Clinical Interpretation & Advanced Imaging: Shoulder

Skill Level: Basic to Advanced

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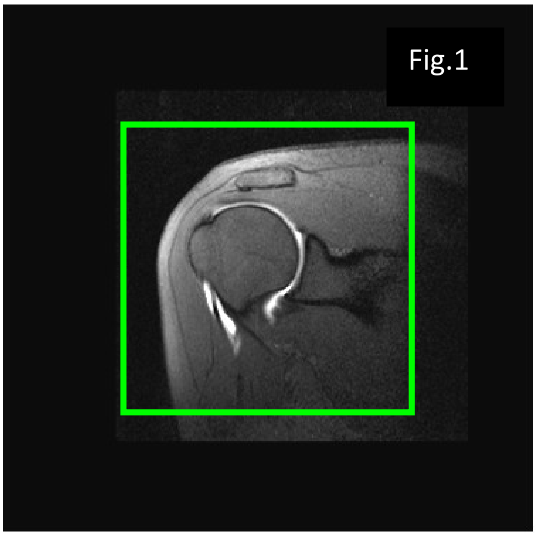
Take Home Points;

- Discussion of patient positioning, basic techniques and protocols available for MRI of the shoulder
- Choices available for basic imaging including differing field strengths and indications for MR arthrography
- Discussion of normal anatomy and the 2 main clinical indications for shoulder imaging;
  - Subacromial Impingement
  - Joint Instability
- Interpretation, relevance and reporting MRI findings

Background
The shoulder has the greatest range of movement of any joint in the body which contributes anatomically to an inherently unstable joint which is particularly vulnerable to injury through direct trauma or overuse. With magnetic resonance imaging (MRI), the radiologist is able to demonstrate a wide range of bone and soft tissue injuries and in many cases can assist in treatment through guided intervention. Currently the principal imaging techniques available for assessing the shoulder are conventional radiographs, CT, ultrasound, MRI and MR and CT arthrography. However many of the important injuries of the shoulder joint involve soft tissues such as the rotator cuff, glenoid labrum and biceps tendon. MRI is readily able to identify abnormalities associated with these structures and is also useful for evaluating osteochondral injuries. Supplementing MRI with arthrographic techniques can increase sensitivity to injuries to the structures.

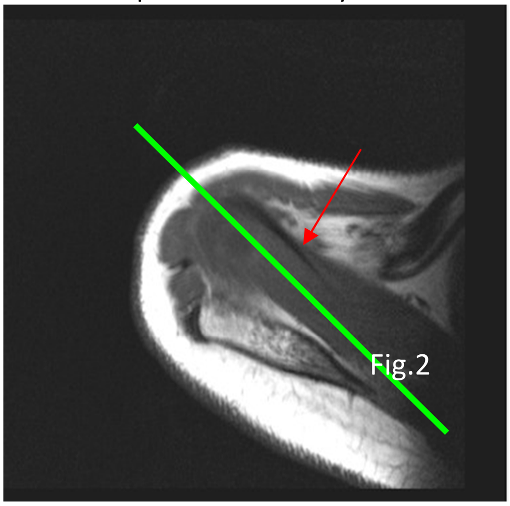
MRI Shoulder Protocols
- *Position - Standard*
  - Supine, hand by side, palm up. If palm up not possible, then thumb up. Must not be internally rotated.
- *Position - ABER*
  - Hand palm up behind head, or at least above head

Scan Planes
Axial - Aligned perpendicular to the plane of the glenoid
Must include acromion on most superior slice
Must cover whole of glenoid (see green Field of View on fig.1 below)



Coronal Oblique

- Set up from high axial slice that shows supraspinatus tendon (SST – red arrow on fig.2 below)
- Align along SST (green line on fig.2 below)
- Slices must cover from coracoid process anteriorly and include entire humeral head



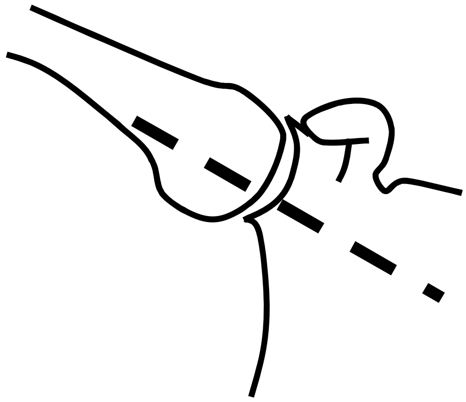
Sagittal Oblique

- Perpendicular to coronal oblique plane
- Must extend laterally to include whole humeral head and extend medially to include whole of coracoid process

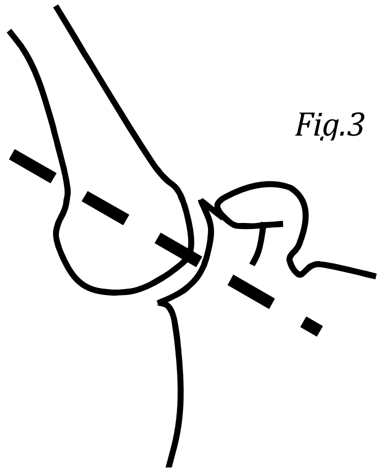
ABER

- Align from coronal scout perpendicular to glenohumeral joint line (perpendicular to glenoid)
- Ideally this will be along the humeral shaft but if arm is very abducted the angle of section will be less than this (see Fig.3)

Fig.3



Ideal Plane for ABER



Plane for ABER with arm more abducted

SHOULDER – Shoulder Coil

1 Routine non arthrogram Protocol

- Axial PD TSE (fat sat
- Coronal Obl PD TSE (fat sat)
- Coronal Obl T2 TSE (fat sat)
- Sagittal Obl T1 SE
- Sagittal Obl T2 TSE (fat sat)

2 MR Arthrogram Protocol

- Axial T1 SE
- Axial T1 PD (fat sat)
- Sagittal Obl T1 SE (fat sat)
- Coronal Obl PD SE (fat sat)
- Coronal Obl T2 TSE (fat sat)

Reposition patient – Body Matrix Coil

- ABER Position T1 SE Axial Oblique (fat sat)

Shoulder Anatomy

The humeral head balanced on the relatively small glenoid is analogous to a golf ball sitting on a tee, additionally requiring deepened of the glenoid by a circumferential fibrocartilage labrum. This potentially unstable arrangement requires soft tissue structures to help maintain the stability of the joint. The stabilisers of the joint are generally divided into two groups:

1) The dynamic stabilisers. These are the rotator cuff tendons which function throughout the large range of motion keeping the humeral head centered on the glenoid by competent neuromuscular function
2) The static stabilisers. These comprise the glenoid labrum and glenohumeral ligaments which function at the end range of motion keeping the humeral head from subluxing or dislocating by acting as a check rein.

The rotator cuff

The rotator cuff muscles act to control the position of the humeral head on the glenoid drawing it towards the glenoid and maintaining it in a central position while the more powerful muscles of the shoulder girdle such as the deltoid, pectoralis major and latissimus dorsi act on the arm. The rotator cuff is made up of four muscles and tendons:

- Supraspinatus
- Infraspinatus
- Subscapularis
- Teres minor

All four muscles arise from the scapula and insert into the tubercles of humeral head. The subscapularis arises from the anterior scapula and inserts into the lesser tubercle of the humerus. Supraspinatus arises from the supraspinatus fossa, while infraspinatus and teres minor arise from the posterior aspect inferior to the spinous process. These latter three muscles insert via their tendons into the greater tuberosity of the humerus. The tendons of supraspinatus, infraspinatus and teres minor blend together at their insertion to form a continuous cuff, but are separated from the subscapularis tendon by a small gap known as the rotator interval. The long head of biceps tendon passes through the rotator interval as it tracks from its origin on the superior glenoid to the upper arm. As it transits the rotator interval it emerges from the joint capsule and is surrounded by a synovial sheath that is continuous with the joint cavity. It is now generally accepted that the long head of biceps tendon is important in maintaining shoulder stability.

The majority of fibres in the rotator cuff tendons are arranged longitudinally but a focal, deep portion of the supraspinatus and infraspinatus tendons containing fibres running transversely. These perpendicularly arranged tendon fibers on the articular side of the cuff extend in an arc from the anterior insertion of supraspinatus to the posterior insertion of infraspinatus and are known as the rotator cable.

The static stabilisers

The glenoid labrum and the glenohumeral ligaments make up the labroligamentous complex The coracohumeral ligament which anatomically forms the roof of the rotator interval between the subscapularis and supraspinatus and also stabilizes the biceps tendon.

It is well recognised that there are many variations in normal labral morphology. While the labrum can be firmly attached to the glenoid along its outer and central edge throughout its attachment which occurs via a transitional zone made of fibrocartilage; a well recognised variant is that the central edge is mobile with resulting recesses and foramina.

The glenohumeral ligaments represent thickened bands within the joint capsule and attach to both the margin of the glenoid through the labrum and to the proximal humerus. Although they are normally lax they become taut at the extremes of movement. It is at this point that they become vulnerable to disruption should movement continue beyond the endpoint reached. Three glenohumeral ligaments are recognised:

1. The Inferior glenohumeral ligament (IGHL). the most important of the glenohumeral ligaments
2. The middle glenohumeral ligament arises from the anterosuperior glenoid rim, attaching via the labrum. It passes inferiorly across the anterior aspect of joint capsule to its insertion into the anatomical neck of the humerus close to the less tuberosity. It resists extreme external rotation in the lower ranges of abduction. The middle glenohumeral ligament is extremely variable. Studies have found that it is absent in around about 30% of cases. On the other hand it may be extremely prominent and cord like. In this latter situation it may be associated with an absence of the anterosuperior labrum, a normal variant known as the Buford Complex.

3. The superior glenohumeral ligament is a smaller structure arising from the interval between the middle glenohumeral ligament and the biceps tendon.

The longhead of biceps and rotator interval

The long head of biceps arises from the superior glenoid with a variable attachment from the bony glenoid (superior glenoid tubercle and the labrum). Due to the continuity with the labrum the unit is best referred to as the biceps labral complex. There are well recognised variations in the way the biceps labral complex attaches to the glenoid. The attachment ranges from a firmly adherent attachment with no sublabral sulcus or foramen, through to an attachment with a very deep sulcus giving the labrum a meniscoid configuration.

Rotator Cuff Disease

Rotator cuff tendinopathy is defined as collagenous degeneration of the rotator cuff tendons and most commonly involves the supraspinatus tendon. Sporting activity may lead to cuff tendinopathy through overuse or impingement mechanisms. Tendinopathic change may subsequently progress to partial or full thickness tearing of the cuff, although the tendinopathic cuff is painful even in the absence of tearing. There may be associated subacromial or subcoracoid bursitis. Ultrasound and MRI are generally the imaging modalities of choice when investigating rotator cuff disease and impingement.

Impingement

Two types of shoulder impingement are recognized and both may be associated with rotator cuff pathology.

1. External impingement refers to impingement of the rotator cuff and overlying bursal structures on the structures of the coracoacromial arch which comprises of the coracoid process, coracoacromial ligament and acromion.
2. Internal impingement refers to the impingement of the undersurface of the rotator cuff on the glenoid labrum and humeral head. Complex mechanisms are involved and the exact pathophysiology remains poorly understood.

This syllabus will focus on external impingement and rotator cuff tears but time allows further types of impingement such as postero-superior impingement will be presented in the lecture.

Rotator cuff tendinopathy and external impingement

The aetiology of rotator cuff tendinopathy (and subsequent rotator cuff tearing remains controversial). While it may be that intrinsic factors to the tendon such as over use and reduced vascularity are important, it was Neer who proposed that 95% of all rotator cuff tears are the result of chronic impingement of the cuff between the humeral head and coracoacromial arch.
Bigliani showed that a hooked shape to the acromion (type III) was more frequently associated with the external impingement process than the curved (type II) or flat (type I)morphologies. This has been contested by others although the confusion may in part be due to the lack of reliability between observers when assessing subacromial morphology.
Other coracoacromial arch configurations associated with external impingement include subacromial osteophyte or enthesophyte formation, thickening of the coracoacromial ligament and lateral downsloping of the acromion. However it has been noted that many of the acquired features described may be a consequence of rotator cuff disease rather than a cause. An anterior os acromiale may be unstable and may predispose to impingement.
Impingement of the subscapularis tendon between the coracoid process and lesser tuberosity known as subcoracoid impingement has also been described. While this may be due to the

congenital configuration of the subcoracoid space it can also be seen after fractures of the coracoid or lesser tuberosity.

Secondary external impingement is due to dynamic narrowing of the subacromial space as a result of micro-subluxation of the humeral head in the glenoid. In contrast to primary external impingement this form of impingement occurs in the presence of a normal coracoacromial arch. The pattern of micro-instability seen in secondary external impingement may result from chronic microtrauma to the static stabilisers such as is seen in overhead throwing athletes. Given that the rotator cuff itself also acts to stabilise the glenohumeral joint it is easy to see that primary degeneration of the cuff can in itself lead to secondary external impingement.

Rotator cuff tears

Tears of the rotator cuff extending from the bursal surface to articular surface of the tendon are known as full thickness tears and result in an abnormal communication between the glenohumeral joint and the subacromial bursa. Partial thickness tears involve only the bursal or articular surface. Intrasubstance tears may also be seen.

Rotator cuff tears typically start at the anterior edge of supraspinatus, close to its insertion into the humerus, or in the region of the rotator crescent previously described. Having developed the tear may propagate. Initially extension tends to be through the rotator crescent and therefore through the remainder of the supraspinatus and into infraspinatus. The tear may also extend anteriorly through the rotator interval into subscapularis. When the tear only involves part of the supraspinatus tendon retraction of the tendon will be minimal, but once the whole tendon is involved there may be considerable retraction.

In the majority of cases rotator cuff tears develop as a consequence of tendon degeneration and impingement. However acute trauma can lead to a tendon tear, or not uncommonly to disruption of the kinetic chain as a result of bone avulsion from the greater or lesser tuberosity.

MRI and MR Arthrography of Rotator Cuff Disease

MRI has been extensively used for the assessment of rotator cuff disease and impingement. Bursal fluid is identified using fat suppressed T2 weighted or STIR imaging and has been shown to correlate with arthroscopic findings of subacromial bursitis. In clinical practice dynamic assessment of the shoulder with MRI is not usually undertaken. However morphological abnormalities of the coracoacromial arch are readily appreciated on MRI such as the configuration of the acromion and coracoacromial ligament. Other features to note include the presence of an os acromiale or undersurface acromial osteophyte/enthesophyte. While these findings are generally best seen on sagittal and coronal oblique imaging, the os acromiale is most easily appreciated on axial imaging and it is important to ensure the acromioclavicular joint has been included on the most superior sections of the axial sequence .

Tendinopathic change in the rotator cuff is seen as thickening of the cuff tendon which takes on an inhomogeneous appearance with increased signal on all sequences . The magic angle effect is a well recognised MRI artefact seen as increased signal on short TE sequences in highly organised linear structures such as tendons when there fibrils are lined close to 55° to B_o of the magnet. The fact the increased signal is seen on all sequences including the long TE sequences implies it is not due to this artefact.

Full thickness tears of the rotator cuff are seen as focal areas of tendon discontinuity . They are easiest to appreciate when the tendon gap is filled with fluid signal intensity but occasionally a gap may be filled with low signal intensity thought to be due to scar tissue. MR arthrography can be considered the gold standard imaging modality for full thickness rotator cuff tears although it is rarely necessary. Contrast will be seen within the subacromial bursa having passed from the glenohumeral joint through the defect in rotator cuff . For this reason MR arthrography can be helpful in distinguishing a partial thickness tear from a full thickness tear.

Occasionally a rotator cuff tear may communicate with the acromioclavicular joint resulting in cystic expansion of the joint capsule and presenting as a pseudo-tumour on the superior aspect of the ACJ. Here direct communication exists between the glenohumeral joint and ACJ cyst, this has been termed the "geyser" sign.
Articular or bursal partial thickness tears are seen on MRI as a focal defect in the tendon filled with joint or bursal fluid. Granulation tissue may also be present. Fat suppressed sequences can increase the conspicuity of fluid at the tear site. T2 weighted sequences as opposed to proton density sequences can be particularly helpful in distinguishing increased signal in the tendon due to tendinopathic change from the higher more intense signal seen in a fluid filled tear. If no communication is shown between the intra-tendinous fluid and either the bursal or articular surface an intrasubstance tear is implied.
MR arthrography offers no advantage over conventional MRI for the diagnosis of bursal surface tears. However contrast extension into articular surface tears may be seen and will improve their conspicuity. MR arthrography can be helpful to distinguish an articular surface partial thickness tear from an intrasubstance tear and a partial thickness tear from a full thickness tear. Visualisation of under surface partial thickness tears may also be improved by scanning the patient with the arm in an abducted and externally rotated (ABER) position. In this position the supraspinatus tendon is flaccid and this encourages fluid or contrast from the joint to pass into any undersurface tear.
In the more chronic stages of rotator cuff tear muscle atrophy may be present. Fat infiltration of the muscles affected can be appreciated on MRI along with loss of muscle bulk. Fat atrophy of cuff muscles is an important negative prognostic factor for rotator cuff surgery. Originally scoring system was developed for assessing fat atrophy on CT by Goutallier et al. However similar assessments of fat atrophy can be made using MRI.

Glenohumeral Instability

Types and Imaging Modalities

Shoulder instability can be considered in two broad categories.

1. Instability occurring following a traumatic dislocation of the shoulder: This will usually be unidirectional and results from the disruption of the stabilising structures of the glenohumeral joint. This form of instability will generally require surgery.
2. Multidirectional instability occurring without a history of injury: Here there is normally a capsular laxity which may be congenital which leads to the instability.

In the younger patient sustaining a shoulder dislocation it is more likely that there will be a disruption of the static stabilisers. In this situation MRI or MR arthrography will be the modality of choice.

Bankart Lesion and Bankart Variants

Anteroinferior dislocation is the most common pattern of dislocation seen and generally occurs with the arm in the abducted and externally rotated position. The anterior band of the IGHL acts as a check rein to further excursion when the arm is in this position and it is this structure and its attachments that is vulnerable when there is an anteroinferior dislocation.
The IGHL most frequently fails at its attachment to the inferior pole of the glenoid where it is intimately associated with the labrum. The most common pattern of injury involves detachment of the ligament at glenoid rim along with the labrum and this is referred to as the Bankart lesion. A soft tissue Bankart lesion involves avulsion of the labrum from the glenoid while a bone or osseous Bankart lesion is seen when a fragment of the glenoid rim itself is also avulsed. The presence and size of any bone component to the Bankart is important to record as it will influence the surgical management.

Several variants of the soft tissue Bankart are recognised:
1. The Perthe's lesion
This is a labroligamentous avulsion but the scapular periosteum remains intact and is stripped medially from the anterior glenoid. The significance of this lesion is that the labrum and ligament may show minimal displacement and the findings on MRI can be extremely subtle.
2. The ALPSA lesion
The ALPSA (anterior labroligamentous periosteal sleeve avulsion) is characterised by the torn labrum being displaced inferomedially by the IGHL and rolling up like a sleeve against the anteroinferior glenoid neck. The labroligamentous complex is displaced medially from the normal position. Healing by fibrosis may occur but the abnormal anatomical location leads to recurrent dislocations.
3. The GLAD Lesion
The GLAD lesion (glenolabral articular disruption) refers to a partial anteroinferior labral tear associated with a divot in the articular cartilage. This may result from a forced adduction injury and, although it causes pain, it is found in a stable shoulder.

Less commonly dislocation causes failure of the IGHL at other locations away from the glenoid attachment.
Sites of failure include:

1. The humeral attachment of the ligament. This is known as a HAGL (humeral avulsion of the glenohumeral ligament) lesion. A bone fragment may be avulsed with the ligament and this has been termed a BHAGL (bony humeral avulsion of the glenohumeral ligaments) lesion although this is rare.
2. The midsubstance of the ligament
3. Very occasionally the glenohumeral ligaments may avulse from the glenoid without associated labral disruption. This has been termed the GAGL (glenoid avulsion the glenohumeral ligament) lesion.

Impaction of the anteroinferior glenoid onto the posterosuperior humerus can cause a compression fracture of the humerus known as a Hill-Sachs fracture. This can increase in size with recurrent dislocations and may cause a dislocated shoulder to lock making relocation extremely difficult. A large Hill-Sachs fracture can also cause locking to occur in extreme abduction and external rotation if the defect engages with the rim of the glenoid.

MRI and MR Arthrography

Using fat suppressed imaging, such as may be used in MR arthrography, can make it difficult to detect small bony components of any Bankart lesion. It is useful to include a non-fat suppressed axial series as part of the protocol. In the soft tissue Bankart the labrum is completely detached from bony glenoid and fluid or contrast will be seen to separate the labrum from the glenoid. The ALPSA lesion is demonstrated on axial and coronal MR imaging where the displaced anterior labrum will be seen lying medially on the neck of the glenoid. In the chronic situation variable amounts of fibrosis may be seen. The Perthe's lesion is perhaps the most difficult to identify because in this situation the IGHL and labrum occupying normal position relative to the underlying glenoid. There may be haemorrhage/oedema at the IGHL attachment site but the most characteristic sign is the presence of subtle linear increased signal intensity at the base of the labrum. This is easier to detect on MR arthrography. MRI in the ABER position can be particularly helpful in improving visualisation by applying traction to the labrum through the IGHL opening up the site detachment. This can also be helpful when looking for the GLAD lesion. When a Bankart lesion is detected it is important to look for associated abnormalities such as a Hill-Sach humeral fracture or articular cartilage damage to be glenoid fossa.
The HAGL lesion can be difficult to detect on conventional MRI in the absence of a joint effusion and MR arthrography is particularly useful here. The high false positive rate has been emphasised.

Coronal images normally demonstrate a “U” configuration to the inferior glenohumeral ligaments as they form the axillary pouch. In cases of HAGL lesion the humeral attachment of the “U” is torn allowing the IGHL to lie more inferiorly giving the ligament a “J” shaped configuration.
In the many cases conventional MRI is able to effectively image shoulder instability, but MR arthrography does increase the conspicuity of the associated lesions and while the literature varies as to whether it is more accurate or not, it can certainly help increase diagnostic confidence. In the context of sports injuries it is worth noting that Magee et al showed that in a population of athletes baseball players higher diagnostic accuracy was achieved with MR arthrography when compared with conventional MRI; the added accuracy of the arthrographic technique was not reproduced to the same extent in a general population. More recently another article has shown that even compared with 3T conventional MRI, MR arthrography shows significantly increased sensitivity for the detection of anterior labral tears along with partial thickness articular surface supraspinatus tears and SLAP tears.

SLAP LESIONS

The SLAP lesion (**S**uperior **L**abral **A**nterior to **P**osterior lesion) describes a tear of the superior labrum, usually involving the biceps anchor, which may extend into the adjacent labrum anterior and posterior to the biceps tendon, or even into other associated anatomical structures. The young throwing athlete is typically affected presenting with pain, clicking and instability; and the mechanisms of injury include repetitive overhead activity such as is seen in throwing athletes and swimmers. The peel-back mechanism described under the internal impingement section of this chapter is now recognised as important in the aetiology of at least a subset of SLAP lesions, typically giving rise to a posterosuperior labral tear. However it may well be that different mechanisms of injury result in different types of lesion.

CONCLUSIONS

This syllabus has detailed the shoulder positioning and basic MR techniques for obtaining high quality diagnostic images that allow the assessment of pathologies associated with shoulder impingement and instability.
The accompanying lecture will reinforce these processes and illustrate the most pertinent features on conventional MRI and MR arthrography.
Subsequent lectures in the course will cover more advanced techniques.

FURTHER READING

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