CT and MR Arthrography of the Normal and Pathologic Anterosuperior Labrum and Labral-Bicipital Complex[1]

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CME FEATURE

See accompanying test at http://www.rsna.org/education/rg_cme.html

LEARNING OBJECTIVES FOR TEST 2

After reading this article and taking the test, the reader will be able to:

- Describe the imaging features of anatomic variants of the anterosuperior labrum.
- Describe the imaging features of pathologic conditions of the anterosuperior labrum and labral-bicipital complex.
- Explain how anatomic variants of the anterosuperior labrum may be misinterpreted as pathologic conditions at CT and MR arthrography.

Interpretation of computed tomographic and magnetic resonance arthrograms of the shoulder is complicated by normal variants of the labrum and glenohumeral ligaments. A superior sublabral recess is located at the 12 o'clock position and represents a normal recess between the superior labrum and the cartilage of the glenoid cavity. A sublabral foramen is located at the 2 o'clock position and represents localized detachment of the labrum from the glenoid rim. Buford complex is characterized by absence of the anterosuperior labrum and cordlike thickening of the middle glenohumeral ligament. Imaging features of damage to the anterior labrum include absence or detachment of the labrum and an irregular frayed appearance. Superior labrum anterior-to-posterior (SLAP) lesions are classified as type I (tear confined to the superior labrum), type II (labrum and biceps tendon detached from the superior glenoid), type III (bucket handle tear of the superior labrum), or type IV (bucket handle tear of the superior labrum with lateral extension into the biceps tendon). Increased distance between the labrum and the glenoid, an irregular appearance of the labral margin, or lateral extension of the separation may suggest a SLAP lesion rather than a normal anatomic variant. However, differentiation between normal variants and pathologic conditions and between various types of SLAP lesions remains difficult.

Abbreviation: SLAP = superior labrum anterior-to-posterior

Index terms: Shoulder, 414.13 • Shoulder, anatomy, 414.92 • Shoulder, arthrography, 414.122 • Shoulder, CT, 414.1211 • Shoulder, injuries, 414.481 • Shoulder, MR, 414.1214

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Introduction

Magnetic resonance (MR) arthrography is increasingly used in the evaluation of the shoulder joint, especially in the setting of labral injury. MR arthrograms can routinely be obtained in the transverse, coronal, and sagittal planes. This modality improves visualization of a variety of capsulolabral lesions compared with conventional MR imaging. Nevertheless, interpretation of computed tomographic (CT) scans and MR arthrograms of the shoulder is made difficult by the frequent occurrence of normal anatomic variants. The complexity of injuries involving the labral-bicipital structures may also contribute to this difficulty (1).

In this article, we discuss and illustrate the normal anatomy of the anterosuperior labrum and labral-bicipital complex. We also describe normal variants including superior sublabral recess, sublabral foramen, and Buford complex as well as pathologic conditions including anterior labral tears and SLAP lesions.

Clinical Experience

We retrospectively reviewed the imaging and arthroscopic findings in patients seen at our orthopedic shoulder clinic during the past 3 years. In addition, we reviewed related cases that were submitted from three other institutions. At our institution, CT arthrography is routinely performed with intraarticular injection of 12 mL of nondiluted iodinated contrast material (Hexabrix; Guerbet, Roissy, France). Spiral CT is performed with 1- and 2-mm-thick sections (Somatom Plus; Siemens, Erlangen, Germany). Reconstructed images from coronal CT scans are also obtained for evaluation of the superior labrum and biceps anchor. MR arthrography is performed with injection of 12 mL of a mixture of gadopentetate dimeglumine and saline solution (1:200 dilution) (Magnevist; Schering, Berlin, Germany) into the glenohumeral joint under fluoroscopic control. Intraarticular injection of paramagnetic contrast material is approved by the ethics committee at our institution. Coronal, transverse, and sagittal images are obtained with a 1.5-T imager (Siemens Vision, Siemens) using T1-weighted spin-echo sequences with or without fat saturation. The shoulder is placed in a neutral position or in slightly external rotation. Typical imaging parameters are as follows: section thickness, 2–3 mm; repetition time, 600 msec; echo time, 15 msec; field of view, 130 × 180; matrix size, 180 × 256; and number of signals acquired, 2.

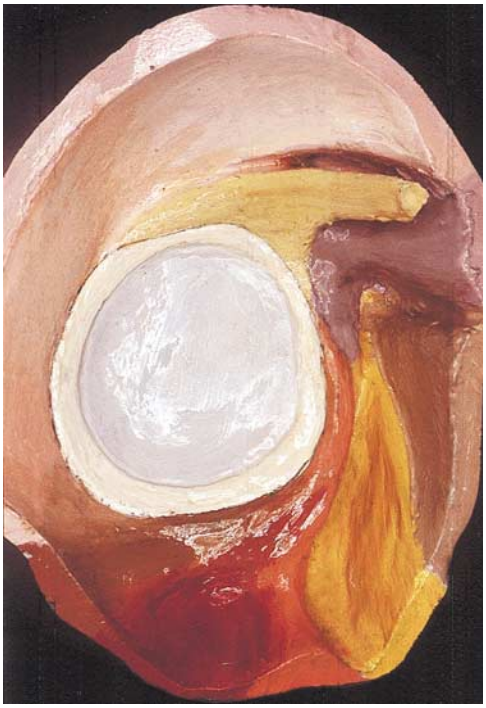

Figure 1. Normal shoulder anatomy. Photograph of a plastic model shows the superior glenohumeral ligament (purple), middle glenohumeral ligament (dark yellow), anterior band of the inferior glenohumeral ligament (orange), axillary pouch of the inferior glenohumeral ligament (red), biceps tendon (bright yellow), labrum (white), and glenoid (light gray).

Three embalmed cadaveric shoulder specimens were dissected and studied in detail. The specimen that best showed anatomic detail was selected and photographed. A negative plaster cast was made of the selected specimen (Molda, Lambert, Belgium). From this negative cast, an enlarged positive cast was made and used as a mold to create an enlarged negative cast made from silicone rubber (RTV 1025; Soudal, Turnhout, Belgium). From this enlarged negative cast, 10 positive polyester casts were made (Uceflex; Vulga, Kraainem, Belgium). On the basis of imaging and arthroscopic findings, the plastic models were adapted to represent normal variants and pathologic conditions involving the anterosuperior aspect of the shoulder joint. These models were then photographed.

Normal Anatomy

Glenoid Labrum

The glenoid labrum is a fibrocartilaginous structure that attaches to the glenoid rim and is about 4 mm wide. Anteriorly, the glenoid labrum blends with the anterior band of the inferior glenohu-

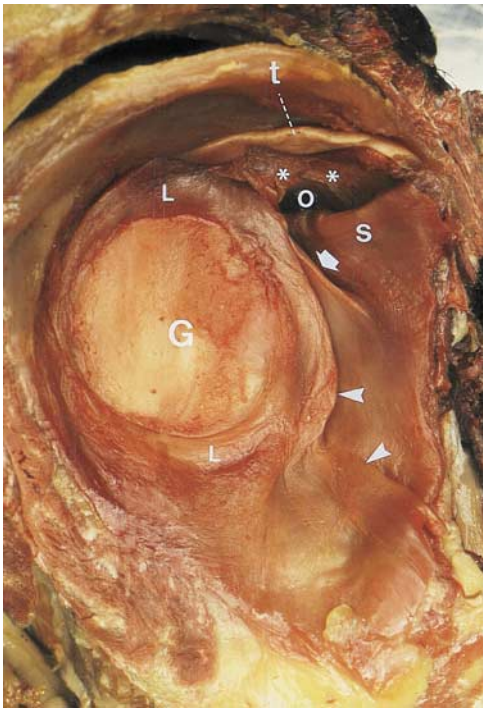

Figure 2. Normal shoulder anatomy. Photograph of a gross specimen shows the labrum (*L*), biceps tendon (*t*), anterior band of the inferior glenohumeral ligament (arrowheads), middle glenohumeral ligament (arrow), superior glenohumeral ligament (*), subscapularis tendon (*S*), glenoid (*G*), and opening to the subcoracoid recess (*O*).

Figure 3. Normal biceps tendon in a 36-year-old man. Transverse MR arthrogram (repetition time msec/echo time msec = 500/12) demonstrates the attachment of the biceps tendon (arrowheads) on the superior labrum (arrows).

Figure 4. Normal biceps tendon in a 37-year-old woman. Transverse CT arthrogram (1-mm section thickness) shows the biceps tendon (arrowheads) and superior glenohumeral ligament (arrow).

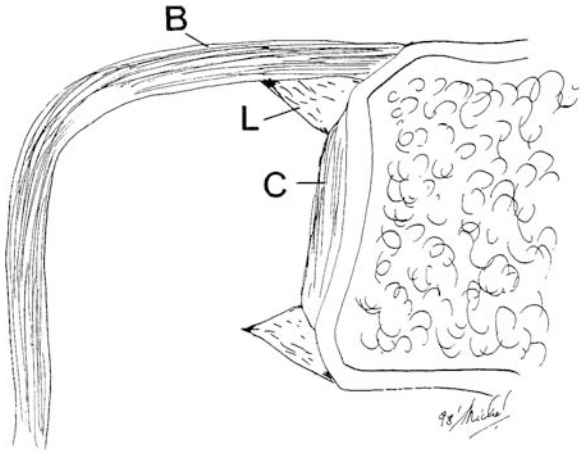

Figure 5. Normal biceps anchor. Drawing representing a coronal section obtained at the level of the labral-bicipital complex illustrates the biceps tendon (*B*), superior labrum (*L*), and glenoid cartilage (*C*), all of which are intimately related in this region.

meral ligament. Superiorly, it blends with the biceps tendon and the superior glenohumeral ligament (2). The labrum may show considerable variation in shape and in mechanism of attachment to the glenoid (Figs 1, 2). It is usually rounded or triangular on cross-sectional images.

Biceps Tendon

The tendon of the long head of the biceps muscle attaches to the anterosuperior aspect of the glenoid rim (Figs 1–5). The attachment of the biceps tendon may demonstrate four components, including fibers that attach to the anterosuperior labrum, the posterosuperior labrum, the supragle-

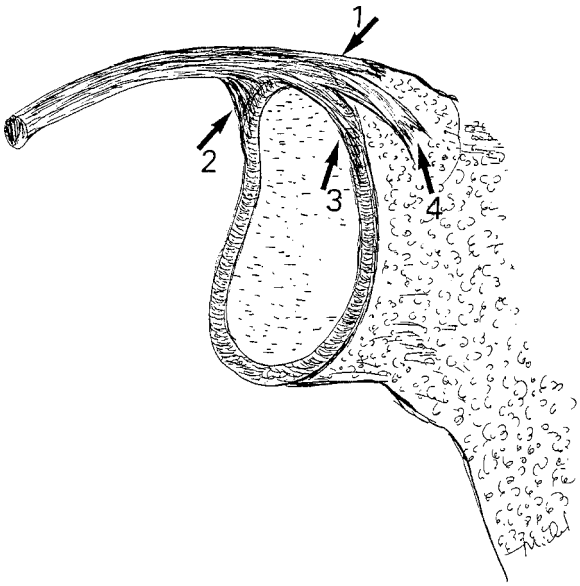

Figure 6. Normal biceps tendon. Drawing of the biceps tendon attachment at the level of the superior labrum and glenoid illustrates attachments to the superior glenoid rim (*1*), the posterior (*2*) and anterior (*3*) labrum, and the base of the coracoid process (*4*).

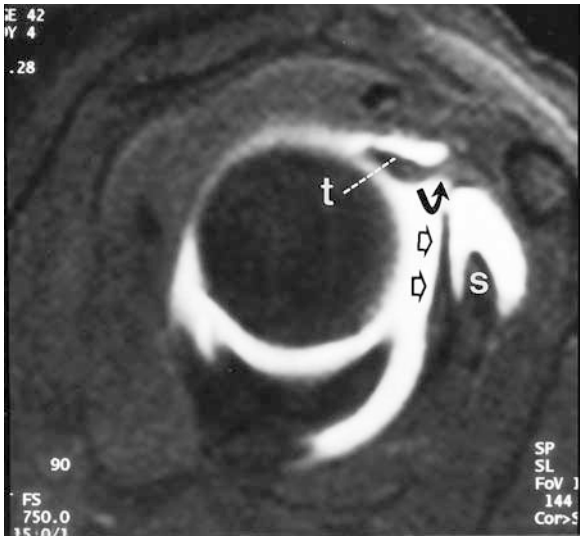

Figure 7. Normal superior glenohumeral ligament in an 18-year-old woman. Sagittal fat-saturated T1-weighted MR arthrogram (750/15) shows the biceps tendon (*t*), subscapularis tendon (*S*), middle glenohumeral ligament (open arrows), and superior glenohumeral ligament (solid arrow).

noid tubercle, and the base of the coracoid process (Fig 6). From its site of attachment, the biceps tendon courses laterally and exits the glenohumeral joint through the intertubercular groove, where it is secured by the transverse ligament. The labral-bicipital complex is well visualized on transverse CT or MR arthrograms as well as on coronal MR arthrograms and reconstructed images from coronal CT arthrograms.

Glenohumeral Ligaments

Superior Glenohumeral Ligament.—The glenohumeral ligaments play a role as shoulder stabilizers and consist of thickened bands of the joint capsule. The superior glenohumeral ligament is the most consistently identified capsular ligament. It can arise from the anterosuperior labrum, the attachment of the tendon of the long head of the biceps muscle, or the middle glenohumeral ligament (1). The superior glenohumeral ligament courses in a plane nearly perpendicular to the middle glenohumeral ligament (Figs 4, 7) and parallel to the coracoid process. It is best visualized on transverse CT or MR arthrograms.

Middle Glenohumeral Ligament.—The middle glenohumeral ligament varies most in size and site of attachment to the glenoid. It typically has an oblique orientation from superomedial to inferolateral. It may attach to the superior portion

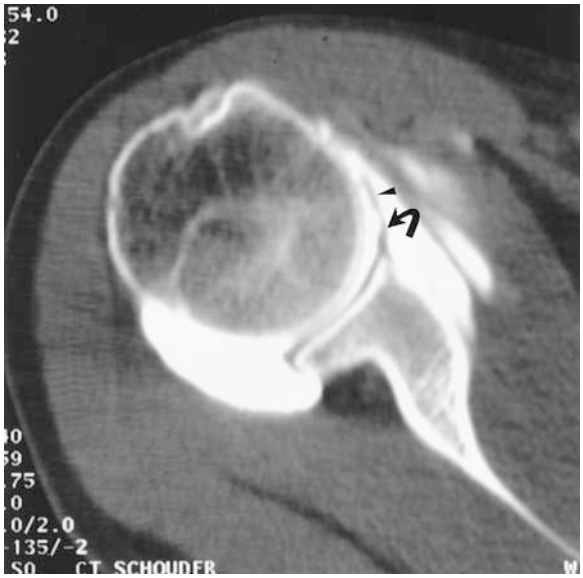

Figure 8. Normal middle glenohumeral ligament in a 30-year-old man. CT arthrogram (2-mm section thickness) shows the middle glenohumeral ligament (arrowhead) attached to the anterior labrum (arrow).

of the anterior glenoid labrum (Fig 8) but more frequently attaches medially on the glenoid neck (Fig 9). The middle glenohumeral ligament may be absent (Fig 10) or may appear thick and cordlike (as, for example, in Buford complex). The appearance of the middle glenohumeral ligament may also change significantly with internal-external rotation of the shoulder (1,3,4). With the arm in external rotation, the ligament is

Figure 9. Normal middle glenohumeral ligament in an 18-year-old woman. Transverse fat-saturated MR arthrogram (560/14) demonstrates the middle glenohumeral ligament attaching medially on the glenoid neck (arrow).

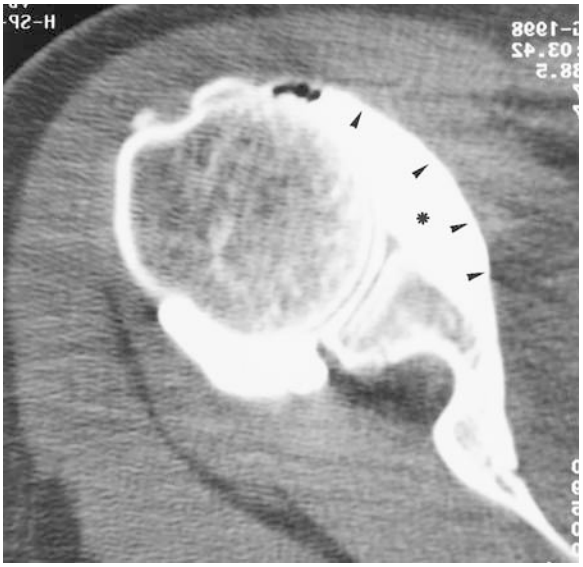

Figure 10. Absent middle glenohumeral ligament in a 40-year-old woman. CT arthrogram (2-mm section thickness) demonstrates absence of the middle glenohumeral ligament (*) and a wide anterior joint recess (arrowheads).

Figure 11. Normal inferior glenohumeral ligament in an 18-year-old woman. Sagittal fat-saturated T1-weighted MR arthrogram (750/15) demonstrates the biceps tendon (*t*), subscapularis tendon (*S*), and anterior and posterior bands of the inferior glenohumeral ligament (arrows).

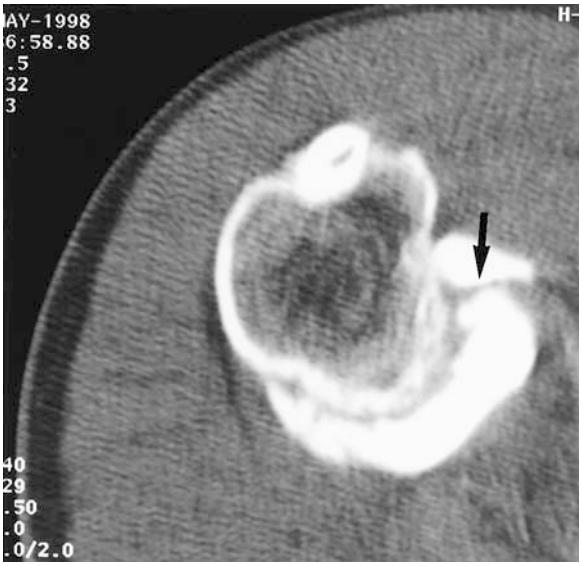

Figure 12. Normal inferior glenohumeral ligament in a 57-year-old man. CT arthrogram (2-mm section thickness) shows the anterior band of the inferior glenohumeral ligament in the axillary joint recess (arrow).

stretched and is located adjacent to the capsule. With internal rotation, the ligament may appear redundant. The middle glenohumeral ligament is best visualized on sagittal MR arthrograms or on transverse CT and MR arthrograms.

Inferior Glenohumeral Ligament.—The inferior glenohumeral ligament is an important stabilizer of the anterior shoulder joint (2,5) and consists of the axillary pouch and anterior and posterior bands (Fig 11). The anterior band inserts 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 quite prominent, although in approximately 25% of cases it is very thin (Fig 12) (2). The posterior band is usually thinner than the anterior band.

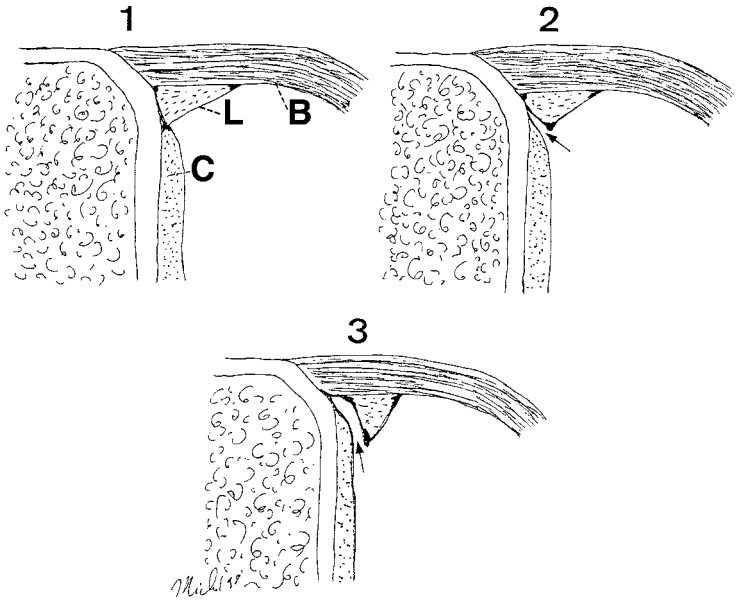

Figure 13. Superior sublabral recess. Drawings representing a coronal section through the labral-bicipital complex illustrate type I (*1*), type II *(2)*, and type III (*3*) labral attachments. In type I, the labrum (*L*) is tightly attached to the glenoid, whereas in types II and III, a recess is present between the labrum and glenoid (arrow). *B* = biceps tendon, *C* = cartilage.

Figure 14. Type III superior sublabral recess. Coronal section of a cadaveric shoulder specimen demonstrates a sublabral recess (arrow) between the superior labrum (*L*) and the glenoid cartilage (*C*). (Courtesy of Donald L. Resnick, MD, Veterans Affairs Medical Center, San Diego, Calif.)

Normal Anatomic Variants

Superior Sublabral Recess

There is an intimate relationship between the superior labrum and the biceps tendon attachment. The mechanism of attachment of the superior labrum to the glenoid at the site of the biceps tendon insertion may show considerable variation (Figs 13–18). A superior sublabral recess is located at the 12 o'clock position. In type I attachment, the labral-bicipital complex attaches firmly to the glenoid rim, so that an arthroscopic probe cannot be inserted between the deep side of the labrum and the glenoid (Fig 16). In type II attachment, a small sulcus is present between the labrum and the glenoid rim (Fig 17). In type III attachment, a deep sulcus is present between the labrum and the glenoid rim, allowing a probe to be inserted between the labrum and the glenoid cartilage (Fig 18). On coronal cross-sectional images, the labrum is triangular and demonstrates a meniscus-like projection into the joint space (1,6, 7). A superior sublabral recess may be continuous with a sublabral foramen. Differentiation on imaging studies between a type III attachment and a type II SLAP lesion may be extremely difficult.

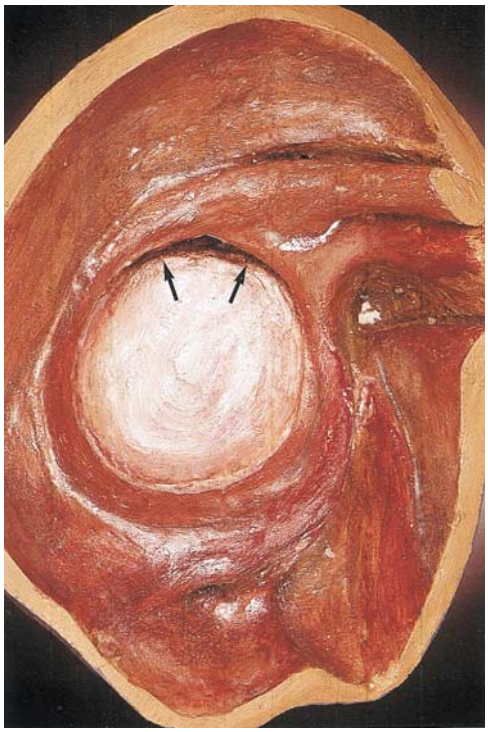

Figure 15. Type II superior sublabral recess. Photograph of a plastic model demonstrates a normal recess between the superior labrum and the glenoid (arrows). Note the sharp free edge of the superior labrum.

Figure 16. Type I labral attachment in a 17-year-old girl. On a coronal MR arthrogram (560/14), the labrum (black arrow) is tightly attached to the glenoid cartilage and biceps tendon (white arrow).

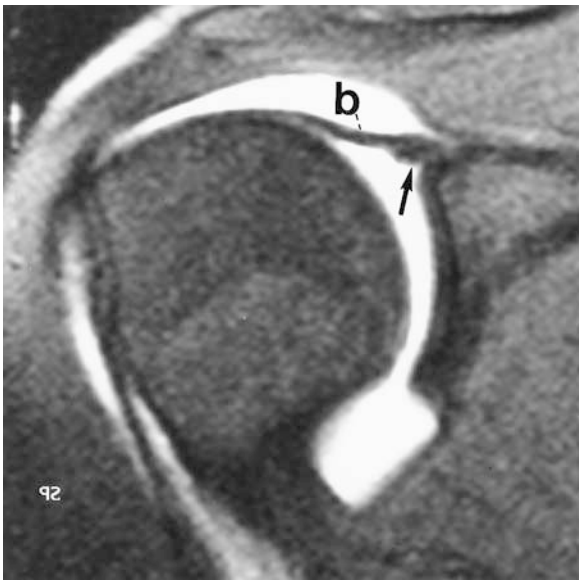

Figure 17. Type II labral attachment. Coronal fat-saturated T1-weighted MR arthrogram (744/20) shows a small recess between the labrum and the glenoid cartilage (arrow). *b* = biceps tendon. (Courtesy of P. Vanhoenacker, MD, O.L.V. Ziekenhuis, Aalst, Belgium.)

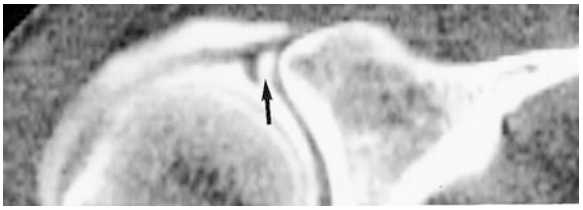

Figure 18. Type III labral attachment in a 22-year-old man. Reconstructed image from a coronal CT arthrogram (1-mm-thick transverse sections) shows a large recess between the labrum and the glenoid (arrow).

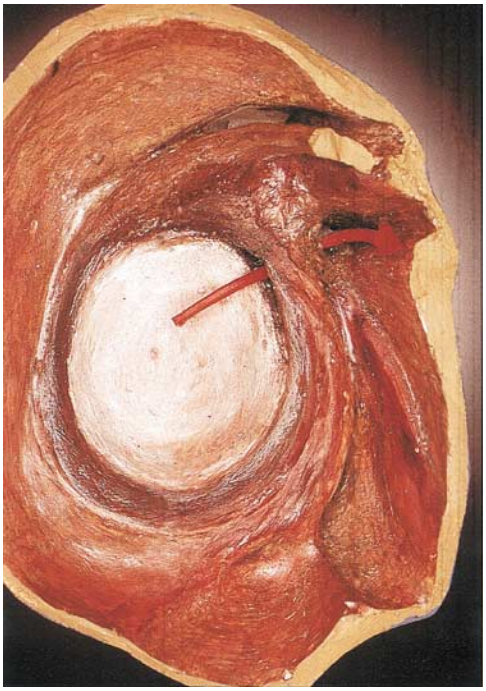

Figure 19. Sublabral foramen. Photograph of a plastic model demonstrates a sublabral foramen at the 2 o'clock position between the labrum and the glenoid. A red plastic arrow is shown passing through the foramen.

Sublabral Foramen

A sublabral foramen (sublabral hole) is seen in 11% of individuals (8). It should not be confused with a superior sublabral recess. In contrast to the latter, a sublabral foramen is located anterosuperiorly at the 2 o'clock position (1,8). A sublabral recess is located at the site of attachment of the biceps tendon, whereas a sublabral foramen is located anterior to the biceps tendon attachment (Figs 19, 20). A sublabral foramen may coexist with a sublabral recess. On an MR arthrogram, a sublabral foramen may erroneously be interpreted as a labral tear.

Buford Complex

Buford complex is seen in 1.5% of individuals (8). It consists of a cordlike thickening of the middle glenohumeral ligament combined with absence of the anterosuperior labrum (1,8). In addition, the middle glenohumeral ligament attaches directly on the anterosuperior glenoid

Figure 20. Sublabral foramen in a 14-year-old girl. Transverse CT arthrogram (2-mm section thickness) demonstrates contrast material between the anterosuperior labrum and the glenoid cartilage (arrow).

Figure 21. Buford complex. Photograph of a plastic model demonstrates absence of the anterosuperior labrum (★) and cordlike thickening of the middle glenohumeral ligament (*m*).

a. **b.**

Figure 22. Buford complex. Sagittal **(a)** and transverse **(b)** fat-saturated MR arthrograms (640/14) demonstrate a thick, cordlike middle glenohumeral ligament (arrowheads). Note the absence of the anterosuperior labrum on the transverse image (arrow in **b**). *S* in **a** indicates subscapularis muscle and tendon.

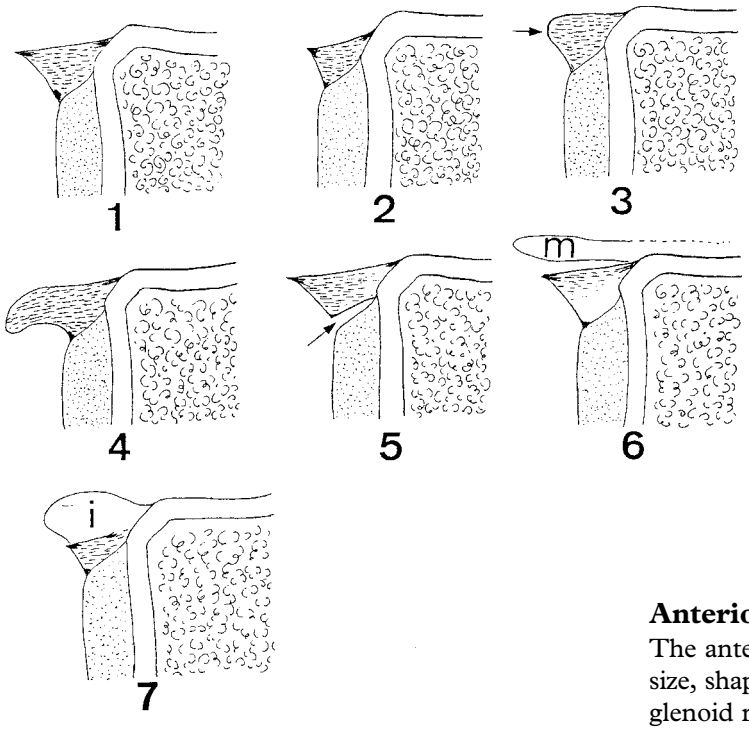

Figure 23. Anterior labrum. Drawings representing a transverse section through the middle aspect of the shoulder joint illustrate various appearances of the anterior labrum. This structure may be triangular (*1*), undersized (*2*), blunt-tipped (arrow in *3*), or crescentic (*4*). Alternatively, there may be a recess between the anterior labrum and the cartilage (arrow in *5*), the middle glenohumeral ligament may be located proximal to the anterior labrum (*m* in *6*), or the anterior labrum may appear small and be accompanied by a thickened inferior glenohumeral ligament (*i* in *7*).

Figure 24. Tear of the anterior labrum. Photograph of a plastic model shows extensive fraying of the anterior labrum (arrows).

(Figs 21, 22). At arthrography, the thickened middle glenohumeral ligament may be mistaken for a displaced labral fragment.

Pathologic Conditions

Anterior Labral Tears

The anterior labrum may vary considerably in size, shape, and mechanism of attachment to the glenoid rim (Fig 23). Its appearance may also change with internal-external rotation of the shoulder. Because the middle and inferior glenohumeral ligaments may be located adjacent to the anterior labrum, they may give the erroneous impression on transverse CT or MR arthrograms that a portion of the labrum is detached or torn. Most often, the labrum is firmly fixed to the glenoid cartilage, but occasionally a recess of variable size may be present between the anterior labrum and the glenoid rim. Such a recess may also be present between the sites of attachment of the middle and inferior glenohumeral ligaments and may simulate labral detachment. Occasionally, a small recess is evident along the entire labrum (5,8,9). The anterior labrum may be very thin and mostly replaced by a thick inferior glenohumeral ligament.

Folds of synovial tissue may form along the anterior capsule due to a chronic inflammatory condition. Such folds may be misinterpreted as labral fragments or fraying of the labrum (9). Imaging signs indicating a damaged labrum include absence or detachment of the labrum and an irregular frayed appearance (Figs 24–26). Labral tears most commonly involve the anteroinferior

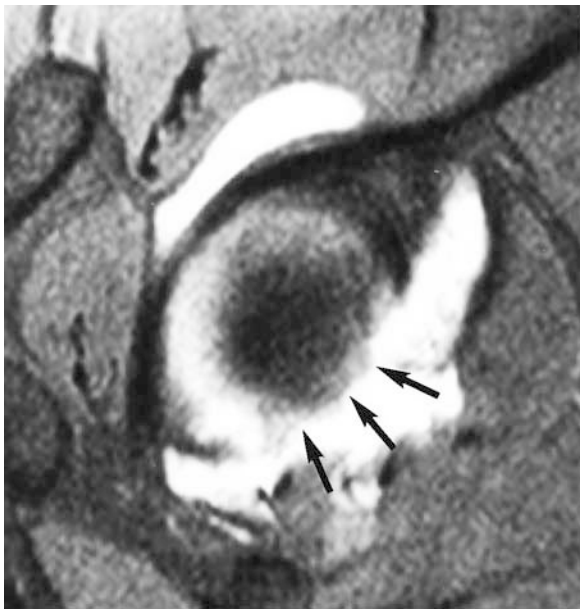

Figure 25. Tear of the anterior labrum. Sagittal fat-saturated MR arthrogram (744/20) demonstrates absence of the labrum and residual irregularity of the anterior glenoid (arrows). (Courtesy of P. Vanhoenacker, MD, O.L.V. Ziekenhuis, Aalst, Belgium.)

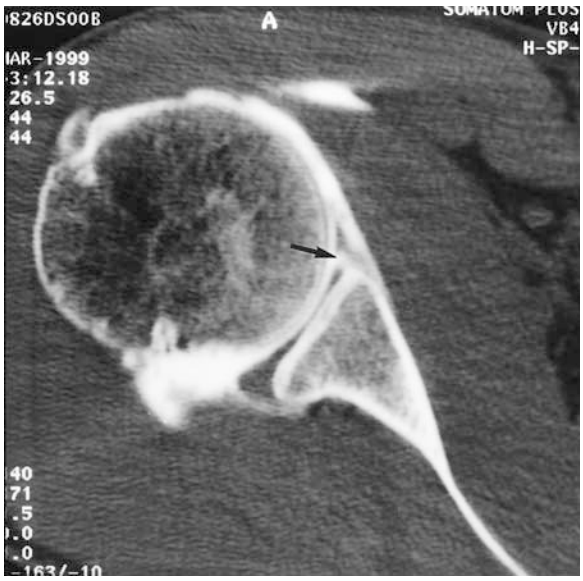

Figure 26. Tear of the anterior labrum in a 26-year-old man. Transverse CT arthrogram (2-mm section thickness) shows injected contrast material extending into a tear of the anterior labrum (arrow).

Figure 27. Bankart lesion in a 28-year-old man. Transverse CT arthrogram (2-mm section thickness) demonstrates absence of the anteroinferior labrum and a compressed fracture fragment of the bony glenoid (arrow).

aspect of the labrum (5). Discussion of the various subtypes of tears involving the anteroinferior labrum (Bankart lesion [Fig 27], anterior labroligamentous periosteal sleeve avulsion, Perthes lesion) is beyond the scope of this article. Positioning the arm in abduction and external rotation at MR arthrography has been used for better evaluation of these lesions. The second most common type of labral tear involves the entire anterior labrum (5). Isolated tears of the anterosuperior labrum are uncommon, and in the absence of other pathologic findings, the possibility that they represent normal anatomic variants should always be considered.

SLAP Lesions

Anterior-to-posterior lesions of the superior labrum have been designated as SLAP lesions. They may occur during sports activity involving overhead arm motion or after a fall on an outstretched arm. Clinical findings include pain and a clicking sensation. SLAP lesions are centered at the attachment of the biceps tendon. However, the portions of the labrum situated anterior and posterior to the site of attachment of the biceps tendon may be involved to a variable extent. Four types of SLAP lesions were initially described (Fig 28) (1). However, combinations of these types of lesions have also been reported, as well as other less common types involving the anterior labrum or glenohumeral ligaments (1,10–13).

In type I SLAP lesions, the abnormality is confined to the superior labrum, which may

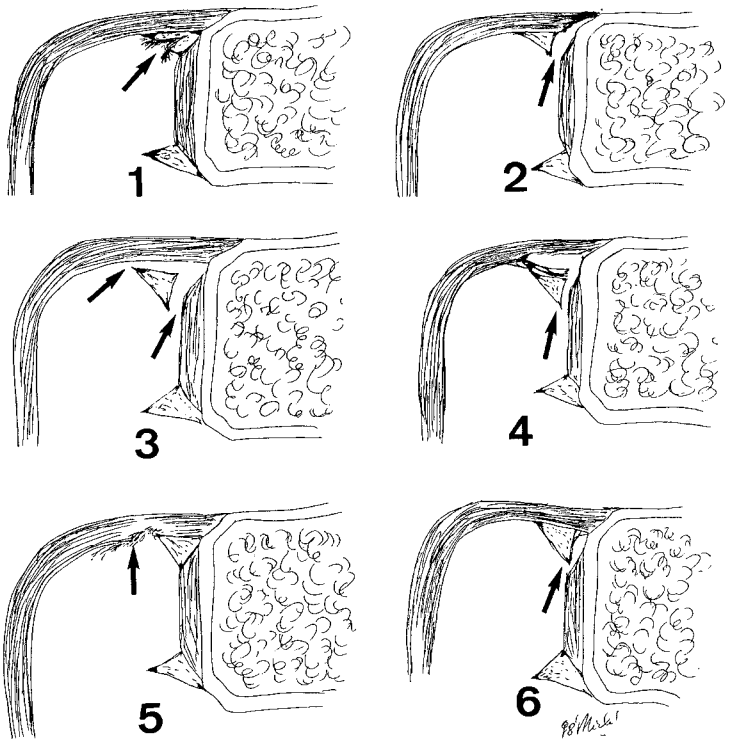

Figure 28. SLAP lesions and anatomic variants. Drawings *1–4* representing a coronal section through the labral-bicipital attachment illustrate the different types of SLAP lesions: type I, fraying or tear of the superior labrum (arrow in *1*); type II, detachment of the labral-bicipital complex from the superior glenoid (arrow in *2*); type III, a bucket handle tear of the superior labrum (arrows in *3*); and type IV, a bucket handle tear with extension into the biceps tendon (arrow in *4*). Drawings *5* and *6* illustrate anatomic variants that do not represent SLAP lesions, including degenerative fraying of the biceps tendon (arrow in *5*) and a type III superior sublabral recess (arrow in *6*).

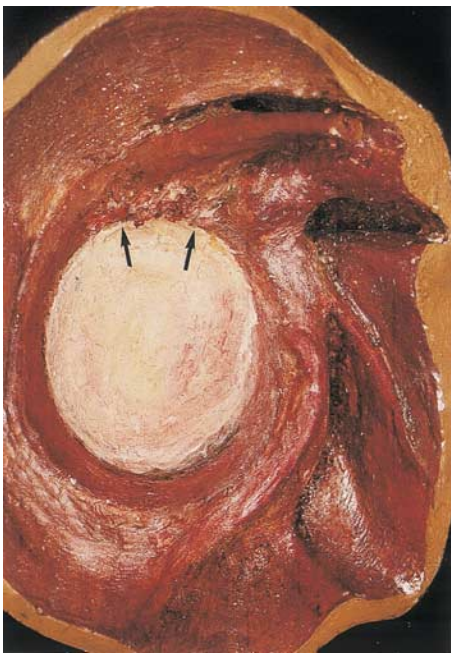

Figure 29. Type I SLAP lesion. Photograph of a plastic model shows fraying of the superior labrum (arrows).

Figure 30. Type I SLAP lesion in a 55-year-old man. Coronal MR arthrogram (560/20) demonstrates a small tear involving the central portion of the superior labrum (arrow).

demonstrate a small tear or irregularity (10). This type of lesion is quite common in elderly persons and may represent a degenerative tear of the labrum (Figs 29, 30). In younger, more athletic individuals, it may represent a traumatic injury. Type II SLAP lesions consist of detachment of the superior labral-bicipital complex from the

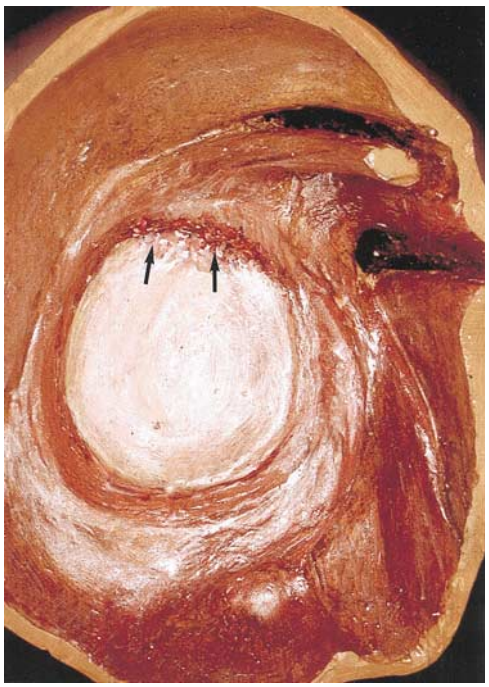

Figure 31. Type II SLAP lesion. Photograph of a plastic model shows detachment of the superior labrum from the glenoid (arrows). Note the irregular fraying and hemorrhagic aspect of the free edge of the labrum.

Figure 33. Type II SLAP lesion. Coronal fat-saturated MR arthrogram (700/16) shows contrast material between the superior labrum and the glenoid (arrow). Note the lateral extension of the tear of the superior labrum.

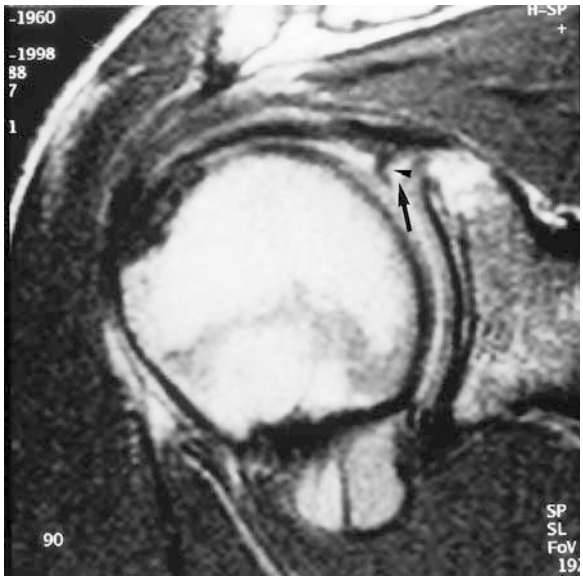

Figure 32. Type II SLAP lesion in a 37-year-old man. Coronal MR arthrogram (520/14; flip angle, 40°) demonstrates contrast material between the superior labrum and the glenoid (arrow). Note also the slight irregularity of the labral margin (arrowhead).

Figure 34. Type II SLAP lesion in a 26-year-old man. CT arthrogram (1-mm section thickness) shows contrast material between the superior labrum and the superior glenoid rim (arrow). The wide separation indicates a SLAP lesion.

superior glenoid rim (Figs 31–35). These lesions may be further classified based on extension anteriorly or posteriorly from the biceps tendon attachment. As mentioned earlier, it may be difficult to differentiate a type II SLAP lesion from a deep superior sublabral recess at CT and MR arthrography (10). Increased distance between the labrum and the glenoid, an irregular appearance, or lateral extension may suggest a SLAP lesion rather than a normal anatomic variant (Fig 36). In type III SLAP lesions, the superior portion of the labrum is detached from both the glenoid

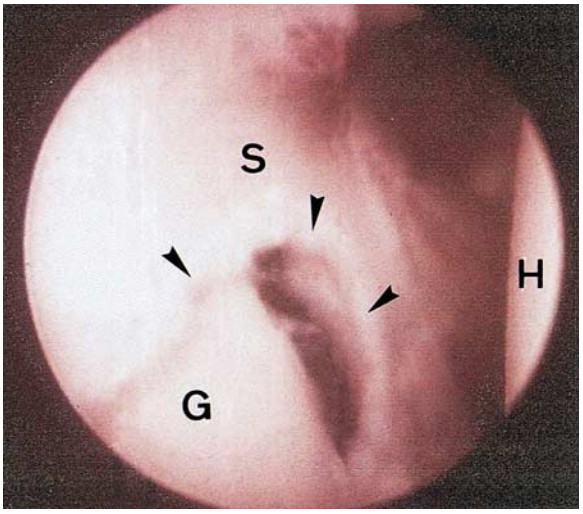

Figure 35. Type II SLAP lesion. On a photograph obtained during arthroscopy, the superior labrum (*S*) is separated from the superior glenoid rim. Note the irregular fraying of the free edge of the superior labrum (arrowheads). *G* = glenoid, *H* = humeral head.

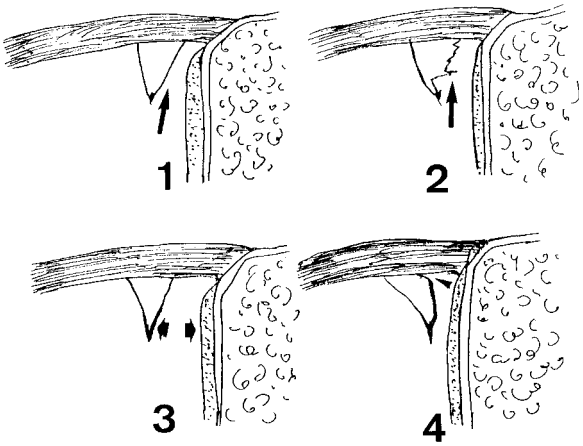

Figure 36. Type II SLAP lesion versus superior sublabral recess. Drawings representing a coronal section through the labral-bicipital attachment demonstrate a normal recess with a sharp free edge of the labrum (arrow in *1*), a type II SLAP lesion with an irregular appearance of the free edge of the labrum (arrow in *2*), a type II SLAP lesion with wide separation between the superior labrum and the glenoid (arrows in *3*), and a type II SLAP lesion with lateral extension of the labral tear (arrowhead in *4*).

and the biceps tendon and may be displaced into the joint space (Figs 37–39). The appearance of these lesions is similar to that of a bucket handle tear of the knee meniscus (10). The attachment of the biceps tendon to the superior glenoid remains intact. Type IV SLAP lesions are similar to

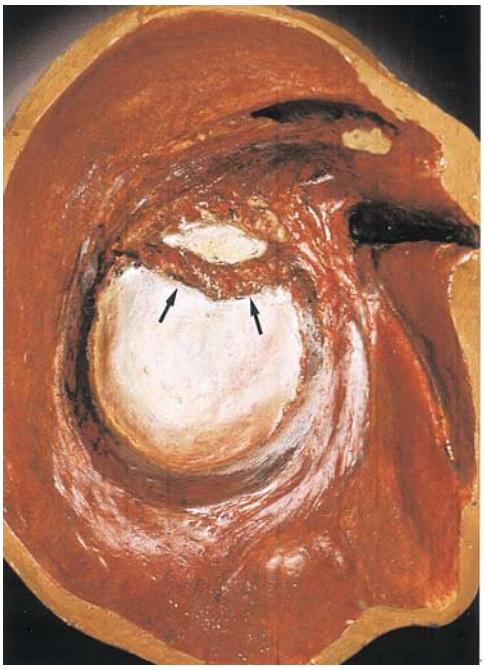

Figure 37. Type III SLAP lesion. On a photograph of a plastic model, the superior labrum is detached from the glenoid and the biceps tendon (arrows), a finding that is similar to a bucket handle tear of the knee meniscus.

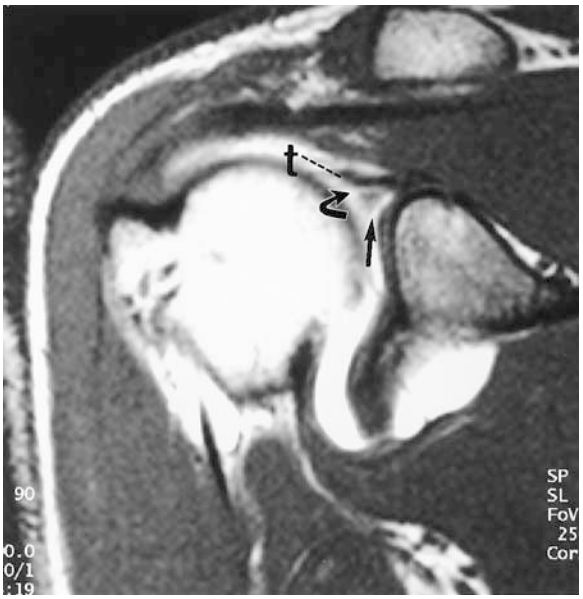

Figure 38. Type III SLAP lesion in a 25-year-old man. Coronal T1-weighted MR arthrogram (500/16) demonstrates contrast material interposed between the labrum and the glenoid (straight arrow) as well as between the labrum and the biceps tendon (*t*) (curved arrow).

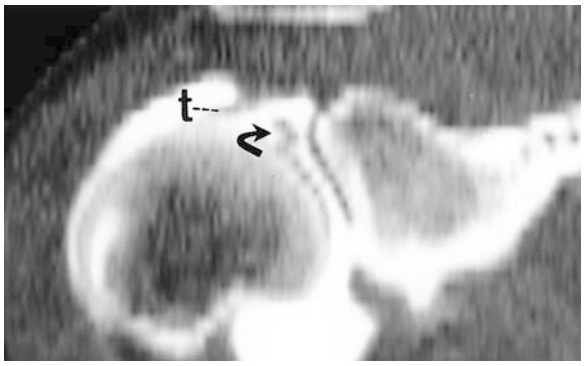

Figure 39. Type III SLAP lesion in a 34-year-old woman. On a coronal reconstructed image from a CT arthrogram, the labrum (arrow) is clearly separated and displaced from both the glenoid and the biceps tendon (*t*).

type III lesions, with the tear extending into the biceps tendon (Figs 40–42) (10,11).

Conclusions

Interpretation of CT and MR arthrograms of the shoulder is made difficult by the frequent occurrence of normal variants of the labrum and the complexity of injuries involving the labral-bicipital complex. It remains difficult to differentiate normal variants from pathologic conditions and to distinguish between various types of SLAP lesions.

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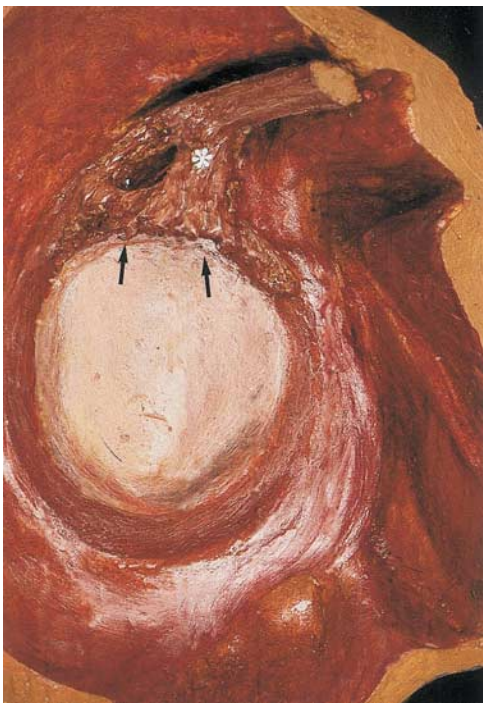

Figure 40. Type IV SLAP lesion. Photograph of a plastic model shows a bucket handle tear of the superior labrum (arrows). Note the extension of the tear into the biceps tendon (*).

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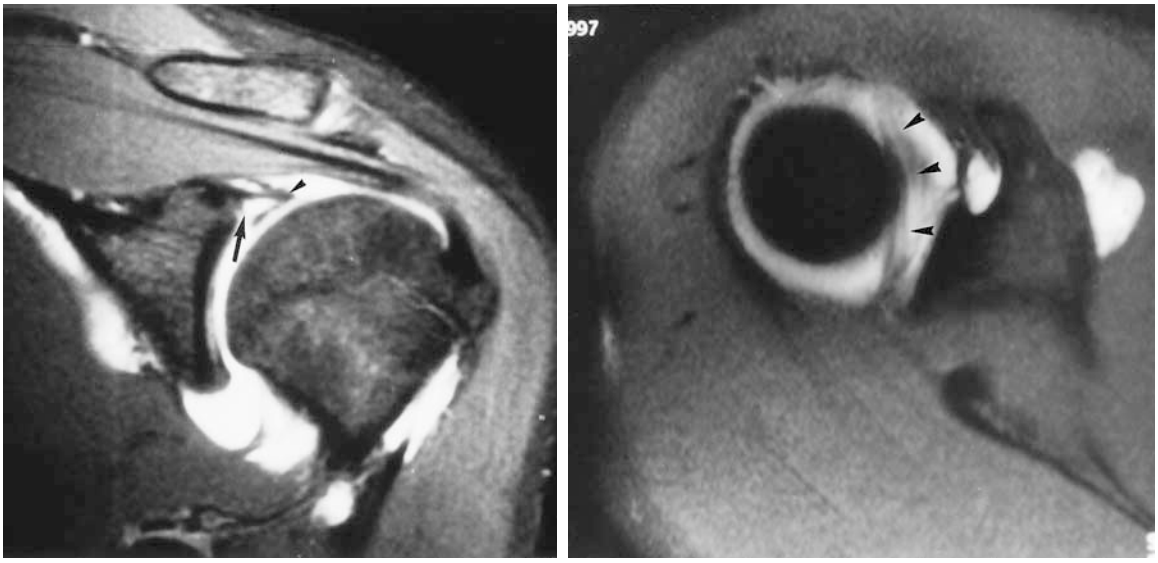

41. 42.

Figures 41, 42. **(41)** Type IV SLAP lesion. Coronal fat-saturated T1-weighted MR arthrogram (640/14) demonstrates separation of the superior labrum from the glenoid (arrow). Note the extension of the tear into the biceps tendon (arrowhead) (cf Fig 40). **(42)** Type IV SLAP lesion in a 25-year-old man. Transverse fat-saturated T1-weighted MR arthrogram (660/12) shows a tear extending into the biceps tendon (arrowheads) (cf Figs 40, 41).

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