapularis tendon insertion as applied to rotator cuff repair. J Shoulder Elbow Surg 2004;13(2):165–169
53 Arai R, Nimura A, Yamaguchi K, et al. The anatomy of the coracohumeral ligament and its relation to the subscapularis muscle. J Shoulder Elbow Surg 2014;23(10):1575–1581
54 Dong Q, Jacobson JA, Jamadar DA, et al. Entrapment neuropathies in the upper and lower limbs: anatomy and MRI features. Radiol Res Pract 2012;2012:230679
55 Cothran RL Jr, Helms C. Quadrilateral space syndrome: incidence of imaging findings in a population referred for MRI of the shoulder. AJR Am J Roentgenol 2005;184(3):989–992
56 Yanny S, Toms AP. MR patterns of denervation around the shoulder. AJR Am J Roentgenol 2010;195(2):W157–W63