Rotator Cuff Tears-Open Repair

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Anatomy

Supraspinatus is not as most textbooks show it. In fact it has a strong tendon that passes from the centre of the muscle belly to insert at the very front edge of the greater tuberosity, and sometimes even in front of the biceps pulley (Fig. 1). This anterior column is very strong and it is this feature that accounts for where tears start, how they progress, and how we can repair them.

Nakajima [1] showed that the central tendon is markedly denser and stronger than the rest of the tendon on histological preparations of the supraspinatus tendon. They demonstrated how the central thick tendon migrates towards the anterior margin of the tendon as you move towards its insertion. Nakagaki et al. [40] and Bigliani et al. confirmed this work and provided correct illustrations of the nature of the tendon. Gagey et al. introduced the concept of the fibrous frame of the rotator cuff. These workers performed three-dimensional reconstruction of MRI scans and demonstrated the deep fibrous re-inforcement of the supraspinatus that is the central oblique tendon. They showed how supraspinatus has one tendon, whereas subscapularis is multipennate and they show how the single tendon of supraspinatus inserts into the anterior extremity of the greater tuberosity. This pattern of migration of the central oblique tendon has been confirmed by Roh et al. Over a 20-year period the chapter author (TDB) has made the observation on ultrasound scanning and at surgery that this central oblique tendon (that we will term the *anterior column*), being the strongest part of supraspinatus, remains intact when all the tendinous tissues around it fail. In effect it acts as a *firebreak* and determines the pattern of postero-superior rotator cuff tearing. From these observations a hypothesis was developed that there is a definite and progressive pattern of cuff tear extension that is determined by the special anatomy of this tendon. Understanding this pattern allows the surgeon to predict which structures are contracted and need to be released, and to develop a plan to close the defect using fundamental surgical techniques such as rotationplasty, rather than treating each surgery as a "magical mystery tour".

Fig. 1 The true anatomy of the cuff, showing the central oblique tendon of supraspinatus

Aetiology of Cuff Tears

For many years we have had a simplistic idea of why cuff tears occur. It is time for this simplistic 'Intrinsic or extrinsic' theory to be challenged. Codman championed the idea of intrinsic degeneration of the cuff tissue (Fig. 2) as the main cause of rotator cuff tearing. Forty years later Neer suggested that tears occurred not through intrinsic damage, but because of extrinsic

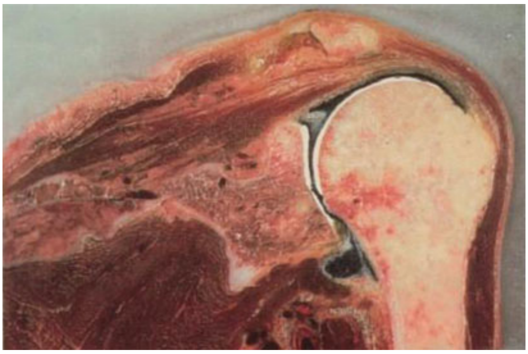

Fig. 2 The footprint of insertion of supraspinatus

damage due to continuing repetitive abutment of the anterior acromion upon the superior bursal side of the cuff. Neer's views held sway for 30 years, and his protégé, Bigliani, said there were morphological differences in the acromion (the hooked acromion) that accounted for this impingement and tearing. The hooked shape of the acromion has now been shown to be reactive, and so. although impingement does occur, it is usually secondary to intrinsic cuff failure and not the primary cause of cuff tearing.

There are two instances where extrinsic cuff compression from the acromion may be the primary event. The first is the 50 year-old with a large cuff tear and a mobile Os Acromiale. The second is the rare patient who is shown to have a bursal-side partial cuff tear with no evidence of a partial thickness articular surface tear or rim rent lesion.

However intrinsic cuff failure is the initiating event in the majority of people. This is why the rim rent lesion (Fig. 3), or partial thickness articular surface tear is so commonly seen in patients with the earliest symptoms and signs of cuff disease undergoing arthroscopy. This rim rent lesion may be caused by repetitive tensile overload with work, daily living or sport, or sudden overload as in a fall. It may also be caused by shear of the articular margin against the glenoid rim that occurs in the elevated position, either repetitively with work or sport, or suddenly with a fall.

Carr's work showed that genetics plays a part, for cuff tears are twice as common in close relatives of patients undergoing cuff repair as in those

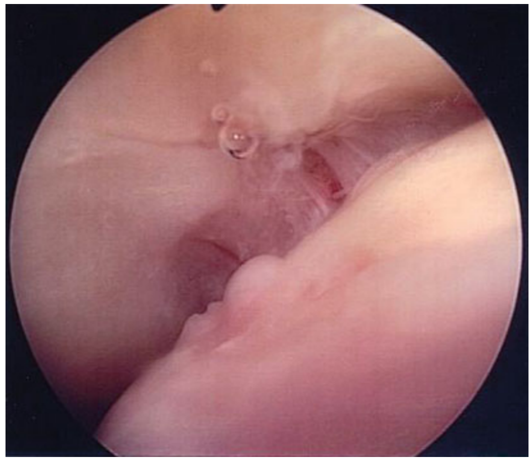

Fig. 3 An arthroscopic view of the rim rent lesion

partners they live with. We also know that they occur with age, Sher's classic work on MRI scanning of asymptomatic individuals showing that cuff tears are rare under the age of 60. In their study no-one under 40 had a cuff tear, between 40 and 60, 4 % did, but of those over 60, 26 % had a full thickness tear.

So cuff tears are complex, there is a genetic element, an ageing element a functional element due to tensile or shearing overload, leading to cuff dysfunction and secondary extrinsic impingement and compressive overload. Add micro- or macro-trauma into the mix and a cuff tear results.

Pattern of Cuff Tearing-Anatomical Factors

Repeated tensile, shear or compressive overload can cause changes within the ageing rotator cuff. Macroscopically this leads to the initiating event, which is the rim-rent lesion. The rim-rent lesion can be demonstrated by ultrasound or by arthroscopy. This lesion is constantly situated 7 mm. behind the biceps pulley just posterior to the insertion of the anterior column. Gradually the rim-rent peels further back off its footprint of insertion into the superior facet of the greater tuberosity. As it does so, secondary reactive changes occur on the bone, which becomes

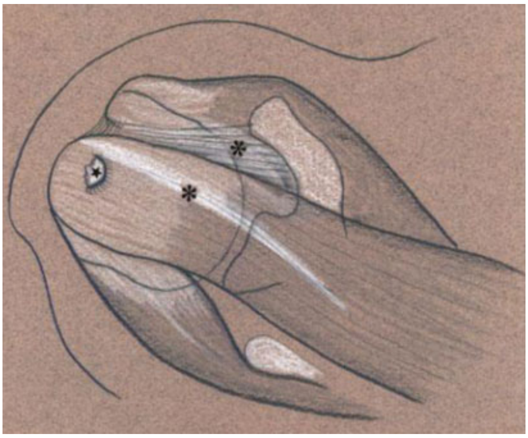

Fig. 4 The small tear starts just behind the anterior pillar

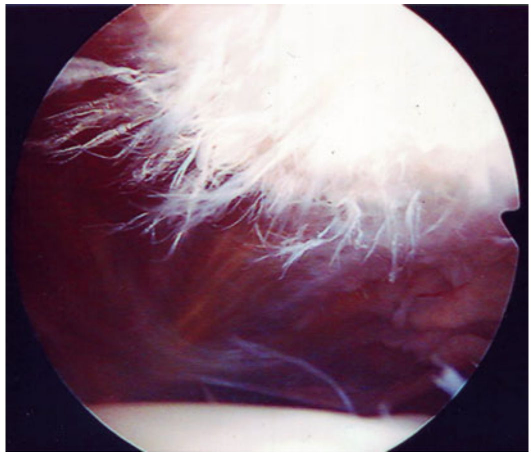

Fig. 5 The impingement lesion

sclerotic and nodular. These nodules appear on radiographs as tiny sclerotic rings and are often misreported as cysts, although tiny true cysts can also occur. Eventually the deep surface rim-rent will peel so far back that it emerges on the bursal side as a pinhole full thickness tear (Fig. 4). This gradual enlargement of the deep surface partial thickness tear may take years to evolve. During this time the supraspinatus is weakened and its normal centring effect is lost. The head subluxes upward and secondary impingement occurs between the bursal surface of the cuff and the acromion.

These secondary reactive changes can be seen by placing an arthroscope into the bursa. The bursa becomes fibrillated, and then wears through and the bursal surface of the cuff becomes damaged and fibrillates, this is the impingement lesion of Neer. Reactive changes will occur on the acromion (Fig. 5) and have been classified into four grades by Uhtoff:

- Firstly, there is a loss of areolar tissue under the acromion.
- Then, the coraco-acromial ligament and the fibrous pad that represents its footprint of insertion into the acromion thicken.
- Thirdly, there is fibrillation of the insertion of the coraco-acromial ligament.
- Finally, there is eburnation of the undersurface of the acromion and loss of the footprint of insertion of the coraco-acromial ligament.

Meanwhile the cuff tear extends, either slowly, or it may suddenly tear with even mild trauma. Knowledge of the normal morphology of the tendon explains the pattern of tear exposed at surgical repair. Knowledge of the morphology of the capsule explains the contractures that occur, and which will need to be released during surgical reconstruction. We must always remember that the tendon and capsule merge and blend towards their combined insertion, and that for a full thickness tear to occur, both capsule and tendon must have dis-inserted. The tendon retracts, but the capsule contracts.

As the small tear extends into a moderate tear the anterior column, being so strong, acts as a firebreak and resists extension, and so instead of becoming a larger crescentic tear, the tear becomes asymmetric or L-shaped (Fig. 6). At the same time the superior capsule, having dis-inserted, contracts back towards the glenoid, pulling the cuff, with which it is merged, along with it. The coraco-humeral ligament re-inforces the superior capsule and, as this powerful thickening of the capsule contracts, it pulls the anterior column with it, towards the coracoid. This determines the releases that will be necessary for a small to moderate tear.

Now a singular event happens, at 3–5 cms. the tear extends over the North Pole of the humeral head, causing a button-hole (boutonniere) situation. Just as in the PIP joint of the finger when

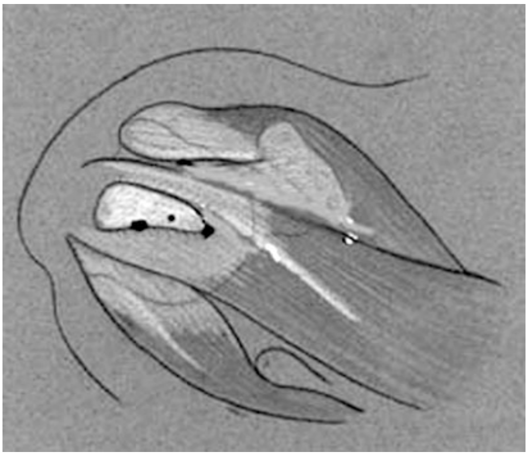

Fig. 6 The small tear extends to a moderate U-shaped or L-shaped tear

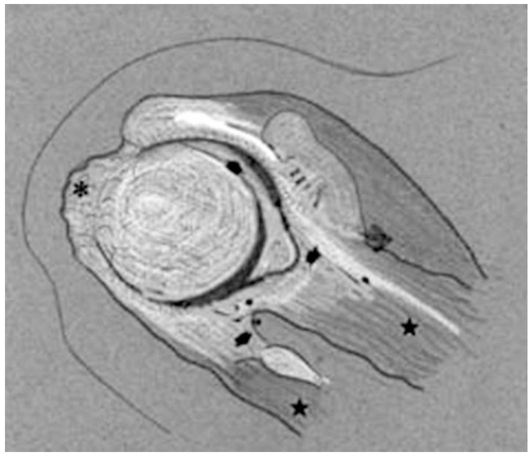

Fig. 8 The tear progresses to a massive fixed tear

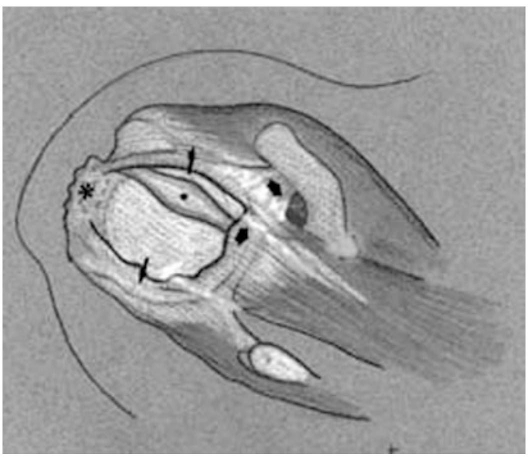

Fig. 7 As the tear progresses a Boutonnière effect occurs

a boutonniere lesion occurs the joint button-holes up through the tear and the lateral slips sublux around the joint (Fig. 7). In the case of the shoulder the lateral slips are the anterior column to the front, and infraspinatus to the rear. Because the infraspinatus has subluxed backwards and cannot be retrieved from under the acromion at surgery the surgeon may erroneously think that it too has torn, but this is hardly ever the case. The capsule at the junction of the supra- and infra-spinatus contracts severely and it is the release of this *junctional scar* that allows advancement of supraspinatus in large cuff tears. This *junctional scar* is hidden under the acromion and the suprascapular nerve runs underneath the spinoglenoid ligament just medial to this contracture. Long head of biceps hypertrophies and may start to fray. The capsule continues to contract. The muscle bellies, being de-functioned, waste away.

Finally the tear continues to extend and retracts right back to the edge of the glenoid rim (Fig. 8). The anterior column may still be intact, although now very stretched. Finally the anterior column uproots, uncovering long head of biceps, which now becomes painful, frays further, and can sublux or rupture. As the biceps pulley fails the superior margin of subscapularis may tear and the humeral head now subluxes forward as well as upward. The capsule contracts further. Infraspinatus subluxes further back yet, contrary to popular opinion, rarely tears although the tendon is stretched out and the wasted muscle belly has no function. The junctional scar becomes even thicker. This is the classic 'bald head tear'.

Arthritic change may now occur between the North Pole of the humerus and the acromion, as well as the surfaces of the humerus and superior pole of the acromion, which are maintained in a subluxed position. This arthritic change is called 'cuff tear arthropathy' (Fig. 9) and is the

Fig. 9 Cuff tear arthropathy

end-stage of the spectrum of cuff disease. 2 % of the population over the age of 80 will have cuff tear arthropathy.

Symptoms and Signs

Codman described the symptoms and signs of the patient with a full thickness tear of the rotator cuff 70 years ago. This portrayal still cannot be bettered. He gave 18 features that are classically present in such a patient. A manual labourer, aged over 40, with a previously normal shoulder, has an injury, with immediate pain, followed by a lucid interval, with severe pain coming on that night, a loss of power, eased by stooping, with a faulty rhythm, a tender point, a palpable sulcus, and eminence, which causes a jog and a wince, and crepitus on elevation, which re-appears on descent, with a normal radiograph.

A manual labourer. In fact the first patient Codman wrote up in 1911 was a woman who was beating her carpets clean in her back garden. Men do get full thickness tears more commonly. We have already stated how manual labour is implicated in the aetiology of cuff tears. Full thickness tears occur rarely under the age of 40. Most shoulder surgeons can count on the fingers of one hand how many cuff tears they have seen in patients under the age of 40!

The shoulder may be previously normal, but this is not always the case. Often the patient will have had a rim-rent tear for some time that will cause intermittent shoulder pain on reaching, particularly if sustained or repeated.

The injury may be relatively trivial, often elevating the arm against resistance (lifting the garage door, putting a case in the overhead locker). The injury can be severe, and dislocation of the shoulder over the age of 40 is a common cause of cuff tear.

The injury gives immediate pain. Yet it is followed by a lucid interval. This confuses the emergency room doctor the following day for, lacking in knowledge, they can not understand how anything serious could have happened if the patient continued working during the afternoon following the injury.

That night *severe pain* comes on, which is the reason the patient goes to the emergency room in the following morning, where a radiograph is taken, which is always normal.

The patient has *a loss of power*. This may be quite subtle in a small tear, but in the large tears there is a pseudoparalysis. As supraspinatus is powered up against resistance the tear is put under tension and this hurts. Stooping, the arm can be swung forwards passively, or the patient can cheat and swing the arm forwards using deltoid alone.

There is a *faulty rhythm to elevation* as pain through the mid-arc makes the patient protective and slows down the velocity of ascent. During ascent supraspinatus is contracting concentrically, but as the arm descends supraspinatus contracts eccentrically, which is weaker, and thus the faulty rhythm is even more apparent and protective coming down. The patient may actually lock the glenohumeral joint through the painful arc, and the scapula pseudo-wings.

On palpation there is a *tender point* over the insertion of supraspinatus. In the thin patient a defect can be felt in the cuff (*the sulcus*), and as the finger slides down the empty footprint of insertion it then bumps up against the greater tuberosity (*the eminence*).

As the arm is elevated the patient hesitates as the tear passes under the anterior edge of the acromion causing *a jog*, which is so painful as to make the patient screw their eyes up and *wince*.

The torn edges of the cuff rub against the acromion causing crepitus, and all these features re-appear, often more exaggerated on descent.

Examination and Investigation

The Poster-Superior Cuff (Supraspinatus)

Neer's Sign

This is the classic painful arc. Movement into the first 70° of flexion is easy and pain-free, but then as the footprint of the supraspinatus passes under the acromion, from 70° to 120°, there is impingement between the surfaces and pain, and motion slows. As the footprint clears the undersurface of the acromion, from 120° to full abduction, pain eases and motion speeds up once more.

Neer's Test

Neer's test is to inject some local anaesthetic into the bursa, bathing the bursal side of the footprint of cuff insertion. This abolishes the impingement and the normal pattern of movement is restored.

Hawkins's Sign

The arm is elevated in the scapular plane to 90°. Now the elbow is flexed to a right angle and the arm is internally, and then externally rotated. Pain is seen to occur on internal rotation as the footprint of supraspinatus impinges against the anterior acromion. The sensitivity and specificity for Hawkins sign is 75 %. It is one of the most useful tests of the posterosuperior cuff. Beware that passive limitation of internal rotation nullifies this test.

Jobe's Sign

The arm is brought up in the scapular plane with the elbow extended and the arm fully internally rotated so that the thumb points to the ground. (The Australians call this the 'empty tinny test' for it is the position in which you test that your can of beer is finally empty). The patient is asked to hold this position against resistance from the examiner. If there is damage to the supraspinatus insertion then pain will register with the patient. If there is a tear of supraspinatus the arm will be weak. The accuracy of Jobe's sign is 58 %. It is another good test.

If either Neer's, Hawkins's or Jobe's signs are positive then ultrasound examination is essential. The ultrasound will show whether there is a tear, give its exact position and a measure of its dimension; it is worth a great number of eponymous tests. However there are many other tests of the posterosuperior cuff and it is pertinent to test for them.

Lag Signs

Lag signs depend on weakness of a segment of the cuff. They are the modern equivalent of the '*drop arm sign*'. The drop arm sign was a particularly unpleasant way of examining a patient with a massive supraspinatus tear. The examiner elevated the arm to 120° in the full knowledge that, without a functioning cuff, the patient will find it impossible to maintain this position. The examiner then let go and the arm dropped to the side! Patients feel severe pain.

The External Rotation Lag Sign

The external rotation lag sign demonstrates that there is a significant tear in supraspinatus. Like the "drop arm" sign this depends on placing the arm into a position that needs a strong supraspinatus and then letting go. The examiner takes the affected elbow and supports the weight of the upper arm with the shoulder in 90° of scapular elevation. Now, using his other arm, the examiner externally rotates the forearm into full external rotation. Maintaining this position against gravity depends upon an intact supraspinatus. Now the examiner lets go of the forearm. If the cuff is intact this position can be maintained by the patient, but if the cuff is torn then the forearm will drop by about 30°, the external rotation lag. There are problems with the test. The examiner must understand exactly what he is doing, as must the patient. Pain may interfere with the test. Stiffness will render it null and void. There is difficulty between assessing how much movement is recoil and how much is lag. It is poorly reproducible. It has a specificity of 63 % and a sensitivity of 80 %. It has been superseded by portable ultrasound.

Hornblower's Sign

This is another lag sign. All military hornblowers must assume an identical position when blowing their horns. This position is with the hand at the lips and the elbow as high as it will go so that the arm, and forearm are parallel to the ground. This position can be maintained even with a torn rotator cuff. However if the examiner now takes the hand, and fully externally rotates the forearm so that the forearm is now perpendicular to the ground we now have a position that can only be maintained with an intact cuff. Let go of the hand now and the forearm will drop, or lag, by 30°. This test suffers from the same problems as the external rotation lag sign. It has been superseded by portable ultrasound.

The Antero-Superior Cuff (Subscapularis)

Tears of the anterosuperior cuff (subscapularis and biceps) are less common than those of the posterosuperior cuff. These tears start around the biceps pulley and the superior part of the insertion of subscapularis into the lesser tuberosity. Subscapularis has a multipennate tendon of insertion into the lesser tuberosity.

The "belly Press" Sign (Napoleon's Sign)

This is the single most useful test of subscapularis function. The patient is asked to place the palm of the hand upon their abdomen. Now they are asked to keep the hand where it is and bring the elbow forward as far as it will go. If there is a complete tear of the subscapularis they will not be able to bring the elbow forwards. If they can pull the elbow forwards they are then asked to press the hand hard into the belly. If there is a partial tear of subscapularis they elbow will drop back (a lag sign). Beware; if the shoulder is stiff a false "belly press" sign occurs, for instance in patients with limited internal rotation from arthritis. Beware, patients can cheat; in this case they flex the wrist pulling the elbow forwards, producing a false- negative "belly press" sign. They must keep the wrist in a neutral position or the test is null and void. Finally biceps problems can mimic subscapularis problems confounding the "belly press" sign.

The Lift off Test

The lift off test is similar to the "belly press" sign, but is performed in more internal rotation. This means that the wrist must be placed on the small of the back, rather than on the abdomen. Now the patient is asked to actively increase the internal rotation by lifting the wrist away from the skin. The problem with this test is pain. Patients with cuff problems do not like placing the hand into internal rotation, and pain nullifies the test. Stiffness will also nullify the test.

Internal Rotation Lag Sign

This is a modification of the lift off test. The arm is placed with the wrist on the small of the back. The examiner now takes the wrist and pulls it 5 cms. away from the skin. With an intact subscapularis, and no pain or stiffness, the patient should be able to maintain this position. However if subscapularis is torn then the wrist will drop (lag) back onto the skin of the small of the back. Once again it is difficult to discriminate between recoil and lag, and has the same problems of pain and stiffness.

The Biceps

There is no good test for biceps! Biceps shape is important. All medical students know the 'Popeye sign' of a ruptured long head of biceps. However you can have a complete intra-articular rupture of long head of biceps without a Popeye sign when the hypertrophied tendon jams in the sulcus, like a cork in a bottleneck. Between these two extremes the biceps can adopt subtle changes in shape.

Lafosse Sign

This test is designed to isolate biceps by asking the patient to supinate the forearm against resistance. The examiner cradles the elbow with the shoulder held at about 40° of scapular elevation. The examiner grips the patient's wrist and pronates the forearm, asking the patient to resist (supinate) this force.

O'Brien's Test

This is designed to detect a SLAP (Superior Labrum antero-posterior) tear. It is performed similarly to the Jobe test, but with the arm held at 20° inside the neutral position (across the body) and at 90° elevation, and full internal rotation. The patient is then asked to resist the attempts of the examiner to push the arm towards the ground.

Yergason only described his test in one patient, yet this test has been copied from textbook to textbook. Speed's test also has a low sensitivity and specificity.

Ultrasound

Medical ultrasound uses wavelengths of 2.5–14 MHz. The higher the wavelength the better the definition of the returning echoes, but more sound is attenuated, meaning you can't see as deeply through the tissues. Fortunately the rotator cuff is reasonably superficial so 8–10 MHz linear array probes can be used that give good definition, indeed the pictures captured on a good machine are so good as to show histology rather than morphology. The problems come with extremely fat or well-muscled individuals where the definition falls off dramatically.

The linear array probe is made of a series of crystals that vibrate as electricity is applied to them (the piezo-electric effect) producing sound waves. In this case ultrasound waves. The crystals are arranged in a row, much like the keys of a piano. Each crystal in turn produces a tiny blip of sound and then waits for the echoes to return as they are reflected by the interfaces between tissues. The echoes causes the crystal to vibrate and this is turned into an electrical impulse, amplified and displayed as a two-dimensional picture of the tissues.

In the clinic, time is important, so an abbreviated study is permitted, scanning in only three planes, as opposed to the 12 planes recommended in most radiological texts. An axial scan is first used to demonstrate the lesser tuberosity, subscapularis, biceps sulcus and long head of biceps tendon. Secondly an oblique coronal (or longitudinal) view is used to show the greater tuberosity and the supraspinatus. Finally a saggittal oblique (transverse) view is used demonstrating the greater tuberosity and supraspinatus tendon, rotator interval and biceps. All findings are recorded in detail at the time. In each of the three planes a record is made of the articular appearance (normal, positive cartilage reflection sign, osteophytes), the bone (normal, irregular, calcification, fracture line), the collagen (normal, heterogeneous, hypertrophic), presence of a defect (rim-rent, cleft, de-lamination, focal absence, absent cuff), and the presence of an effusion (nil, effusion, flattening of bursa, bursal concavity). A firm diagnosis of the state of the rotator cuff and biceps is then recorded. A full thickness tear is diagnosed on sonography if the tendon is absent, or if there is a focal deficit. A combination of one or more indirect signs such as a bursal concavity, an effusion around the biceps, bony irregularity or a positive cartilage reflection sign allow a judgement to be made by the surgeon on the presence of a supraspinatus tear.

Ultrasound has been shown to be an effective tool for determining the presence of a full thickness tear in the hands of trained radiologists with an accuracy of 81–95 %. Errors in detection and measurement are small in the hands of experienced radiologists Teefey [41]. Errors are often clinically irrelevant such as a grading error, mistaking a deep partial thickness tear for a pinhole full thickness tear, or a small measurement error, mistaking a large tear for a massive tear due to inability to follow the retracted tendon under the acromion. Such errors would not change the clinical management of the patient. Inter-observer error between experienced radiologists is low with full agreement on categorization in 92 % of scans Middleton [39]. However referral to a radiologist for ultrasound scanning inevitably leads to a delay for the patient and a journey that involves three attendances, the first to see the surgeon, the second for the scan and the third to return to the surgeon for the result to be discussed and a treatment strategy to be agreed. The delay from first contact to agreement of

Fig. 10 Portable ultrasound

a plan of treatment may vary from a few days to several months depending on the efficiency of the department of radiology. The new generations of back-pack portable high-resolution and relatively inexpensive ultrasound machines (e.g., Sonosite 180 plus) allow for an ultrasound scan to be performed by the surgeon wherever he first meets the patient (Fig. 10). Al Shawi & Bunker [38] showed such a scan performed by a surgeon was sufficiently accurate (96.3 % sensitivity and 94.3 % specificity for full thickness tears), compared to previously published radiology studies, to allow a one-stop clinic where the patient is seen by the surgeon, has the ultrasound performed by the surgeon and a treatment plan agreed at the first encounter.

Magnetic Resonance Imaging (MRI) and MR Arthrography (MRA)

MRI has revolutionised the field of imaging in the shoulder, because it can image the soft tissues. Unlike ultrasound MRI can image through the bone, and it can image the bone, and it can image to depths of tissue that cannot be reached by high frequency ultrasound. It is therefore the imaging modality of choice for instability, as it will demonstrate labral abnormalities. Visualisation of SLAP tears and Bankart tears are improved by MRA using gadolinium enhancement.

MRI is the imaging modality of choice for large rotator cuff tears where the degree of retraction under the acromion, and the degree of wasting and fatty infiltration of the muscle belly will determine whether the tear should be repaired, or whether repair is a forlorn hope. MRA is useful in demonstrating articular side partial tears.

However MRI is not without problems. The equipment is extremely expensive and far from portable! Patients do not like MRI. It is claustrophobic, noisy and patient unfriendly. One third of patients will not have a second MRI scan. It will demonstrate morphology, but not histology. It suffers from a phenomenon called the ‘magic angle effect’ that can produce false positive results. MRI is very bad at showing calcific deposits as these are dark, as is the tendon, so there is no contrast difference between the calcium and the tendon.

MRA suffers from the problem that it is invasive. Intra-articular injection of gadolinium is usually done under image intensifier control and local anaesthetic. This increases the degree of difficulty, often needing two radiology suites, careful timing, transfer from room to room and the time of a skilled radiologist. Additionally, patients do not like invasive diagnostic procedures.

Arthroscopy

Shoulder arthroscopy remains the gold standard forensic investigation for the shoulder. Not only can the inside of the gleno-humeral joint be appreciated (Fig. 11), but also the outside view of the rotator cuff from within the subacromial bursa. An essential pre-amble to arthroscopy is examination under anaesthetic.

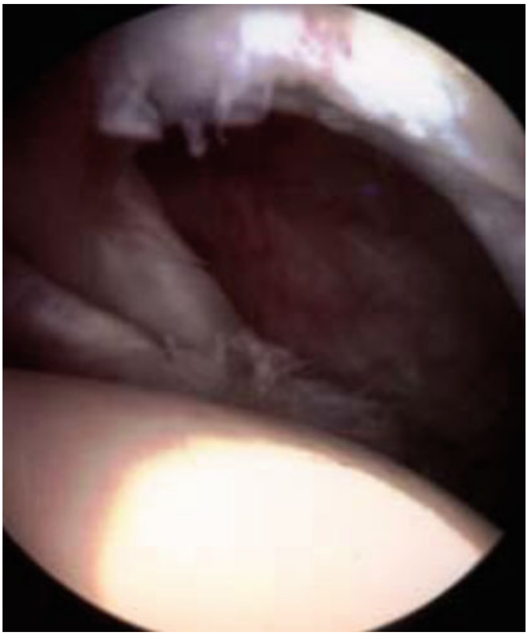

Fig. 11 Arthroscopic view of a moderate cuff tear

Open Treatment of Posterosuperior Rotator Cuff Tears

We have demonstrated how there is a spectrum of advancing pathology, from cuff dysfunction leading to impingement, through partial thickness cuff tears, to small full thickness tears and on through moderate to large, to massive tears of the rotator cuff. Treatment must be tailored to fit the symptoms from which the patient is suffering and the pathology causing the symptoms.

Impingement

The patient is usually aged 40–50 and has mild rotator cuff symptoms. These will include pain on reach and exercise, difficulty getting to sleep, but little awakening, a painful arc on elevation that interferes with recreation but the patient continues in their normal work routine. The pain is relieved by subacromial injection of local anaesthetic (Neer's Test).

Fig. 12 Arthroscopic subacromial decompression

Conservative treatment involves turning the dysfunctional cuff into a functional cuff again. Two facets need to be addressed, pain and function. The pain can be eased by injection of cortisone (in any form) into the subacromial bursa, and refraining from those activities that aggravate the condition (reaching, sport, and overhead work). Therapists can then supervise muscle re-training, starting with scapular control, and then working on to glenohumeral control.

Indications for surgery are failure of proper conservative treatment, in the patient aged over 40 who has true impingement, which has been abolished temporarily by subacromial injection of local anaesthetic.

The surgical procedure of choice is arthroscopic subacromial decompression. Dr. Harvard Ellman who published his results in 1987 pioneered this technique and now this is the benchmark throughout the advanced world. In the properly selected patient arthroscopic subacromial decompression (Fig. 12) should give excellent or good results in 88 % of patients. These days there is no place for open decompression except as a method of exposure for open cuff repair. However this does not mean that lessons cannot be transferred from the era of open surgery. Open acromioplasty evolved from Neer's first description where a wedge of anterior acromion was removed using an osteotome, and ended with the two stage Rockwood acromioplasty. In this technique the first stage is to remove the full thickness of the acromion that extends anterior to the acromioclavicular joint. The second stage is to remove a wedge of anterior acromion extending from the initial cut and exiting the inferior surface of the acromion 1.5 cms. (three burrs-breadths) posterior to the anterior cut. This technique is now copied arthroscopically.

Partial Thickness Tears

There is great debate over how partial thickness tears should be treated. Some authorities advocate decompression alone, but more these days advocate excision and repair. This is the area where arthroscopic repair with anchors or arthroscopic tacks is of increasing importance. Small tears (<1 cm.) can be dealt with in the same manner, either arthroscopically or through the 'mini-open' technique.

Surgical Treatment of Moderate, Large and Massive Tears

The surgical repair of larger tears remains a difficult undertaking for surgeon, patient and therapist. Difficulties for the surgeon include the surgical approach, retraction of the tendon, contraction of the capsule, degenerate tendon, poor healing, soft bone and weak muscles. Problems for the patient include pain, protection of the repair and frustration due to the long time-course for healing. Problems for the therapist include weak muscles that have lost their control, adaptive muscle patterning and posture and the psychology of protracted recovery. With all these difficulties to overcome it is not surprising that re-tear rates vary from 15 % to 50 % in the massive tears.

Conservative treatment should be tried before recourse is taken to surgery. The only exception to this is the acute massive tear following trauma where surgery is far better immediately and before the tendon retracts. However most large cuff tears present as a chronic problem or an acute-on-chronic problem. In these cases an injection of cortisone should be given to relieve pain and therapy started to regain control of the scapula and then the glenohumeral joint.

Specific Indications for Surgery

The indication for surgery is a proven rotator cuff tear, demonstrated by ultrasound or MRI, in the patient aged over 40 yet under 70, who has symptoms which interfere with daily life, or awaken at night. Weakness up to the point of pseudo paralysis may or may not be present. The patient should have failed a proper course of conservative treatment.

There are six *principles of surgery*:

1. Assess the cuff tear
2. Release the capsular contractures
3. Re-introduce healing biology
4. Re-attach the tendon to its anatomical footprint
5. Protect the repair
6. Regain movement and its control

Assessing the cuff tear means exposing it such that the front, the medial retracted edge and the rear of the tear can be seen. This is best done arthroscopically. However this is not always easy. The bursa may be thickened so much that it mimics cuff tissue; de-lamination makes assessment tricky; the bursa is often inflamed with quite an aggressive nodular synovitis; and the assessment must be performed rapidly before swelling occurs. The size and pattern of the tear, the state of long head of biceps, and subscapularis must be assessed. The degree of retraction and the mobility of the tendon edges can be seen by inserting a grasper and pulling. The quality of the cuff should be noted as to whether it is an acute or chronic tear, whether the adjacent cuff tissue is malacic or de-laminated.

Contractures must be released so that the tendon can be brought without tension to its anatomical position. For moderate tears this means releasing the capsule in the paralabral gutter just as one would for a contracted (frozen) shoulder. For large tears the coracohumeral ligament and rotator interval also need to be released. For massive tears the junctional scar must be released. In all cases the bursa needs to be freed of scar tissue.

Re-introducing healing biology. Most cuff tears are chronic and any attempts to heal have long ago been abandoned by the local cells. They need to be re-awakened by decorticating the greater tuberosity so that blood and, with it, fibroblasts, can actively engage in repair. In the future it may be possible to stimulate repair using synthetic growth factors.

The tendon must be *re-attached* to its anatomical insertion point, its footprint, over as wide an area as possible. This is where the skill of the surgeon is paramount and will be described in greater detail below.

Finally the *repair must be protected* against forces of a magnitude that would re-tear it during the healing phase (6 weeks) and the strengthening phase (3 months). The patient or the therapist, in error or in ignorance, may apply these forces. Protocols must be adhered. Unfortunately in this area ignorance is widespread.

Recovery is a team effort. The team consists of the surgeon, the anaesthetist (who gives the scalene block and controls post-operative pain) the patient, the nursing teams in theatre, on the wards and in outpatients, and in particular the therapist.

Re-Attaching the Tendon

There are three *technical objectives* for the surgeon:

- Adequate exposure
- Sufficient release
- Secure hold

Exposure must be extensile. There are six stages to the extensile exposure. These are:

- All-arthroscopic repair
- Arthroscopic subacromial decompression and mini-open repair
- Matsen deltoid-on with two stage Rockwood modification of Neer's acromioplasty
- Plus acromio-clavicular excision
- Plus trapezius take down (Wiley extension)
- Plus oblique acromial osteotomy (Grammont Osteotomy)

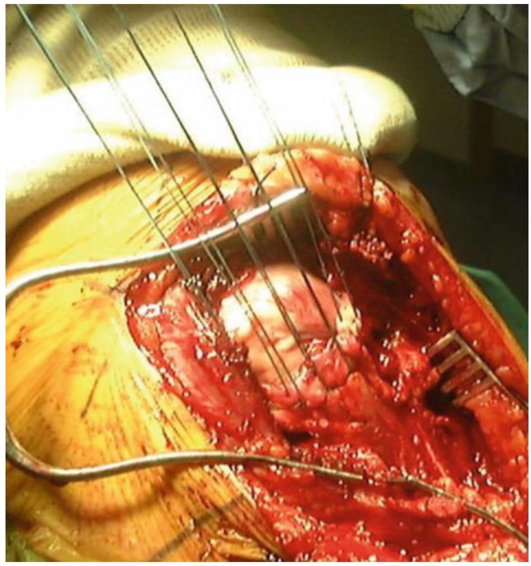

Fig. 13 Exposure of the cuff tear with stay sutures inserted

All-arthroscopic repair is beginning to come of age for small, mobile tears, in the hands of an expert. However it is a difficult procedure with a long learning curve. In 5 years time it will probably become the standard treatment for small and moderate tears. Presently it should be restricted to expert shoulder arthroscopists only.

The Matsen deltoid-on approach is a deltoid split that meets the front of the acromion half way across its anterior surface. Medial and lateral flaps are created in line with the split in deltoid lifting the periosteum from the top surface of the acromion, and then if necessary splitting the trapezius in the same line. Thus two flaps are raised which consist of deltoid-periosteum-trapezius; much like the direct lateral approach to the hip this technique lifts intact fascio-periosteal flaps off the bone. In this manner the acromion is exposed, yet the flaps can be closed side-to-side with no weakening of deltoid. The problem with this approach is that the periosteum over this part of the acromion is very thin; particularly in women, and can easily tear. For this reason this author splits the deltoid so that the split exposes the acromio-clavicular joint. The superior acromio-clavicular ligament is divided much as the periosteum would be with the true Matsen deltoid-on approach, but it is five times as thick as the periosteum and much easier to repair.

If the tear is too big to be seen through a deltoid-on approach with an acromioplasty then the first extension is made, excising the acromio-clavicular joint. One third of the bone is taken from the acromion, and two-thirds from the clavicle, leaving a 1.5–2 cms. gap. This now allows the fat pad to be raised off the belly of supraspinatus and exposure is increased.

If the whole tear still cannot be seen, stay sutures are placed in the edges of the tear, and the humeral head extended and rotated to see if the whole tear can be seen (Fig. 13). If it cannot then the next extension is made. This is the trapezius take-down, which allows an excellent view of the suprascapular fossa and the belly of supraspinatus.

If at this point the whole tear cannot be seen,the full time shoulder surgeon now has a choice, to perform an oblique scapular osteotomy or to perform tendon transposition or augment. The results of tendon transfers (deltoid flap or latissimus transfer) are to improve the shoulder from a Constant score (CS) of 30 to a CS of 60. The alternative is the Grammont osteotomy of the spine of the scapula. This gives a fantastic view of the rotator cuff, and is re-assembled with a small locking plate but is beyond the limits of this text.

Release of Contractures

The second technical objective is to release the capsular contractures. Now an understanding of the sequence and pattern of tearing will turn the course of the operation from a "pot pourri" to a controlled predictable experience.

Small tears (less than 1 cm.) will not have any contractures, the capsule has not retracted enough and so no releases will be needed.

Moderate tears may have enough capsular retraction for stiffness to set in. Here the contraction will be similar in extent to contracted (frozen) shoulder, and the same release (along the paralabral gutter) will need to be performed. This can be done arthroscopically or open.

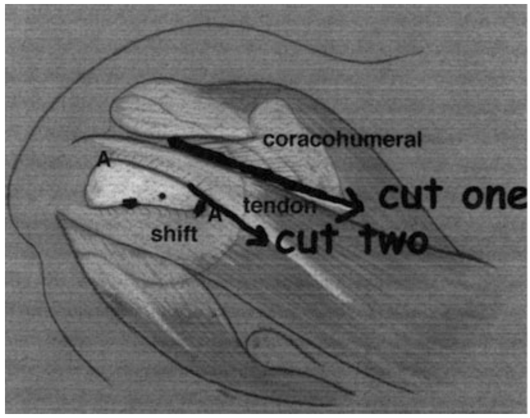

Fig. 14 An extension is made behind the central oblique tendon and A is rotated to A

Large and massive tears have additional scarring at the front of the tear and at the back. At the front the coracohumeral ligament contracts and tethers the anterior pillar. At the back the junctional scar develops at the base of the spine of the scapula. This plane between the supraspinatus and infraspinatus needs to be released, but care must be taken not to damage the adjacent suprascapular nerve.

Rotationplasty or Margin Convergence?

Even with all the contractures released a large to massive chronic tear may have such a loss of tendon material that the tidied-up edge of the tendon cannot be advanced on to the prepared bony footprint. Now what can be done? The alternatives are to lash the front of the tear to the back (margin convergence), perform a rotator interval slide (which is now condemned as a poor procedure), perform a rotationplasty, or give up the idea of direct repair and either augment or perform a tendon transfer.

Margin convergence is the preferred method for the arthroscopist. This is because it is relatively easy and it will work for a tear that is not extensive from front to back. It will not work for a tear that is extensive in both directions.

In the rotator interval slide the only remaining strong attachment of the supraspinatus, the anterior column is detached, this allows the anterior column to be re-attached further back and what is acheived is to close the back of the defect by opening up the front. This actually makes things far worse, for now the head will escape through the anterior defect, decreasing cuff function.

If the tear is extensive in both directions then basic plastic surgical techniques must be adapted to close the defect, and this means a rotation flap (Fig. 14). The remaining anterior column and its attachment should be protected. If the tear pattern is an anterior L-shape, then an extension is made along the back of the central oblique tendon and the cuff is rotated clockwise to close the defect. If the shape is a posterior L-shape then the extension is between supra- and infraspinatus (through the junctional scar) and the cuff is rotated anticlockwise to fill the defect. Sometimes if the tear is massive then both extensions are required and the block of posterior cuff is advanced.

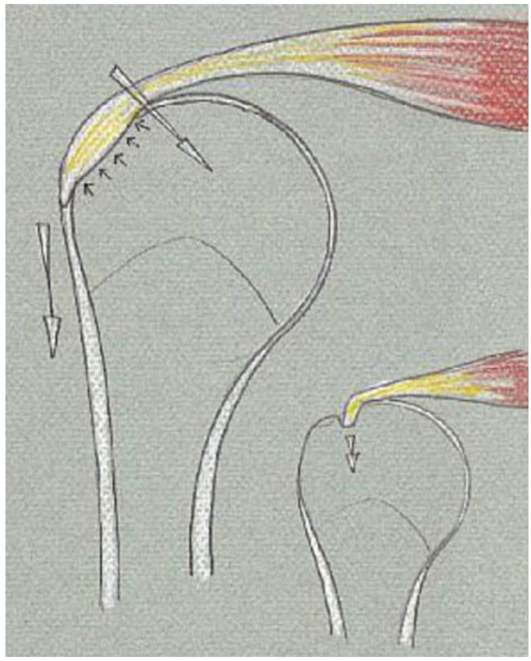

Fig. 15 Two row repair gives a stronger and better footprint than one row

Secure Repair. Eliminating the Weakest Link

The final technical objective is to gain a secure repair to the de-corticated and bleeding surface of the greater tuberosity, over as large a footprint area as possible, for long enough for biological union to occur. Most surgeons will use a *two-row technique* in order to attach the tendon to as great an area of footprint as possible. Two-row arthroscopic repair was first devised by DeBeer from Cape Town (2002). However, open two-row repair came first. By 1992 it was our favoured method of open repair and we first published and illustrated this in our textbook ((Fig. 15) Bunker and Schranz: Challenges in Orthopaedic Surgery; the Shoulder) in 1997. Two-row repair involves attaching the cuff to both extremities of the de-corticated tuberosity. The two-row repair has been made more secure by over-sewing the cuff, joining the proximal and distal rows using such techniques as the *suture bridge* (Fig. 16).

Any method of linking tendon to bone has a potential to separate wherever there is a *weak link in the chain*. In rotator cuff repair there are five linkage points:

- Tendon to suture
- The suture itself
- The knot
- Suture to anchor
- Anchor to bone

A great deal of effort has gone in to over-engineering all these linkages to prevent failure. Some of the weak points are under the surgeon's control, but the quality of the tendon and the quality of the bone are not.

The Suture-Tendon Junction

Decades of effort by generations of hand surgeons have seen the grasping core suture become the method of choice for flexor tendon repair. Gerber and Schneeberger showed experimentally how grasping sutures remain secure under load when simple sutures cut out. They found that the best grasping suture was the Mason Allen grasping suture, closely followed by the modified Kessler. Grasping sutures are extremely difficult to perform arthroscopically, so it was with

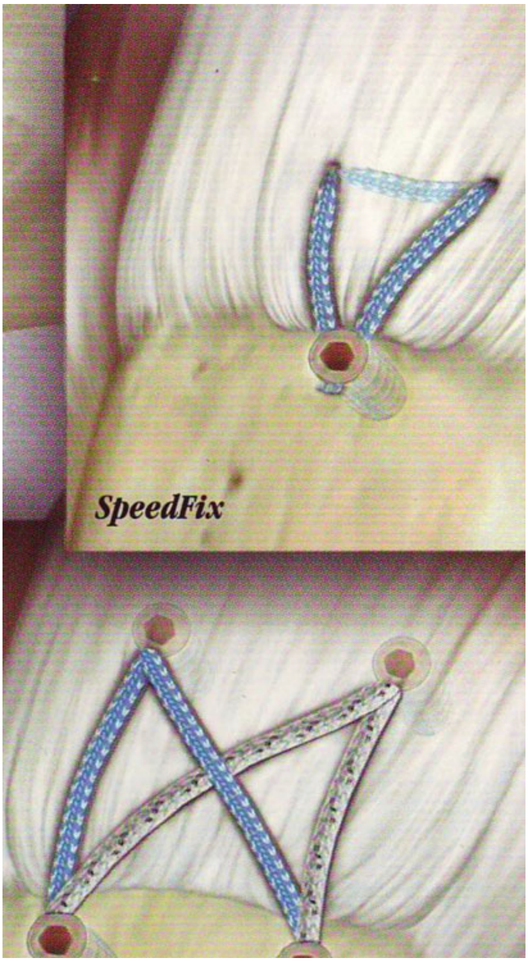

Fig. 16 Suturebridge technique

concernthat experienced shoulder surgeons saw the arthroscopic pioneers performing cuff repairs with simple sutures, a technique that they knew from observation failed at open surgery. However White & Bunker showed that the strength at this interface might be proportional to the number of passes of the suture through the tendon rather than the pattern of passage. Thus two mattress sutures (four passes) are as strong as one Mason-Allen suture (three passes). The Mason Allen suture is easy and quick to perform open and remains the gold standard.

The Suture

Properties of the suture depend upon the material, whether it is monofilament or braided and the diameter of the suture. Theoretically one could over-engineer the suture just by increasing its diameter so that its breaking strain was far greater than the original tendon, but the thicker the thread the more difficult it becomes to knot, so a compromise needs to be made. Any suture thicker than number 2 knots poorly. The break-through with sutures has been in materials. New sutures such as orthocord and fibrewire are almost unbreakable.

The Knot

All knots have a breaking strain of half the suture itself. Clearly it is a weak link. All knots rely upon friction between the two suture ends. One of these is designated the post and the other the loop. Friction is increased by reversing the post for alternate half hitches, and by increasing the number of half hitches performed. The surgeons knot is the strongest knot and better than sliding knots of whatever variety.

Because the knot is a weak link surgeons have tried to get rid of them using knotless techniques. Most of these involve trapping the knot within the anchor using a pop-rivet technique.

Suture to Anchor

The sutures have been linked to the anchor with an eyelet. The eyelet has been a real problem as early anchors had sharp metal edges where the eyelet had been drilled or formed in the anchor. This sharp edge used to cut the anchor. Gerber and Schneeberger modelled arthroscopic repair and found that the weakest point was always the eyelet. Better anchor manufacture and the new unbreakable super-sutures have eliminated the eyelet problem.

The Anchor

The original descriptions of rotator cuff repair by the pioneers such as McLaughlin and Neer described attaching the suture to the bone using bone tunnels, because they had nothing else. These days we have suture anchors and suture screws. Whereas a bone tunnel of 1 cm. in length will fail with a low force of 16 N, suture anchors will take 280 N to pull out. Anchors are not only stronger but also easier and quicker to use.

Bone tunnels are still used by some because anchors are expensive. Gerber has tried to overcome the weakness of bone tunnels by using a titanium plate to augment the sutures and Bunker has used a metaphyseal screw or post with a pull-out strength of 900 N. For the last decade anchors have been so secure compared to all the other links in the chain that failure was unheard of. However the new generation of super-sutures have removed the weakest link and recently failure by anchor pull-out has been described.

Results of Rotator Cuff Repair

The Panacryl Study appears to give the most honest appraisal of the results of surgery for rotator cuff repair. This was a British multi-centre prospective controlled study of rotator cuff repair. 159 patients were analysed from 15 UK centres. 17 % of the tears were small and closed with side-to-side sutures, 83 % were closed with modified Mason-Allen suture technique. Patients were assessed by Constant scores pre-operatively, at 6 months and at 1 year. They were also followed by real-time dynamic ultrasound scanning performed by experienced consultant ultrasonographers.

The Constant pain scores improved following surgery from 6/15 to 12/15 at 6 months where 15 is no pain at all. Total Constant scores improved from 46/100 to 66/100 at 6 months.

The re-tear rate was 26 % overall at 6 months, but varied from 15 % in tears less than 5 cms. in diameter to 51 % in massive tears. Despite the high re-tear rate there is still a good effect from the surgery with statistically significant improvements in most parameters of the Constant score, including pain and total scores.

Subscapularis Repair

Ruptures of the anterior cuff are far less common than postero-superior tears. They are often consequent on transient or locked dislocation in the elderly patient. However they may follow on from expanding pulley lesions or medial biceps dislocations. They are almost impossible to repair through a superior approach. An MRI must be performed before surgery to assess the wasting and degree of fatty atrophy of the muscle belly, because if this is marked then repair should not be undertaken.

The surgical approach should be the standard deltopectoral approach to the shoulder. Often the tendon will have retracted under the conjoined tendon. This means that the musculo-cutaneous nerve should be identified and a pre-drilled coracoid osteotomy performed. Subsequently a 360° release of the subscapularis tendon should be performed taking care not to damage the posterior cord of the brachial plexus that is scarred on to the anterior surface of subscapularis and always closer than the surgeon has estimated. The lesser tuberosity is now de-corticated and a two-row repair of the mobilised tendon is performed using the techniques that have just been given for supraspinatus repair.

Biceps is always damaged with a substantial subscapularis tear. Biceps will need to be tenotomised close to its origin and an extra-articular tenodesis performed.

Tendon Transfers

Pectoralis Major Transfer

This transfer is reserved for inoperable subscapularis tears. The aim of surgery is to replace the absent subscapularis with a local muscle tendon unit that can cover the defect, thus containing the humerus and increasing the power of internal rotation. The sternal head of pectoralis major has all these attributes.

Surgery is affected through a standard deltopectoral approach. The combined heads of pectoralis major, or just the sternal head are harvested from their insertion on to the humeral shaft. They are then transferred to cover the anterior defect and are attached to the prepared lesser tuberosity using suture anchors. There is some theoretical advantage to using the sternal head and taking it under the conjoined tendon so that it replicates the line of pull of subscapularis more accurately. However this is more difficult and great care must be taken to identify and protect the musculocutaneous nerve.

Early results with this transfer show that it is the method of choice for irreparable tears of subscapularis.

Latissimus Dorsi Transfer

The primary repair of massive postero-superior rotator cuff tears is extremely difficult and is associated with prolonged rehabilitation and a high re-tear rate. This then raises the question, is there an alternative surgical solution to the problem of pain and weakness in this situation? The latissimus dorsi transfer has long been used in children with brachial plexus palsy, where it goes by the name of the L'Episcopo procedure. The effect of this transfer in children with C5 plexus palsy (effectively causing a suprascapular nerve palsy) is to give them external rotation at the shoulder. The idea behind latissimus dorsi transfer is to affect the same result in the elderly patient with a massive cuff tear. The aim of the operation is two-fold, to contain the humeral head against upward subluxation, and to increase the power of external rotation. It has been found that two criteria must be satisfied for this transfer to work. The first is that deltoid must be functional, and the second that subscapularis is intact. The results of latissimus transfer in the face of a tear extending into subscapularis are so poor that it should not be attempted.

At surgery the patient is placed in lateral decubitus so that both the front and the back of the shoulder are available to the surgeon. A single posterior incision or the classic two incision approach can be used. The first is a standard superior approach to supraspinatus and the main incision runs along the lateral margin of the latissimus. Care is taken to protect the axillary nerve where it exits the quadrilateral space, and the tendon of latissimus is identified and traced to its insertion on the humerus. The radial nerve and the profunda brachia vessels pass below the tendon insertion through the triangular space and these must be protected as well. The muscle belly is now cautiously released taking care not to damage the neurovascular supply. The tendon is now whip-stitched and a tunnel developed under deltoid and the acromion so that the tendon can be passed from the posterior incision through to the anterior incision where it is attached to infraspinatus stump, or if possible the supraspinatus stump on the anterior facet of the greater tuberosity of the humerus.

Early clinical results of latissimus transfer, in well-selected patients, operated upon by good surgeons have shown promise. Time will tell how acceptable this technique will become.

Conclusions

Surgeons are only just beginning to understand rotator cuff disease. Our understanding has been helped by examining the precise anatomy of the supraspinatus tendon, and by recent advances in comprehending the aetiology of this disease, as well as advances in investigation such as ultrasound, MRI and arthroscopy. We are beginning to understand the natural history of rotator cuff dysfunction and tearing, and the pattern of cuff tears and capsular contractures. Principles for surgery and technical objectives are now understood and the techniques for surgery are beginning to be worked out. Despite all of this, surgery remains difficult for the surgeon, painful and frustrating for the patient and demanding of the therapist. We have a long way to go before we have all the answers for this extremely common, yet extremely disabling, degenerative disease of the shoulder.

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