Principles of Shoulder Imaging

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Contents

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Keywords
Anatomy • Arthrography • CT and CT arthrography • MR & MR arthrography • Radiographs • Ultrasound

Introduction

Radiographs, fluoroscopy, ultrasound (US), computed tomography (CT) and magnetic resonance imaging (MRI) are the modalities most frequently used in investigating the shoulder. US and MRI are most often used for evaluating the rotator cuff.

The need for imaging of the shoulder, particularly the rotator cuff, has increased over the last few years, probably related to the ageing population and an increase in sport-related injury. The first publication regarding the use of US for the evaluation of the rotator cuff was by Seltzer et al., published in 1979 and for MRI was by Kneeland et al. in 1986. In the ensuing years advances in imaging technology and extensive research have improved understanding of rotator cuff pathology. At present both these modalities still have limitations and a rotator cuff imaging gold standard is yet to be realised. CT and MRI arthrography have significantly improved the imaging of the labrum and ligamentous structures of the gleno-humeral joint. Conventional arthrography is currently not used in isolation for diagnostic purposes. In this chapter we aim to provide the reader with a comprehensive overview of the imaging modalities for investigating shoulder pathology.

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Anatomy

An in-depth knowledge of the anatomy of the shoulder is key to the interpretation of any shoulder imaging. Below is a short overview.

Biceps

The biceps has two heads: the short head of biceps, which arises from the coracoid process, and the long head of the biceps, which arises from the supraglenoid tubercle and superior labrum. The long head of biceps follows an intra-articular, intrasynovial path to descend into the intertubercular groove, between the greater and lesser tuberosities. It is one of the structures in the anterior (rotator) interval of the rotator cuff along with the coraco-humeral ligament and the superior gleno-humeral ligament. The anterior interval is located between the subscapularis and supraspinatus tendons. The biceps tendon inserts into the radial tuberosity of the radius, with an additional aponeurotic insertion into the lacertus fibrosus.

Deltoid

The deltoid arises from the lateral clavicle, the acromion and the lateral scapular spine and inserts into the deltoid tubercle of the humerus.

Rotator Cuff Tendons

Subscapularis

The subscapularis arises from the anterior aspect of the scapula and inserts into the lesser tuberosity of the humerus.

Supraspinatus

The supraspinatus arises in the suprascapular fossa of the scapula and inserts into the superior facet of the greater tuberosity of the humerus.

Infraspinatus

The infraspinatus arises from the medial aspect of the infraspinous fossa of the scapula and inserts onto the middle facet of the greater tuberosity of the humerus.

Teres Minor

The muscle arises from the lateral margin of the scapula and inserts onto the inferior facet of the greater tuberosity of the humerus (Table 1).

Gleno-Humeral Joint

This is the most mobile and the least stable of the joints in the body. This is because the articular surfaces are asymmetrical in size and morphology, with the small and relatively flat glenoid surface, articulating with the large, round articular surface of the humeral head, within a lax joint capsule. This laxity of the capsule allows for a greater range of movement at the shoulder joint, but makes the shoulder inherently unstable and prone to subluxation and dislocation. The fibrocartilaginous labrum at the periphery of the glenoid deepens and widens the shallow glenoid.

The articular surfaces of the humeral head and glenoid are covered by hyaline cartilage. Humeral articular cartilage extends to the anatomical neck, which is also the lateral attachment of the joint capsule. Medially the capsule is attached to the margin of the glenoid just medial to the labrum, posteriorly and inferiorly. Inferiorly, it is lax and this is the weakest part of the capsule. Anteriorly, based on the attachment of the capsule in relation to the glenoid labrum, it is classified into three types:

Type 1. Capsule inserts onto the labrum

Type 2. Capsule inserts onto the scapular neck, within 1 cm of the labrum

Type 3. Capsule inserts onto the scapular neck, greater than 1 cm from the labrum.

Superiorly it extends to the root of the coracoid and contains the supraglenoid origin of the long head of the biceps.

There are two apertures in the capsule, one between the humeral tuberosities, which allows the passage of the biceps tendon, and the other is

Table 1 Anatomy of the rotator cuff muscles

Muscles	Origin	Insertion	Action	Nerve Supply
Subscapularis	Anterior aspect of body of scapula	Lesser tuberosity	Adduction & internal rotation	Upper and lower subscapular nerves
Supraspinatus	Supraspinous fossa of the scapula	Superior facet of the greater tuberosity	Internal rotation & abduction	Suprascapular nerve
Infraspinatus	Infraspinous fossa of the scapula	Middle facet of the greater tuberosity	External rotation	Suprascapular nerve
Teres Minor	Lateral border of the scapula	Inferior facet of the greater tuberosity	External rotation	Axillary nerve
Biceps	Short head: coracoid process Long head: supraglenoid tubercle & superior labrum	Radial tuberosity of the radius and lacertus fibrosus	Supination & flexion	Musculocutaneous nerve
Deltoid	Lateral clavicle, acromion and scapular spine	Deltoid tubercle on the shaft of the humerus	Abduction	Axillary nerve

the subscapularis recess in the sub-corocoid region, which connects the subscapular bursa with the synovial space.

Synovium lines the fibrous capsule and forms a tubular structure around the biceps tendon as it passes through the intertubercular groove, extending to the surgical neck of the humerus. Multiple ligaments (coraco-humeral and the superior, middle and inferior gleno-humeral) re-inforce the capsule. The gleno-humeral ligaments extend from the anterior margin of the glenoid to the lesser tuberosity. These, especially the anterior band of the inferior gleno-humeral ligament, limit external rotation and anterior translation of the humeral head. The coraco-humeral ligament arises from the coracoid and inserts into the lesser and greater tuberosities, re-inforcing the capsule over the biceps tendon.

Acromioclavicular Joint

This joint lies between the medial aspect of the acromion and the lateral aspect of the clavicle. It is a synovial joint and is therefore prone to inflammatory athritis. Osteophytes projecting inferiorly can cause rotator cuff pathology. The joint is re-inforced by strong acromioclavicular ligaments, which limit joint movement, and contains a fibrocartilagenous disc. The coracoclavicular ligament, consisting of the trapezoid component laterally and the conoid component medially also aid in stabilizing the joint.

Sternoclavicular Joint

This joint lies between the medial inferior aspect of the clavicle and the superolateral aspect of the manubrium. It is lined by fibrocartilage and also has a fibrocartilage disc. This joint can be difficult to evaluate with radiographs. Thin section CT or MRI, with the patient prone to stabilise the sternum, provides better quality imaging.

Coraco-Acromial Arch

This is formed by the anterior acromion, the coraco-acromial ligament and coracoid process. The coraco-acromial ligament extends from the anterior acromion to the coracoid process and measures between 2 and 5 mm. in thickness. The subacromial space lies between the coracoacromial arch and the humeral head. The contents of this space are the subacromial bursa, the supraspinatus and infraspinatus tendons and the joint capsule. Thus, any narrowing of this space can cause impingement of the rotator cuff and the other constituents of the subacromial space. Bigliani has classified the under surface of the acromion into three types:

Type 1 (flat), Type 2 (concave) and Type 3 (anterior down slope, or hook, which can narrow the subacromial space).

Radiographs

Despite the advances in imaging technology, standard radiography is still the mainstay of shoulder imaging and is usually the first investigation.

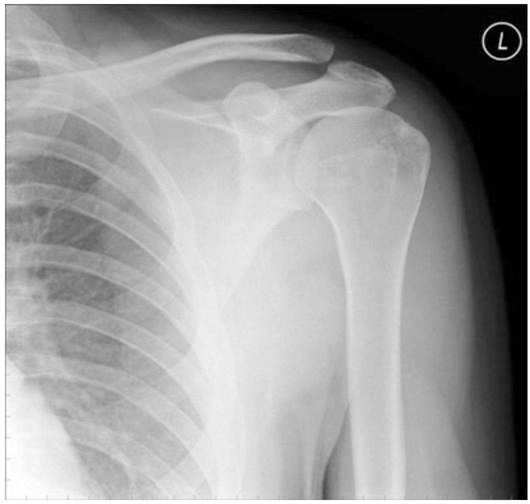

Fig. 1 AP radiograph of the shoulder

Indications

Any acute or chronic shoulder pathology: trauma, including fractures, dislocations (acute or chronic and the resulting bony injury); bony anatomy in chronic shoulder pain (morphological variants that may predispose to dysfunction, extent of arthropathy); radiographic features of rotator cuff disease; calcific tendonosis. Due to the complex anatomy of the scapula, fractures may be poorly demonstrated.

The most frequently used radiographic projections are:

- Anteroposterior (AP) view (Fig. 1)
- Gleno-humeral (GH) view (Fig. 2)
- Lateral (trans-scapular or "Y" view) (Fig. 3); with caudal angulation to show "outlet"
- Axial views (including axillary (Fig. 4) and variants: Stripp [1], Bloom Obata [2]) (Figs. 5, 6)
- Acromioclavicular Joint
- Stryker notch view (Fig. 7a, b)
  See Table 2

Fig. 2 AP radiograph of the glenohumeral joint

Arthrography

Indications

- As a therapeutic (long-acting local anaesthetic agent (LA) combined with corticosteroid) or diagnostic (with long-acting LA only) injection. Confirmation of intra-articular injection allows specific assessment of the effect of the injection; alleviation of pain post injection localises the pain to the shoulder joint.
- As part of a CT arthrogram or MR arthrogram with either iodinated contrast (CT) or gadolinium (MRI) injection into the joint.
- Therapeutic hydrodilatation as treatment of adhesive capsulitis. A large volume injection

Fig. 3 Lateral scapular "Y view" radiograph

Fig. 4 Axial radiograph

(typically consisting of iodinated contrast, corticosteroid, local anaesthetic and normal saline) is injected under fluoroscopic control to disrupt adhesions in the joint.

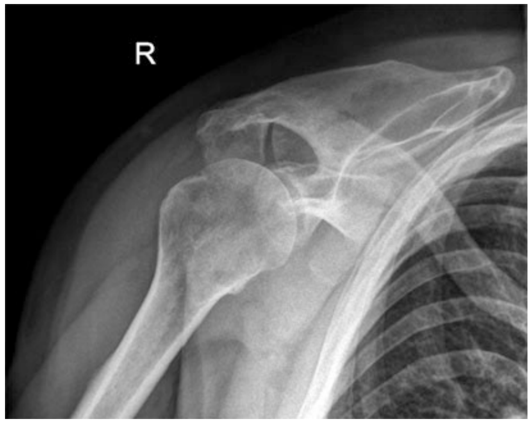

Fig. 5 Stripp (inferosuperior) axial radiograph

Fig. 6 Bloom Obata (superoinferior) axial radiograph

Anterior Approach

Patient lies supine with arm in external rotation (this moves the biceps tendon lateral to the puncture site and also allows maximum exposure of the humeral articular surface for puncture). The fluoroscopic beam is perpendicular to the table. This is the most common approach used by musculo-skeletal radiologists. The puncture site is variable [3], but usually immediately vertical to the medial cortex of the humeral head, where the skin is marked, cleaned and local anaesthetic administered. A 21 or 22G needle are suitable for joint puncture. The needle is introduced vertically and, when intra-articular, contrast medium is administered to confirm position of the

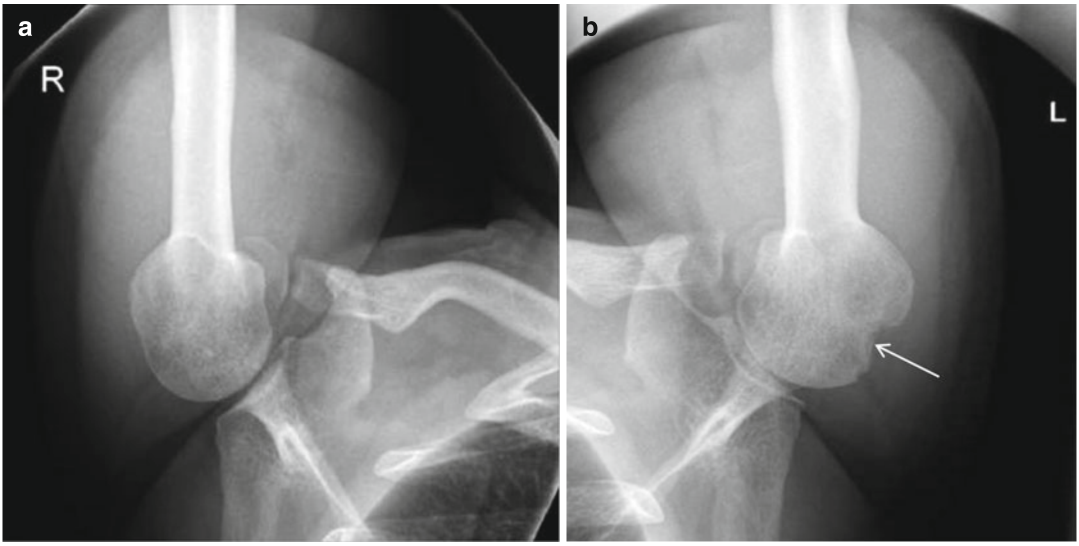

Fig. 7 (**a**) Stryker view (normal) (**b**) Stryker view – Hill-Sachs defect (*arrow*)

needle (Fig. 8). If this is a therapeutic or a diagnostic injection, a mixture of steroid and local anaesthetic or just local anaesthetic respectively is injected into the shoulder joint. If this is part of a CT or MR arthrogram intra-articular contrast medium is administered. A total of 10–15 ml is can be injected, but lax joints will be able to accommodate a larger volume. With adhesive capsulitis, the joint capacity is much reduced.

Posterior Approach

The advantage to this approach is that it prevents inadvertent contamination of the anterior structures by contrast medium.

Patient is in the prone oblique position. A 21G needle is aimed at the inferomedial quadrant of the humeral head.

Ultrasound

Indications

Identification of tendinosis and tears of the rotator cuff (partial and complete tears can be differentiated); tendinosis, rupture and subluxation of the biceps tendon; joint and bursal effusions; muscle, bone and articular cartilage lesions variably demonstrated; paralabral cysts (suggesting possibility of labral tear); suprascapular and axillary nerve pathology; AC and sternoclavicular joint. It also allows for dynamic assessment of impingement and for ultrasound-guided interventional procedures.

Ultrasound (US) has the advantages of being dynamic, with good spatial and contrast resolution, while remaining non-invasive and inexpensive. With good equipment and a skilled examiner, US enables assessment of partial and complete tears of the rotator cuff with high sensitivity and specificity. Many patients prefer US to MRI, as it is quicker and better tolerated.

Linear ultrasound probes or transducers use a range of high of frequencies, providing high resolution images. Broadband transducers use a spectrum of frequencies, for example 12–5 MHz, rather than a single frequency. High frequency components provide greater spatial resolution but limited depth penetration, whereas low frequency components extend the penetration depth [4]. Other ultrasound functions, which are of use in musculo-skeletal ultrasound, include Doppler, compound imaging, extended field-of-view imaging and beam steering.

Table 2 Radiographic assessment of the shoulder

Radiographic positions	Patient position	Technique/ Centring	Indications
Anteroposterior (AP) view	Patient standing, sitting or supine, with back against film (Fig. 1)	Coracoid process	Acute trauma of shoulder and proximal humerus (less patient discomfort); acromioclavicular joint. Gives an oblique projection of the gleno-humeral joint
Glenohumeral view (true AP of the shoulder joint)	Patient standing, sitting or supine, with back against film. Turn the patient toward the affected side to get the glenohumeral joint in profile (blade of scapula parallel to film) (Fig. 2)	Coracoid process	Chronic (occasionally acute) glenohumeral joint pathology (previous dislocation, arthropathy) demonstrates the gleno-humeral joint in profile
Lateral ("Y") view (posteroanterior)	Patient erect (standing or sitting), affected shoulder rotated 45° anteriorly, placed against the film (blade of scapula perpendicular to film) (Fig. 3)	Humeral head	Subluxation of humeral head; alternative second view in acute trauma
Outlet view (posteroanterior)	As for Y view, with 15° caudal angulation	Glenoid fossa	Contour of coraco-acromial arch, subacromial space
Axial view (superoinferior [SI], inferosuperior [IS])	Patient standing (generally IS), sitting (SI) or supine (IS), film against superior aspect of GH joint (IS) or curved cassette in axilla (SI), with arm abducted. Tube angulation away from (SI) or towards the trunk (IS) (Fig. 4)	Middle of GH joint through axilla	Acute trauma (limited by patient's ability to move); chronic shoulder pain; (Os acromiale) Can be performed erect with limited abduction in severe pain/ acute trauma
Stripp Axial (inferosuperior)	The patient sits on a stool with back to the x-ray tube. The x-ray tube is inverted such that the central ray is directed vertically upwards. The cassette placed over the affected shoulder, kept in place by the patient's other hand. The patient leans back slightly (Fig. 5)	Vertical, central ray directed through the axilla	Provides an axial view without the need to abduct the arm in a painful or immobile shoulder
Bloom-Obata Axial (superoinferior)	Patient on stool, leaning back onto table, such that shoulder is vertically above cassette on tabletop. X-ray tube positioned such the central ray directed vertically downwards (Fig. 6)	Vertical, central ray directed to the lateral tip of the clavicle	Provides axial view of the glenohumeral joint. Again useful when abduction is limited
AC Joint	The patient with back to film	Horizontal ray centred at midline at level of head of humerus	Demonstrates subluxations. Both sides on same film for comparison
Stryker (notch) view	Patient supine, hand behind head with shoulder externally rotated and abducted (Fig. 7a, b)	Central ray directed to coracoid process with 10° cranial angulation	Shows humeral head contour (useful in chronic anterior dislocation to show presence of Hill Sachs deformity)

The patient is positioned on a stool with the examiner standing either in front or behind, depending on individual preference. A posterior approach allows for easy access to the US keyboard and the patient's shoulder.

All tendons are examined in their long and short axis, for example, in the following order: the biceps, the subscapularis, the supraspinatus, the infraspinatus and teres minor. A systematic approach, even for

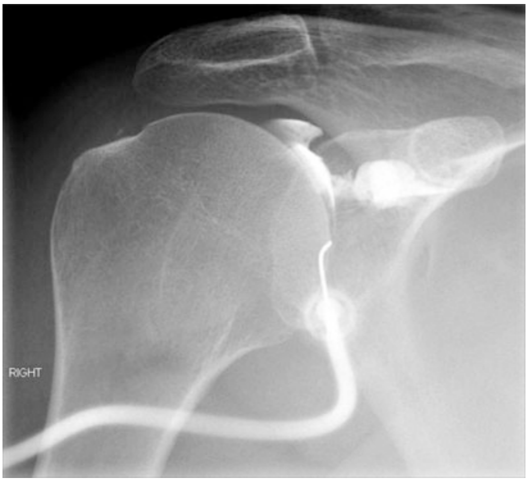

Fig. 8 Fluoroscopy guided needle placement for arthography

Fig. 9 Position of the probe for examination of the long head of biceps tendon in short axis (elbow flexed to 90°). Turn the probe through 90° to visualise the biceps in the long axis

experienced examiners, will ensure that less obvious findings are not overlooked.

It is important that the US transducer is always orientated perpendicular to the tendon; this avoids the loss of echogenicity, which can simulate a tendon tear. This is apparent hypo-echogenicity of the tendon is called anisotropy and can be overcome by slight rotation/angulation of the transducer. If this is due to real pathology, the hypo-echogenicity will persist. However, if it is due to positioning, the hyper-echoeic tendon fibrils will be visualised again on proper positioning of the transducer perpendicular to the tendon [5].

Ultrasound Examination of the Shoulder

Long Head of Biceps

The normal biceps tendon has a fibrillar appearance. A non-fibrillar appearance is abnormal and would suggest degeneration (tendon tissue still visible) or rupture (tendon not visible). An additional reason for non-visualization of the tendon is subluxation/dislocation from the bicipital groove and the tendon should always be sought in a more medial location. Tendon (tendonosis, partial and complete tears, instability) and tendon sheath (synovitis, synovial bodies) pathologies should be assessed.

Patient position. The patient is seated comfortably on a stool, with the arm to be examined in the neutral position (arm against trunk, elbow bent to 90°, forearm supinated), or in slight internal rotation (Fig. 9).

The bicipital groove is identified between the lesser and greater tuberosities of the humerus. Within it, the arcuate artery may be identified lateral to the tendon. The biceps tendon is visualised in both the short (Fig. 10) and long axis (Fig. 11). Slight cranial angulation of the probe is usually required in both planes to abolish anisotropy. The myotendinous junction is at the level of insertion of the pectoralis major muscle into the lateral lip of the intertubercular groove. From the neutral position the arm is moved from internal to external rotation to check for subluxation/dislocation.

Rotator Cuff

On US the rotator cuff is variably hyper-echoic when compared to the overlying deltoid muscle. However this echogenicity is age-related and the rotator cuff may not be as hyper-echoeic in older patients.

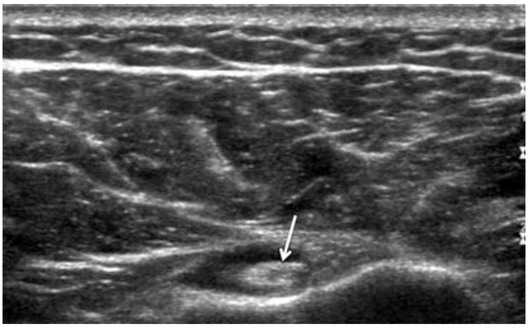

Fig. 10 The long head of biceps – short axis (*arrow*), with a small surrounding tendon sheath effusion

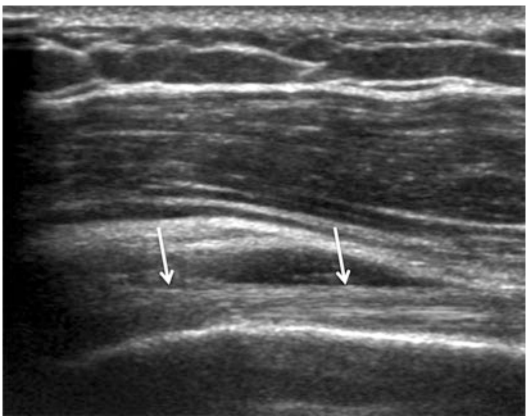

Fig. 11 The long head of biceps – long axis (*arrows*). Note the normal fibrillar pattern

Fig. 12 Position of the probe for examination of the subscapularis tendon in long axis. The patient's shoulder is externally rotated (varying the position allows examination of the whole tendon), the elbow remains against his side. Turn probe through 90° to examine tendon in the short axis

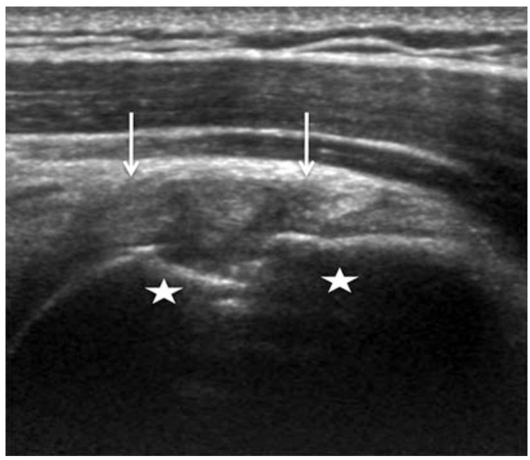

Fig. 13 Short axis view of the multipennate subscapularis tendon (*arrows*). Lesser tuberosity (*asterisks*)

Subscapularis

The patient is then asked to externally rotate the arm (from the neutral position for examination of the biceps tendon), which allows more complete evaluation (Fig. 12). Varying the degree of external rotation allows visualization of the entire tendon.

The short axis view shows the normal multipennate appearance (Fig. 13), which could be mistaken for a tear by the uninitiated. The long axis view demonstrates the insertion into the lesser tuberosity (Fig. 14). Dynamic assessment during internal/external rotation is used for subcoracoid impingement.

Supraspinatus

The patient is then asked to position himself with the arm to be examined behind his back or with the hand in/on his back pocket (Fig. 15). This moves the supraspinatus from under the acromion. In the short axis, the biceps tendon marks the anterior aspect of the supraspinatus tendon in the rotator interval (Fig. 16); extend this view in the same plane (cranial movement of the transducer) to visualise

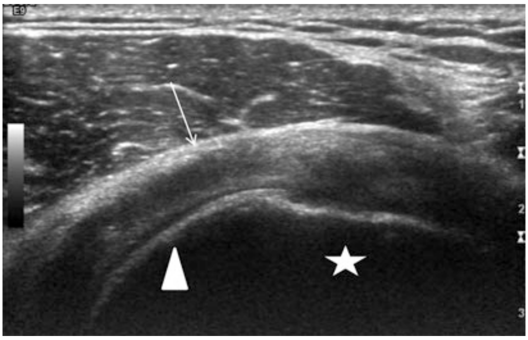

Fig. 14 Long axis view of the subscapularis tendon (*arrow*); lesser tuberosity (*asterisk*). Tendon passes from medial (*on the left*) to lateral (*on the right*) over the humeral head (*arrowhead*)

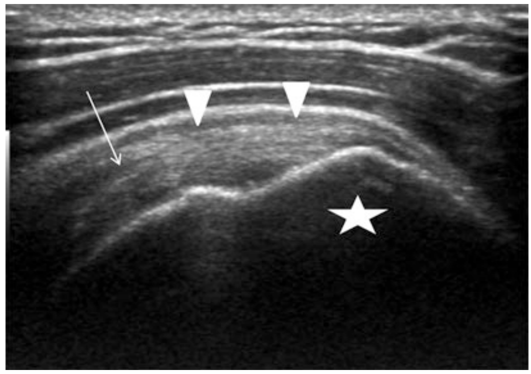

Fig. 17 The supraspinatus tendon – long axis (*arrow*); subacromial bursa (*arrowheads*), greater tuberosity (*asterisk*)

Fig. 15 Position of the probe for examination of the supraspinatus tendon in short axis. The patient's hand is placed over his back pocket

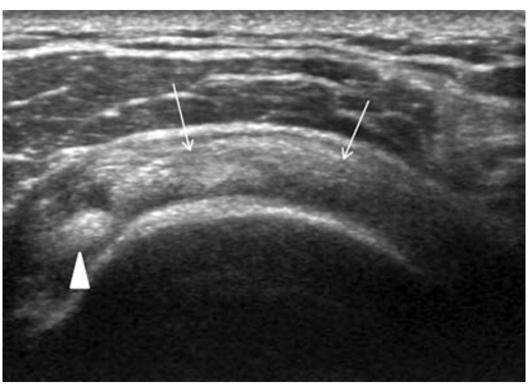

Fig. 16 The supraspinatus tendon – short axis (*arrows*); long head of biceps (*arrowhead*)

the entire tendon in short axis. It is important to visualise the biceps tendon in this view. In the long axis, the insertion into the greater tuberosity is demonstrated (Fig. 17). Partial thickness tears at the bursal surface are identified more clearly, due to abnormal contour of the usually smooth, convex bursal surface of the tendon. Early calcification within the tendon is identified more sensitively than on standard radiographs; evaluation of the subacromial-subdeltoid bursa is possible simultaneously (may be thickened or contain a fluid collection suggesting bursitis).

Infraspinatus

The patient is asked to place the ipsilateral hand on the contralateral shoulder (Fig. 18), allowing better visualisation of the tendon in the short and long axis (Figs. 19, 20). The muscle is examined and fatty atrophy can be clearly seen. The tendon merges posteriorly with teres minor without clear differentiation distally, but the morphology of the muscle belly and separation of the tendons more proximally allows the individual tendons to be evaluated.

Acromio-Clavicular joint AC joint

Examination is also possible in two planes, placing the transducer anteriorly and superiorly over the acromioclavicular joint. Osteophytes, subchondral cysts, synovitis, capsular hypertrophy and ganglia may be seen. The articular disc is

Fig. 18 Position of the probe for examination of the infraspinatus (long axis). The patient's hand is placed on the contralateral shoulder

Fig. 21 CT of the shoulder, axial reconstruction. There is an anterior glenoid fracture

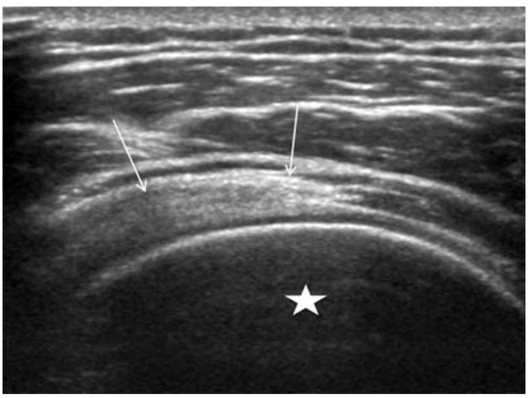

Fig. 19 The infraspinatus tendon – short axis (*arrows*); humeral head (*asterisk*)

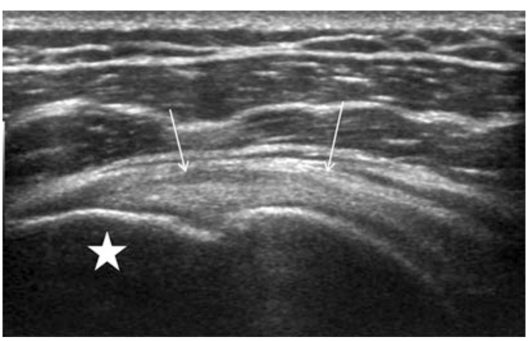

Fig. 20 The infraspinatus tendon – long axis (*arrows*); greater tuberosity (*asterisk*)

particularly well demonstrated in the short axis of the joint (sagittal probe position).

Gleno-Humeral joint

A limited evaluation is possible with ultrasound. The transducer is placed posteriorly over the joint with an increased field of view. Large gleno-humeral joint effusions/synovitis may be seen.

Computed Tomography (CT) and Computed Tomography Arthrography (CT Arthrography)

Indications

Provides high resolution assessment of bone (qualitative, quantitative and morphological) (Fig. 21). Useful for the characterisation of fractures; assessment of the morphology of the glenoid and humeral head, for example humeral torsion, glenoid version; further characterisation of focal bone lesions demonstrated by other imaging techniques (radiographs, MRI), for example the nidus in osteoid osteoma and sequestrum in osteomyelitis; assessment pre- and post- shoulder arthroplasty.

CT arthrography has two parts:

(A) The arthrogram and (B) The CT. The indications are similar to MR arthrography but

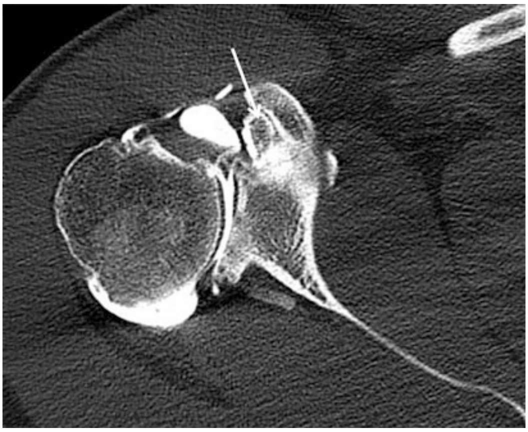

Fig. 22 CT arthrogram, axial reconstruction. There is osteoarthritis, posterior subluxation of the humeral head and an ossified intra-articular body (*arrow*) next to the coracoid process. The glenoid appears retroverted

it can be performed in patients with absolute contra-indications (e.g. pacemaker) and relative contraindications to MRI (e.g. post-arthroplasty). CT arthrography assesses the labrum, articular cartilage, joint capsule, rotator cuff tears and intra-articular bodies.

A. Arthrogram: Refer to the arthrogram section for the procedure. Once the intra-articular position of the needle is confirmed, 10–15 ml of iodinated contrast media is administered to distend the joint (single-contrast arthrography) or 2–3 ml contrast followed by air (double-contrast). Passive movement of the shoulder helps the contrast spread evenly through the joint. The patient should keep the arm close to the body with minimal movement to prevent dissipation out of the joint.
B. CT scan: Multi-planar reconstruction enables full appraisal of the labrum and joint in multiple planes (Fig. 22).

MR and MR Arthrography

Indications

Shoulder MR is used to assess the integrity of the rotator cuff tendons, the muscles of the rotator cuff, with additional arthrography particularly useful for assessment of articular side partial thickness tears, joint surfaces and intra-articular bodies and the labro-ligamentous complex/capsule. Conventional shoulder MR provides accurate diagnosis of full thickness tears of the rotator cuff, however it is less sensitive in the diagnosis of partial thickness tears. Both US and MRI evaluate cuff tendons accurately, but with full-thickness tears, cuff muscle atrophy (originally studied using CT [6]), crucial in the long-term functional outcome post-surgical repair, can be assessed and graded more easily (and with less operator-dependability) using MRI [7]. MRI also has the advantage of giving a more "global" assessment of the shoulder region.

Normal Anatomical Variants

There are some normal variants in relation to the glenoid labrum that must not be confused with labral tears. If the glenoid articular surface is viewed as the face of a clock most normal variants occur in the 11–3 o' clock position (anterosuperior quadrant) [8].

Sub-Labral Foramen

A localised detachment of the anterosuperior labrum from the glenoid at the 2 o' clock position, anterior to the biceps tendon attachment [9]. It can be difficult to differentiate from an anterosuperior labral tear.

Sub-Labral Recess

A synovial reflection between the cartilage of the glenoid cavity and the superior labrum. It is located at the 12 o' clock position at the site of attachment of the biceps tendon. It can communicate with the sub-labral foramen. This may be misinterpreted as a superior labral anteroposterior (SLAP) tear [9].

Buford Complex

The antero superior labrum is congenitally absent and is associated with a thickened cord like middle gleno-humeral joint. This can simulate an avulsed anterior labral fragment [10].

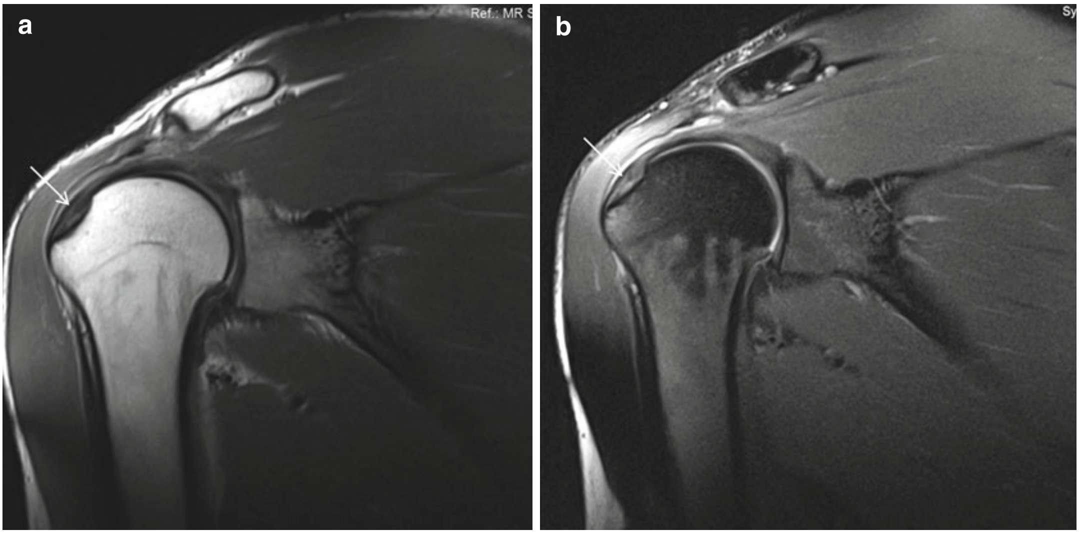

Fig. 23 (**a**) MRI shoulder. Coronal proton density, showing the supraspinatus tendon (*arrow*) (**b**) MRI shoulder. Coronal proton density with fat saturation, showing the supraspinatus tendon (*arrow*)

MR Sequences

Coronal Oblique Images

These are obtained parallel to the supraspinatus tendon, in the coronal oblique plane. Multiple sequences may be used: the authors' preference is proton density (PD) and PD with fat saturation (FS) or inversion recovery sequences (STIR). A high resolution, fluid-sensitive sequence, usually with fat-saturation, gives accurate assessment of full-thickness tears of the cuff (Fig. 23). Fat suppression techniques improve the ability to diagnose full and partial thickness rotator cuff tears [11].

Sagittal Images

These are obtained in a plane perpendicular to the long axis of the supraspinatus tendon. They are useful for assessment of the rotator cuff tendons in short axis, cuff muscle bulk and signal, the subacromial sub- deltoid bursa and the acromioclavicular joint. Useful sequences are proton density (with or without FS) or T2-weighted fast spin echo (Fig. 24).

Axial Images

These evaluate the AC and gleno-humeral joints for arthropathy; useful for visualising the subscapularis tendon in the long axis, the long head of biceps tendon in the bicipital groove and labral pathology is occasionally seen (better evaluated with intra-articular contrast). Common sequences include T2-weighted gradient echo (T2*) and fat-saturated proton density (Fig. 25).

MR arthrography has been found to be more sensitive than conventional MR for labral tears and is considered to be the imaging gold standard for the detection of labral pathology. It is also better at detection of partial (articular surface) supraspinatus tears, gleno-humeral articular cartilage deficiency and intra-articular bodies than conventional MR. 3 T MRI has recently been shown to improve the demonstration of some of these lesions without contrast injection. MR arthrography is certainly not required in all patients and should be restricted to those with appropriate indications, often instability, in view of the additional time required to perform the arthrogram, the small risk of complications and the limited additional information obtained in some cases.

MR arthrography, similar to CT arthrography, has two components: (A) The arthrogram and (B) MR:

A. Arthrogram: Refer to the arthrogram section for the procedure. Once the intra-articular position of the needle is confirmed using iodinated

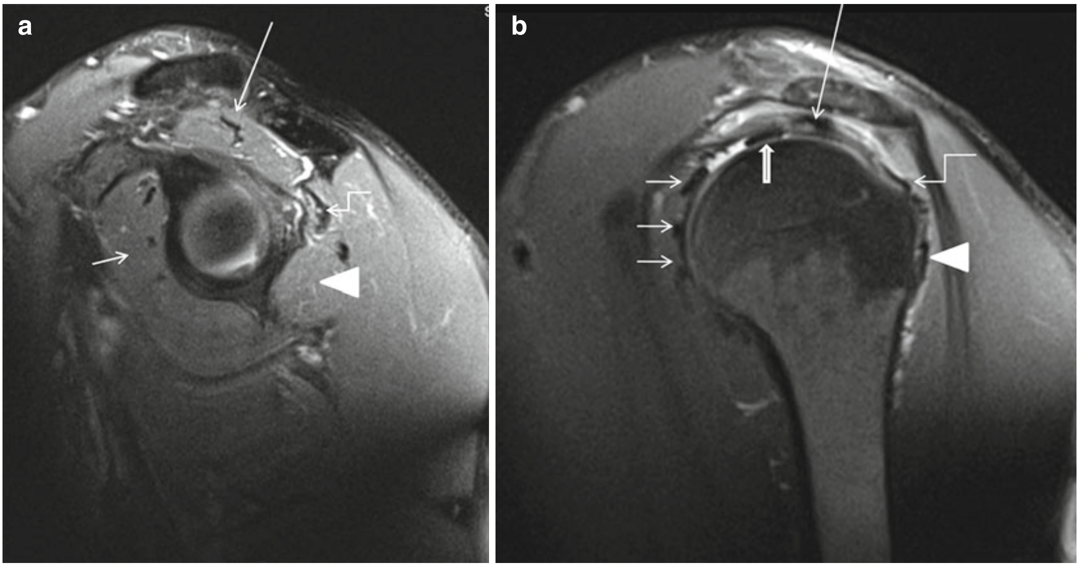

Fig. 24 (**a**) MRI shoulder. Sagittal proton density image with fat saturation at the level of the glenoid, to show cuff muscles and forming tendons. Subscapularis- short arrow, supraspinatus- long arrow, infraspinatus- curved arrow, teres minor- arrowhead (**b**) MRI shoulder. Sagittal proton density image with fat saturation, obtained more laterally for visualisation of the tendons close to their insertions. Subscapularis-short arrows, supraspinatus- long arrow, infraspinatus- curved arrow, teres minor- arrowhead, long head of biceps- block arrow

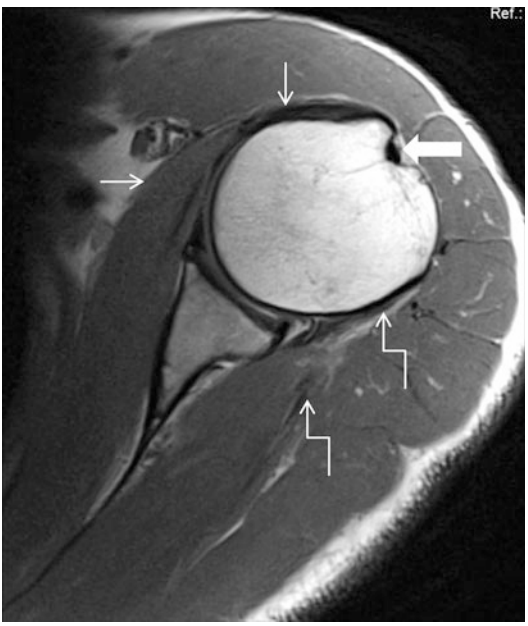

Fig. 25 Axial MR (proton density) image. Subscapularis-*short arrows*, infraspinatus- *curved arrows*, long head of biceps- *block arrow*

contrast, either dilute gadolinium or saline is injected into the shoulder joint. Passive movement of the shoulder helps the contrast spread evenly through the joint. After this the patient should keep the injected arm close to the body with minimal movement to prevent dissipation out of the joint. Care should be taken to avoid injection of even small quantities of air.

B. MRI: The patient then has a shoulder MRI. Depending on whether gadolinium or saline is injected the imaging obtained is either T1-weighted with fat-saturation (with gadolinium) or proton density/T2-weighted. Following injection, MRI should be performed without delay while there is maximal joint distension [12] (Fig. 26).

Indirect MR arthrography is less invasive than direct MR arthrography. This technique involves an intravenous injection of gadolinium, followed by gentle exercise and delayed imaging (15–20 min). This results in contrast in the joint

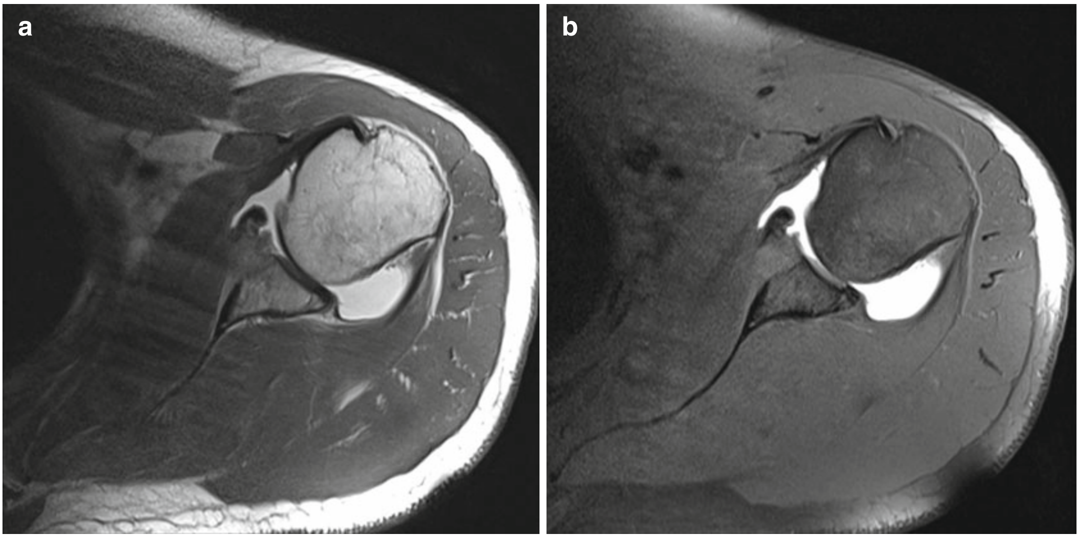

Fig. 26 (**a**) MR arthrogram: axial proton density image (same patient as Fig. 21, anterior glenoid fracture). (**b**) MR arthrogram: axial T1-weighted image with fat saturation (same patient as Fig. 21, anterior glenoid fracture)

secondary to diffusion across the synovium [13]. There is no significant joint distension from injected contrast and intra-articular structures are consequently less well shown – it may be of use if an arthrogram cannot be performed.

Post-Surgical Shoulder

The post-surgical shoulder is imaged using the various imaging modalities previously described (radiographs, ultrasound, CT (+/− arthrogram) and MRI), each of which have advantages and disadvantages.

The challenges to imaging the post-operative shoulder come from the altered anatomy, post-operative scarring and, on CT and MRI, from the artifacts due to ferromagnetic screws, staples and metal shavings. Use of titanium and non-metallic fixation help reduce these artefacts. Also, use of specific sequences such as turbo-spin echo (TSE) and fast-spin echo (FSE), as an alternative to conventional spin-echo and gradient-echo, help reduce the susceptibility artefact. Fat suppression sequences are more prone to disruption and fast-spin echo inversion recovery (STIR) sequences can be helpful in these situations [14]. MR arthrography can be useful in the post-operative shoulder by distending the joint, which provides improved delineation of the rotator cuff, capsule-labral structures and tendons [15], but CT arthrography is often more appropriate for evaluation of the cuff following shoulder arthroplasty.

References

1. Stripp W. Special techniques in orthopaedic radiography. In: Murray O, Jacobson HG, editors. The radiology of skeletal disorders. 3rd ed. Edinburgh: Churchill Livingstone; 1990.
2. Bloom M, Obata W. Diagnosis of posterior dislocation of the shoulder with use of Velpeau and angle-up roetgenographic view. J Bone and Joint Surg Am. 1967;49A:943–9.
3. Shortt C, Morrison W, Roberts C, Deely D, Gopez A, Zoga A. Shoulder, hip and knee arthrography needle placement using fluoroscopic guidance: practice patterns of musculoskeletal radiologists in North America. Skeletal Radiol. 2009;38:377–85.
4. Whittingham T. Broadband transducers. Eur Radiol. 1999;9 (Suppl 3):S298–303.
5. ESSR Ultrasound Group Protocols. Available at www.essr.org (educational material)

6. Goutallier D, Postel J, Bernageau J, Lavau L, Voisin M. Fatty degeneration in cuff ruptures. Pre and postoperative evaluation by CT scan. Clin Orthop. 1994;304:78–83.
7. Zanetti M, Gerber C, Hodler J. Qualitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. Invest Radiol. 1998;33:163–70.
8. McCarthy CL. Glenohumeral instability. Imaging. 2007;19:201–7.
9. De Maeseneer M, Van Roy F, Lenchik L, et al. CT and MR arthrography of the normal and pathological anterosuperior labrum and labral –bicipital complex. Radiographics. 2000;20:S67–81.
10. Tirman P, Feller J, Palmer W, et al. The Buford complex- a variation of normal shoulder anatomy: MR arthrographic imaging features. AJR Am J Roentgenol. 1996;166:869–73.
11. Reinus W, Sady K, Mirowitz S, Totty W. MR diagnosis of rotator cuff tears of the shoulder: value of using T2-weighted fat saturated images. AJR Am J Roentgenol. 1995;164:1451–5.
12. Andreisek G, Duc S, Froehlich J, Hodler J, Weishaupt D. MR athrography of the shoulder, hip and wrist. Evaluation of contrast dynamics and image quality with increasing injection to imaging time. AJR Am J Roentgenol. 2007;188:1081–8.
13. Bergin D, Schweitzer M. Indirect magnetic resonance arthrography. Skeletal Radiol. 2003;32:551–8.
14. Wu J, Covey A, Katz L. MRI of the postoperative shoulder. Clin Sports Med. 2006;25:445–64.
15. Mohana–Borges AV, Chung CB, Resnick D. MR imaging and MR arthrography of the postoperative shoulder: spectrum of normal and abnormal findings. Radiographics. 2004;24:69–85.