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# Options Before Reverse Total Shoulder Replacement

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## Abstract

Management of massive tears of the rotator cuff tears is one of the most difficult problems an upper limb surgeon encounters. Patients with similar tears can present with minimal discomfort through to a flail shoulder. There are a bewildering number of options available, many with published outcomes not always borne out in clinical practise. These range from rehabilitation, simple arthroscopic surgery, attempts at repair, complex tendon transfers and ultimately a reverse total shoulder replacement. More recently further options of patch augmentation and balloon arthroplasty have been added. This paper attempts to provide a critical assessment of the evidence available.

**Keywords:** massive rotator cuff tear, treatment options, repair, patch, augmentation, bridging

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## 1. Introduction

Rotator cuff arthropathy has gained increased attention in recent years, partially because the ageing population has made it more prevalent. Cuff arthropathy is now one of the major problems a shoulder surgeon has to face nowadays in clinical practise. It is caused by a long-standing large or massive rotator cuff tear, leading to functional upriding of the humeral head due to unrestrained deltoid action and elevation of the effective centre of rotation of the gleno-humeral joint, often providing patients with a serious disability. The classic pseudoparalytic or flail shoulder with pain may be associated with degenerative changes in the gleno-humeral joint, but patients are frequently seen with minimal arthritic changes. The most definitive solution for treatment of rotator cuff arthropathy is the reverse Total Shoulder Arthroplasty (RTSA or RSA). Indications for RSA are mostly pain and to lesser extent loss of function. It often dramatically improves pain and function in patients with irreparable rotator cuff tears

associated with pseudoparalysis. Satisfactory results can even be obtained in patients who have undergone previous procedures, such as rotator cuff repair [1]. Current available literature documents an implant survival rate of 91% at 10 years [2]. Given these promising results, it is no wonder that reverse total shoulder replacement is increasingly commonly used, making in 2015 over 45% of shoulder replacements performed in the UK according to the National Joint registry [3]. For patients with irreparable cuff tears aged 70 years or greater, it has practically replaced the other procedures. However successful, the longevity of reverse TSR does not yet match those expected for replacements of the hip and knee. For that reason, replacement before the age of 70 is not recommended by some authors [1, 3]. What are the options then for patients with symptomatic large and massive tears of the rotator cuff and little evidence of arthropathy, particularly in the younger patients unsuitable for reverse TSR?

In this chapter we will go through the most current concepts regarding massive and irreparable cuff tears, as well as cuff tear arthropathy. We will show the reader contemporary view on diagnosis and treatment of these conditions, but also share technique developed by the senior author and used in our daily practise.

## 2. Massive and irreparable rotator cuff tears

Massive rotator cuff tears (MRCT) make up to about 20% of all cuff tears [4, 5]. The number gets higher if we look at recurrent tears: in this group MRCT constitute of up to 80% [4, 5]. Cofield described cuff tear as a massive if its anteroposterior dimension reached or exceeded 5 cm [6]. Davidson and Burkhart in an attempt to add to their definition a second dimension, defined a massive tear as tears in which both coronal length and sagittal width were at least 2 cm long [7]. Gerber et al. defined a cuff tear as a massive once it involved a complete tear of at least two tendons [8]. Lädermann et al. advocated that to constitute a massive tear, at least one of two tendons should be involved, and should retract beyond the level of humeral head apex [9].

Once identified, massive tears can then be further classified by chronicity or with regard of a tear pattern.

If subdivided by the chronicity, tears can be defined as acute, acute on-chronic and chronic [10]. Acute MRCT are very infrequent, usually occurring after traumatic events and are more common among younger population [1, 10]. Individuals with a truly acute, traumatic massive cuff tear often present with a completely pseudoparalytic shoulder [1]. Plain radiographs should be taken to exclude a fracture and/or dislocation and may also document a wide joint space due to interposition of an avulsed cuff. MRI is used to assess the cuff, and in the presence of a massive tendon tear without the radiological signs of chronic tendon involvement (such as fatty muscle infiltration), earliest possible repair should be undertaken [1].

Apart from dramatic circumstances described above, most acute massive tears are actually acute on chronic tears where new onset or acutely deteriorating shoulder pain is due to underlying long lasting cuff pathology. These tears show often some signs of degeneration of the cuff and bony changes on greater tuberosity and acromion on radiograph [11].

Finally, the chronic massive tears are the most common and are found almost exclusively in older patients. They are associated with degenerative tendon changes such as myotendinous retraction, loss of musculotendinous elasticity, fatty infiltration of muscles, static (superior) subluxation of the humeral head, and ultimately, osteoarthritis [1].

If classified by anatomic tear pattern, MRCT usually fall into two distinct groups: posterosuperior and anterosuperior tears [12]. Most tears involve the supraspinatus and the infraspinatus, with or without the teres minor tendon, and these are considered as posterosuperior tears. Anterosuperior tears involve a complete tear of supraspinatus and subscapularis tendons [12]. Collin et al. made the tear pattern classification more precise and detailed, dividing the rotator cuff into five components: lower subscapularis, upper subscapularis, supraspinatus, infraspinatus and teres minor [13]. Depending on which component is involved in a tear, 5 tears patterns can be distinguished: Type A are supraspinatus and superior subscapularis tears; Type B are supraspinatus and entire subscapularis tears; Type C are supraspinatus, superior subscapularis, and infraspinatus tears; Type D, supraspinatus and infraspinatus tears; Type E are supraspinatus, infraspinatus, and teres minor tears [13]. This classification not only organizes all tears into tear pattern groups, but also aims at linking tear patterns with specific function loss. Therefore, Type A disruption typically causes a decrease in internal rotation strength with positive Belly press and Bear Hug tests, combined with a positive test for superior cuff insufficiency, e.g. empty can test. To a different extent the same is true for type B and C. Type D may show weakness of external rotation, while posterosuperior MRCT with an extension to the teres minor (Type E) may have an external rotation lag sign and often exhibit a positive Hornblower's sign (the inability to maintain external rotation with the arm abducted to 90) [13].

Fortunately irreparable rotator cuff tears (IRCT) are just a subgroup of massive tears, as some of the latter are amenable for repair. Exact incidence of IRCT is unknown, with some studies estimating it between 6.5% and 22.4% [10]. To be considered irreparable, a defect should be impossible to close at the time of surgery or show traits which have been empirically determined to be associated with structural failure of the repair [1]. According to Gerber, clinical signs which suggest that a repair is unlikely to be successful include:

- static anterosuperior subluxation with the head under the skin in front of the anterior acromion and associated pseudoparalysis of anterior elevation
- dynamic anterosuperior subluxation of the humerus upon resisted abduction
- positive lag sign and Hornblower's sign (both associated with substantial fatty infiltration of infraspinatus and teres minor respectively) [14, 15].

The imaging finding most commonly associated with irreparability of the cuff tear is a fatty infiltration of cuff muscle which equals or exceeds 50% of muscle's volume determined by CT or MRI (stages 3 and 4 of fatty infiltration according to Goutallier) [16]. Fatty degeneration is irreversible even with successful complete repair and leads to reduced function of the rotator cuff musculature [8, 17]. Some authors reported that in higher stages (Goutallier 3 and 4) of fatty infiltration, MRCT may fail to heal in up to 92% of cases. Another key imaging

finding helping to predict irreparability of a tear is a static superior subluxation of a glenohumeral joint with an acromiohumeral interval of 7 mm or less. Also static anterior subluxation observed in CT scan or MRI appears to be indicative of irreparability of the tear [1].

### 3. Clinical signs and symptoms

As the incidence of rotator cuff tears increases with age, especially after age 60, elderly patients are the most likely group to seek help due to massive rotator cuff tears [10, 18]. Some of them might report a traumatic event and an acute loss of function, with or without previous symptoms; however, most will deny any noticeable trauma and complain of variable levels of pain [10]. It is important to ascertain that the pain reported by the patient is actually caused by the massive cuff tear, and not from another source.

If it is accompanied by stiffness, especially with limitation of passive external rotation and passive glenohumeral abduction, it is very likely that the pain is due to adhesive capsulitis rather than MRCT.

Acromioclavicular joint pain, though different from the usual rotator cuff pain [19] is the second most common cause of pain that is not caused by, but is occasionally [1] attributed to rotator cuff tear.

Loss of function and disability are the next biggest complaint, as MRCT is always accompanied by some degree of shoulder weakness. This weakness is especially marked with the limb away from patient's body. Anterosuperior tears usually result with painful weakness of elevation. Posterosuperior tears and global tears cause weakness of elevation and external rotation [20]. This usually spans from hardly any perceived weakness to so-called pseudoparalysis of elevation and/or external rotation [1]. Pseudoparalysis of anterior elevation describes the inability to elevate the arm to 90 deg. in the presence of unrestricted passive range of glenohumeral motion and in the absence of any neurologic impairment [21]. Pseudoparalysis of external rotation describes complete loss of active external rotation power in the presence of unrestricted passive external rotation and in the absence of neurologic impairment [1]. Collin et al. demonstrated that dysfunction of the entire subscapularis and supraspinatus or three rotator cuff muscles are risk factors for pseudoparalysis [13]. There are studies suggesting that primary arthroscopic repair can lead to reversal of preoperative pseudoparalysis in 90% of patients, but this number drops to 43% in revision surgeries [22].

Examination of the patient with suspected massive or irreparable rotator cuff tear should be performed with patient's torso exposed allowing proper comparison between two shoulders. Any atrophy in the supraspinatus or infraspinatus fossa should be noted, indicating a chronic tear. If the coracoacromial arch is incompetent, the outline of humeral head might be more prominent due to anterosuperior subluxation. Visible deltoid atrophy is especially of concern in patients with previous open surgeries. The long head of the biceps tendon might be affected by massive cuff tears and is often torn resulting in a 'Popeye' deformity (a visible bulge just proximal to the elbow).



Active and passive range of movement should of course be assessed and compared with the contralateral side. Active shoulder motion is usually decreased. Limitations of passive motion may be due to scar tissue formation associated with chronic tears, but these are usually mild and not very painful. It is important to discern this from the often much more painful adhesive capsulitis.

In patients with anterosuperior tears, significant weakness of the subscapularis will be noted. The bear hug test will most likely be positive. The belly-press manoeuvre, which tests the upper portion of the subscapularis muscle, is more likely to be abnormal than the lift-off test, which mainly reflects the lower subscapularis muscle function [10, 23]. Increased passive external rotation of the shoulder may also be present [10].

Two provocative manoeuvres can determine the extent of the posterosuperior cuff involvement. The external rotation lag sign. If the patient cannot actively maintain maximal external rotation of the shoulder with the elbow by his side, the test is considered positive for the infraspinatus tendon tear. The Hornblower's sign tests the integrity of teres minor [10]. With the elbow supported, the patient is asked to maintain maximal shoulder external rotation with the shoulder abducted to 90°. Inability to maintain this position is highly sensitive for teres minor tear [15]. The supraspinatus tendon tear is always involved and so patients from both these groups should show weakness of supraspinatus strength (positive empty can test).

## 4. Investigations

Plain radiographs are of a great value to the evaluation. They provide information on the glenohumeral joint, acromial morphology, and the position of the humeral head. Standard evaluation consists of anteroposterior, axillary, and an outlet or scapular Y views. Grashey view (a true anteroposterior view) is most helpful to show the status of the glenohumeral joint, whereas an outlet and scapular Y views can be useful to examine acromial pathology [10]. Plain anteroposterior views will demonstrate any upridding of the humeral head and any osteoarthritic changes. Decreased interval between the humeral head and undersurface of the acromion is often associated with massive and irreparable cuff tears. This distance, the acromiohumeral interval (AHI), measures 7–14 mm in healthy shoulders [24] and as previously mentioned if it falls below 7 mm, the probability of successful cuff repair drastically decreases [25]. Hamada et al. [26] demonstrated correlation between progression of rotator cuff tear and reduction of AHI. He developed a radiographic classification of massive rotator cuff tear arthritis which divides massive rotator cuff tears into 5 grades: in Hamada Grade 1 the AHI is maintained, and narrows in Grade 2. Acetabulization (concave deformity of the acromion undersurface) in addition to the Grade 2 narrowing is classified as Grade 3. In Grade 4, narrowing of the glenohumeral joint is added to the Grade 3 features, and Grade 5 comprises instances of humeral head collapse [26]. Walch et al. recognized a group with massive tears that demonstrated glenohumeral narrowing without acromial acetabulization. Thus, they divided Grade 4 of Hamada into two subtypes: Grade 4A, glenohumeral arthritis without

subacromial arthritis (acetabulization); and Grade 4B, glenohumeral arthritis with subacromial arthritis (Grade 4 of Hamada et al.). These subtypes allowed for more specific classification of patients and almost all patients could be classified [26].

CT scan was the original investigation described by Goutallier in assessment of fatty atrophy, and can still be used for patients where any bony changes need to be more accurately determined and the state of muscle wasting and atrophy. Goutallier et al. classified muscle quality by the amount of fatty infiltration in the rotator cuff muscle as identified on CT in the axial plane, with a thorough analysis of the whole muscle belly [16]. They graded muscular fatty degeneration into 5 stages: Stage 0 is a normal muscle with no fatty infiltration and stage 1 is a muscle in which some fatty streaks can be seen on CT. Stage 2 is a muscle with substantial fatty atrophy but still affecting less than 50% of visible muscle. In stages 3 and 4 fatty atrophy affects 50% and over 50% of muscle respectively [16]. According to various authors fatty muscle infiltration beyond Goutallier stage 2 represents a non-functional muscle belly making a successful repair of its tendon virtually impossible [1, 16].

One of the most common imaging modalities for assessing the rotator cuff is magnetic resonance imaging (MRI). It can reliably identify and characterize the rotator cuff tendon tears [27]. MRI scan is easier to read in assessing the size of any rotator cuff tear and both muscle wasting and fatty atrophy, but patients with sore shoulders may struggle to stay still for the duration of the scan which may take 45 min. With the growing popularity of magnetic resonance imaging Goutallier classification was adapted to MRI. Some authors correlated it with surgical outcomes and retear rates [10] and found that like for CT the advanced degree of fatty infiltration (over 2 Goutallier) on preoperative MRI was a strong predictive factor of cuff repair failure [10].

It is worth remembering that for MRI, the Goutallier scoring uses a different plane compared to CT. It is no longer the axial plane but the most lateral parasagittal image on which the scapular spine is still in contact with the scapular body (Y view) [28]. This makes the method prone to false interpretation in cases of massive cuff tears, because severe muscle-tendon retraction can cause bunching of the muscle that may actually create an illusion of a larger muscle belly than in reality [10]. Some authors reported the use of so-called 'tangent sign' [29] as an indicator of advanced fatty infiltration [30] and as a predictor of whether a rotator cuff tear will be reparable [31]. A tangent sign is positive when atrophied supraspinatus muscle falls below a tangent line drawn between superior border of coracoid process and superior margin of scapular spine. This is assessed, just like Goutallier score, on the most lateral MRI image on which both coracoid process and scapular spine are still in contact with scapular body [32]. However a recent study by Kim et al. showed that tangent sign alone was not a good predictive indicator of outcome of massive cuff repair. According to authors the single most predictive factor of successful repair in MRCT remains infraspinatus fatty infiltration  $<3$  according to Goutallier [32].

Another important diagnostic modality is a ultrasound scan, which has become a popular modality for evaluating rotator cuff pathology because of its low cost and reliability in identifying the presence of a tear and its size even during the postoperative period [10]. Unfortunately ultrasound cannot penetrate through bone and may not provide accurate information about large rotator cuff tears where the tendon edges have retracted medial to the lateral acromial border [33]. Its optimal use is also notoriously dependent on the technician's experience.

## 5. Treatment options

### 5.1. Conservative treatment

Conservative treatment is often appropriate if a tear is proven to be irreparable, or the patient does not want operative intervention. Patients without any significant symptoms of pain may benefit from the anterior and middle deltoid rehabilitation programme. This has a success rate of about 30% and is particularly useful for those patients with loss of function without a great deal of pain. In this group conservative treatment may lead to a very satisfactory clinical situation with restoration of active arm elevation but to an inevitable increase in joint degeneration [1]. Zingg et al. [34] have documented a surprisingly good clinical outcome using non-operative treatment with a substantial structural deterioration of cartilage, tendon, and muscle.

In general, in irreparable cuff tears non-operative management is attempted for 6 months before considering surgery [9]. Typical treatment includes physiotherapy, anti-inflammatory and analgesic drugs, re-education, acupuncture and judicious use of subacromial (which in case of MRCT are also intraarticular) injections. Injections of either corticosteroids or hyaluronic acid are used. While repeated intraarticular steroid injections are discouraged by some authors as being largely ineffective [35, 36], others pointed out on a good and comparable therapeutic effect of both dexamethasone and sodium hyaluronate [37]. Hyaluronans are meant to act by blocking pain receptors, stimulating endogenous hyaluronan production and have a direct anti-inflammatory effect by inhibiting leukocyte action [38]. These injections have been shown to be of benefit for early and late osteoarthritis of the shoulder [39, 40]. A series of infiltrations with hyaluronic acid (once a week for 3 weeks) followed by rehabilitative treatment yielded significant pain reduction, improvement of range of motion, and autonomy in daily life activities [41] in a cohort of 22 patients (mean age 78y) with rotator cuff tears.

Conservative treatment does not substantially alter the course of the natural history of massive tears and as such can only be advised for patients whose cuff tears are already irreparable and who for various reasons would not be suitable for operative treatment [1].

Somewhere in between conservative and surgical treatment is a place for supra scapular nerve block and ablation. This salvage procedure can be used for pain relief where this is the major symptom, after initial conservative therapies have been exhausted [42] and the patient is not fit for major surgery, or does not want an operation. The suprascapular nerve is derived from the upper trunk of the brachial plexus (C5, C6) and is a mixed motor and sensory nerve. It provides the main sensory innervation to the posterior shoulder joint capsule, acromioclavicular joint, subacromial bursa, coracoclavicular and coracohumeral ligament [43] and motor branches to both supra and infraspinatus muscles. Blockade of the suprascapular nerve has been shown to improve chronic pain in numerous studies [44]. Among different techniques described are supra scapular nerve blocks (SSNB) [42], percutaneous SSN pulsed radiofrequency and arthroscopic SSN neurectomy [45]. Pulsed radiofrequency (PRF) works by delivering an electrical field to neural tissue rather than thermal coagulation and affects the smaller pain fibres more than the larger motor fibres, thus preserving any residual motor function [45]. There is morphologic evidence that PRF is less neurodestructive than CRF (continuous radiofrequency)



and it is possible that nerve fibres may regenerate after PRF treatment [42]. Kane et al. [42] showed that pulsed radiofrequency to the suprascapular nerve in a cohort of 12 patients with painful cuff tear arthropathy resulted in a significant improvement in Constant, Oxford and Visual Analogue scores at 3 months. In their technique suprascapular notch was identified by use of direct visualization with an image intensifier. The landmark to guide the initial entry point was a line drawn along the length of the scapular spine, bisected with a vertical line from the angle of the scapula. A radiofrequency needle was introduced through the skin, 2.5 cm along the line of the spine in the upper outer quadrant, and then guided to the edge of the suprascapular notch by use of the image intensifier. The nerve was located accurately by stimulating at 2 Hz (threshold <0.5 V). PRF was applied for 120 s 2 or 3 times. The total treatment time was 6–8 min.

Nizlan et al. [46] described an arthroscopic SSN neurectomy technique in patients who were poor surgical candidates for shoulder arthroplasty with significant chronic pain [45]. They performed arthroscopic examination through the standard posterior viewing portal first, confirming a complete and irreparable rotator cuff tear. A lateral working portal was created a few centimetres from the lateral edge of the acromion at the level of the posterior border of the acromioclavicular joint. Through this portal, a radiofrequency device and a shaver were used to clear the soft tissue within the spinoglenoid notch to identify the nerve at the floor of the notch. Once the nerve was identified on the floor of the spinoglenoid notch, it was traced proximally towards the transverse scapular ligament. The nerve was then divided proximally by use of the ablator at the suprascapular notch and distally at the floor of the spinoglenoid notch. They used their technique for severe shoulder pain treatment in a group of 20 patients 17 with a rotator cuff arthropathy, two with glenohumeral arthritis and one with a rotator cuff-deficient shoulder following an unsuccessful arthrodesis [46]. At an average follow-up of 29 months, 75% of their patients reported good to excellent pain relief scores.

## 5.2. Surgical treatment

### 5.2.1. Arthroscopic debridement with or without long head of the biceps tenotomy

Debridement of rotator cuff tears has been known to be associated with a satisfactory short term results, especially in patients with low demands [47–49]. The goal of the surgery is to remove the sources of pain; therefore, the torn edges of the rotator cuff tendons are debrided and a gentle bursectomy is completed. Complete anterior acromioplasty should be avoided in the setting of a massive tear as it may put coracoacromial ligament at risk and lead to postoperative anterosuperior subluxation of humeral head [50]. As it is reported that lateral acromion might be responsible for more impingement than the anterior part [51] some recommend lateral acromioplasty in addition to limited anterior acromioplasty [52, 53]. Despite these concerns, however, when Rockwood et al. [54] first proposed open debridement for treatment of massive cuff tears in 1995, he performed it with aggressive acromioplasty and complete release of the coracoacromial ligament. In this study, 50 patients (53 shoulders) were followed up at an average of 6.5 years, with 83% of patients having a satisfactory outcome with a significant decrease in pain. The average active elevation improved from an average 105° to 140° [54]. Gartsman et al. [55] reported positive outcomes with open debridement for patients with massive rotator cuff tendon tears, but noted a decrease in strength and suggested that

this weakness may be due to the incompetent coracoacromial ligament and the loss of superior humeral head containment. He also showed that superior head migration or incompetent subscapularis or teres minor were a negative prognostic factors for this treatment [55].

If sole debridement and acromioplasty do not suffice, a tuberoplasty might be an alternative or a good addition to treatment [56]. Described by Fenlin et al. [57] in 2002, its main goal is to contour and reshape the greater tuberosity to create a smooth congruent articulation between the greater tuberosity of the humerus and the under surface of the acromion. An arthroscopic tuberoplasty technique was presented by Scheibel in 2004 and described as 'reversed arthroscopic subacromial decompression' [56]. Studies by Verhelst et al. and Lee et al. [58, 59] confirmed the benefits of the procedure as an option in patients with irreparable cuff tears, showing good and excellent results. Both authors highlighted importance of maintaining the coracoacromial arch as a passive stabilizer to anterior and superior subluxation of the proximal humerus.

The management of the long head of biceps (LHB) tendon at the time of debridement is still controversial. Tenotomy of the biceps was described as a routine pain treatment in rotator cuff disease by Walch et al. in 1997 [60]. Concerns about the safety of this treatment were expressed as according to some, the biceps tendon acts to depress the humeral head in absence of the rotator cuff tendons [61]. In theory, release of the long head of the biceps might lead to further proximal migration of the humeral head. However, a number of studies found no proof to support these concerns [47, 62]. The available evidence suggests that the proximal long head of biceps tendon may be a source of significant pain and that LHB tenotomy provides a reasonable pain relief without the additional risk of superior migration of the humeral head. A couple of multicentre studies identified LHB tenotomy as a valuable option giving good pain relief in patients with MRCT [63, 64]. It seems also the results are the same whether it is tenotomy alone or with tenodesis [1].

In summary, it seems that debridement of rotator cuff tendon stumps with subacromial decompression leads to satisfactory clinical results with large majority of patients with MRCT. A tuberoplasty might also be considered in this patients group. Coraco-acromial ligament, a major restraint against superior migration of the humeral head, should be handled with care, and can be detached but should not be resected in this group of patients [65, 66]. A biceps tenotomy, with or without tenodesis seems to be a safe additional procedure, helping decreasing the pain associated with massive cuff tears [64]. Debridement gives good pain relief but does not influence the progression of joint degeneration, so its role should be limited to treatment of irreparable cuff tears in low-demand patients whose primary complaint is pain [1].

### *5.2.2. Rotator cuff repair*

If a massive rotator cuff tear can successfully be repaired, short- and long-term clinical results are excellent and joint degeneration is halted or at least markedly decelerated [67, 68]. According to Burkhart the goal of a repair, even if partial, is to restore force couples acting on the joint [50]. During shoulder motion, the rotator cuff muscles act together to centralize the humeral head against the glenoid fossa and balance the force couples about the glenohumeral joint. A force couple is a pair of forces that act on an object and cause it to rotate. For the object to be in equilibrium, the forces must be balanced, so must be equal in magnitude and opposite

in direction [50]. In the shoulder, Inmann et al. [50] described coronal plane force couple as a result of the balance of moments created by the deltoid versus those created by inferior cuff (infraspinatus, teres minor and subscapularis). In order to oppose the superior pull of deltoid exerted during abduction, the inferior cuff must be intact. The second important force couple is the transverse force couple where action of subscapularis anteriorly is balanced against the posterior cuff (infraspinatus and teres minor). In massive cuff tears extending far posteriorly, the weak posterior cuff is unable to balance the anterior moment created by subscapularis and the equilibrium in transverse plane is not maintained. If large enough and affecting the inferior part of the cuff, the massive tear can disrupt the equilibrium in coronal plane. Lack in balance in two planes will lead to anterior and superior translation of the humeral head and inability to maintain a stable fulcrum of motion [50]. So during the repair it is more important to balance these force couples in coronal and transverse planes, than just to cover cuff defect [50].

In the context of the irreparable rotator cuff tear, it was felt by Burkhart that even partial repair of these tears could lead to good outcomes provided that the balance in both planes was restored [69]. Another important concept introduced by this author, helping to understand cuff anatomy, mechanics and principles for repair was 'suspension bridge analogy'. When viewed arthroscopically the undersurface of the intact cuff shows a 'cable-like' thickening of the capsule, surrounding a thinner crescent of tissue that inserts into the greater tuberosity of the humerus [50]. This 'cable-like' structure is a thickening of the coracohumeral ligament and extends from its anterior attachment to the greater tuberosity just posterior to the long head of the biceps, to its posterior attachment near the inferior border of the infraspinatus. This cable potentially serves a protective role, transferring the stress along the rotator cable, thereby stress-shielding much thinner, avascular crescent tissue, thus the analogy to the suspension bridge. The cuff can still successfully serve its function as long as the cable is intact. This is how authors explained good results of even partial repair, without watertight closure, but with reconstruction of cable attachments [50].

Although very difficult, complete repair of the massive cuff tears is not impossible, but requires very gentle soft tissue handling. One of the most significant issues in repairing a massive rotator cuff tears is the ability to mobilize the retracted tendon back to its insertion [10]. All adhesions around the cuff tendons must be removed. Common locations for these adhesions include the undersurface of the acromion, the posterior deltoid, the bursa and the interval between the undersurface of the tendon and labrum or glenoid [10]. If these release do not give relatively tension-free repair, additional techniques must be used. Tauro popularized the arthroscopic technique of the interval slide, which Burkhart [10, 50] later redefining it as an anterior interval slide, adding that a posterior slide as an option. Anterior interval slide is performed by releasing the rotator interval between subscapularis and supraspinatus, exposing the coracoid process. In its later version, named 'anterior interval slide with continuity', the rotator interval is released medially to the so-called 'comma tissue'. This comma tissue, a remnant of the bicep pulley, connects the superior border of subscapularis tendon with the anterior edge of supraspinatus and helps to repair one of the tendons after the other has been repaired. The posterior interval slide is performed between the supraspinatus and infraspinatus tendons up to scapula spine [10, 50].

Another useful technique, helping to decrease the tension from the cuff tissue and thus making massive cuff tears repairable, is a margin convergence [50]. This technique converts irreparable U-shaped and L shaped defects into more a manageable crescent-shaped tears that can be repaired completely [50]. The tears are initially repaired with side-to-side suturing of anterior and posterior leaves of the tear, from medial to lateral. This causes the free margin of the cuff to converge laterally towards the bony bed of the greater tuberosity, and then the free margin can be securely anchored to the bone with relatively little strain [50].

To account for poor quality tissue (osteopenic tuberosities, weak and non-elastic tendons) in chronic tears, and to minimize the likelihood of a retear after the repair, various other techniques have been described. These include the use of stronger sutures, various suturing configurations (e.g. Mason-Allen technique), larger and more rigid suture anchors, and bone tunnels, with or without a metallic plates and buttons [70, 71].

If the complete repair is impossible, the previously mentioned partial repair seems to represent a reasonable option in this challenging subset of patients [45]. The main goal of partial repair is to achieve sufficient tendon healing to regain relatively pain-free overhead activity [50]. To accomplish this, the rotator cuff repair must satisfy 5 biomechanical criteria:

- force couples must be balanced in coronal and transverse planes;
- a stable fulcrum kinematic pattern must be re-established;
- the residual defect should occupy a minimal surface area; and
- the residual defeat must possess edge stability.

These five criteria can be achieved by balancing the force couples between the anterior and posterior portions of the shoulder, which requires an intact subscapularis muscle anteriorly, an intact inferior half of infraspinatus posteriorly and preferably intact attachments of the rotator cable [50]. Although shoulder strength may not improve after this intervention, function is usually enhanced because of relief from pain caused by mechanical impingement [9].

There is a lack of strong evidence showing that either arthroscopic or open rotator cuff repair is superior. If the repair heals by either approach, the results are comparable. Despite high structural failure rates of the tendon in massive rotator cuff repair (retear rates of 34–94% have been reported [1], clinical outcome scores remain consistently good when compared with preoperative values [1, 72].

### 5.2.3. *Tendon transfers*

For those patients whose rotator cuff tendon cannot be repaired completely or even partially to provide symptomatic relief, a salvage reconstruction with muscle-tendon transfer may be considered [73]. The ideal candidate for this type of procedure is a young, active patient with an irreparable rotator cuff tendon tear and minimal glenohumeral arthritis whose primary complaint is weakness [10]. Various tendons transfer techniques has been described for patients with massive irreparable tears, with the most common being latissimus dorsi with or without the teres major, pectoralis major, and trapezius [10, 41].



Pectoralis major transfer is used where there is a deficiency of anterosuperior rotator cuff, particularly in patients with recurrent anterior instability resulting from subscapularis insufficiency [74]. In the original description of the technique of pectoralis major tendon transfer from 1997 by Wirth et al., the upper portion of the pectoralis major tendon was transferred [75]. Resch described a technique in which the upper portion of the pectoralis major is rerouted underneath the conjoint tendon. In his opinion, this would give a more favourable line of action for the transfer compared with the traditional pectoralis major transfer [76]. To improve the line of action of the transferred pectoralis major without jeopardizing the musculoskeletal nerve, Warner modified the original pectoralis tendon transfer by rerouting its sternal head underneath the clavicular head before fixation to the lesser tuberosity (split pectoralis major transfer, SPM transfer) [77].

A slight modification of Warner technique was proposed by Gerber et al. Their tendon transfer combines the split pectoralis major tendon and the teres major tendon (SPM–TM transfer). The rationale of this combined tendon transfer is to replace the upper and lower portion of the subscapularis muscle with the split pectoralis major and teres major, respectively [78].

Recent literature confirms that pectoralis major transfer is a safe and quite reliable procedure. In their systematic review of pectoralis major transfer in irreparable cuff tears, Shin et al. included eight studies with a total 195 shoulders. The mean follow-up was 33.4 months (range 6–80 months). Constant scores improved from a mean pre-operative score of  $37.8 \pm 6.8$ , to a mean postoperative score of  $61.3 \pm 6.5$  ( $p < 0.0001$ ). Although improvement in pain scores was impossible to assess due to different scores used, a trend in pain reduction was noted in all articles [79]. The Constant scores were significantly higher in patients following subcoracoid transfer of the pectoralis major tendon compared to patients who received supracoracoid transfer ( $p < 0.001$ ). The overall reported incidence of postoperative nerve palsy is low (one transient musculocutaneous nerve palsy and one axillary nerve dysfunction out of 195 cases) [79].

It seems that pectoralis major transfers are a reasonable surgical option for the management of irreparable anterosuperior rotator cuff tears, particularly when the patient is experiencing anterior instability as a result of subscapularis insufficiency [41].

Latissimus dorsi transfer for a deficient superolateral and posterosuperior rotator cuff can produce a dramatic restoration of elevation of the shoulder. Transfer of the latissimus dorsi with or without the teres major has been known as a salvage procedure for irreparable superolateral rotator cuff tears since 1992, when it was first published by Gerber et al. [80]. It has been proved by many authors to be a valuable treatment option for painful or pain-free pseudoparalysis of external rotation provided that the subscapularis is intact. Results are better if there is no chronic pseudo paralysis of anterior elevation and if the teres minor does not show advanced fatty infiltration [1]. The ideal candidate is a patient who has maintained active anterior elevation, but lacks control of the arm in space in external rotation (simple weakness in external rotation is not a sufficient indication for surgery), and who also has an intact subscapularis and no glenohumeral arthritis [9]. Several surgical techniques have been used for latissimus dorsi transfer, including single-incision, double-incision, and more recently arthroscopically assisted transfer [41]. When it is transferred, the muscle no longer serves as an internal rotator but rather is an external rotator and humeral head depressor. A more posterior placement of



the transfer on the greater tuberosity results in more external rotation, whereas more superior placement results in more humeral head depression [41]. Iannotti et al. [81] in their technique put patient in lateral decubitus position. A superior approach to the rotator cuff is achieved with detachment of the deltoid origin from the anterior aspect of the acromion and with a 4 cm split of the middle deltoid fibres. The coracoacromial ligament is taken off with the deltoid and is reattached at the conclusion of the operation. The bursa is excised, and the rotator cuff is inspected. All attempts are made to mobilize and repair the cuff. Acromioplasty is performed if needed. The subscapularis tear should be repaired if presents. A second incision is made along the lateral border of the latissimus dorsi to the posterior axillary crease. The latissimus dorsi insertion is identified with the arm abducted and internally rotated, and it is detached sharply from the humerus. The neurovascular pedicle is identified and protected, and the muscle is freed from its deep fascia attachments. A 1-mm Dacron suture is passed with use of a Krakow suture technique along each side of the tendon from the musculotendinous junction to the end of the tendon. Blunt dissection is performed to create a wide tunnel deep to the deltoid and superficial to the posterior cuff musculature. The latissimus dorsi muscle and tendon are brought over the top of the humeral head and are repaired anteriorly to the subscapularis, laterally to the greater tuberosity, and, if possible, medially to the torn retracted edges of the rotator cuff [81]. More recently arthroscopically assisted transfers have been reported. Arthroscopic assisted procedures can have a couple of advantages over open counterparts, one being easier identification and treatment of concomitant intraarticular pathologies [82].

In a systematic review of the literature performed by Namdari et al. results from 10 studies (258 patients, 262 shoulders) were compared. Patients were followed for a frequency-weighted mean of 45.5 months (range, 24–126 months). Frequency-weighted mean adjusted Constant score improved from 45.9 preoperatively to 73.2 postoperatively ( $p < 0.001$ ). The frequency-weighted mean active forward elevation improved from 101.9° preoperatively to 137.4° postoperatively ( $p < 0.001$ ), and the frequency-weighted mean active external rotation improved from 16.8° to 26.7° ( $p < 0.001$ ). Authors found that subscapularis muscle insufficiency, advanced teres minor muscle atrophy, and the need for revision surgery were correlated with poor functional outcomes. The overall reported complication rate was 9.5% (25 of 262), which included among other seven cases of neuropraxia (2.7%) and nine tears of the transferred tendon (3.4%) [87].

In their long-term follow-up of minimum 10 years of 46 shoulders in 44 patients, Gerber et al. observed the mean subjective shoulder value (SSV) increase from 29% preoperatively to 70% at the time of final follow-up. The relative Constant score improved from 56 to 80, and the pain score improved from 7 to 13 points ( $p < 0.0001$  for all). Mean flexion increased from 118° to 132°, abduction increased from 112° to 123°, and external rotation increased from 18° to 33°. Mean abduction strength increased from 1.2 to 2.0 kg ( $p = 0.001$ ). There was a slight but significant increase in osteoarthritic changes. Inferior results occurred in shoulders with insufficiency of the subscapularis muscle and fatty infiltration of the teres minor muscle [84].

Latissimus dorsi transfer (with or without terms major) demonstrated to be a valuable option for improvement in shoulder function, range of motion, strength, and pain relief in patients with irreparable posterosuperior rotator cuff tears, however patients and physicians should not expect an outcome of 'normal' function or complete pain relief [83].

There is increased interest in using lower trapezius transfers for treatment of massive irreparable posterosuperior rotator cuff tears. Its use was first described by Elhassan et al. to improve external rotation in patients with brachial plexopathy [85]. A biomechanical investigation found that a lower trapezius transfer is more effective in restoring external rotation than the latissimus dorsi transfer [86]. In 2016 Elhassan et al. published their results of lower trapezius transfer with Achilles tendon augmentation at an average follow-up of 47 months [87]. All 32 patients had significant improvement in pain, subjective shoulder value, and shoulder range of motion [87]. Another relatively recent concept is the use of latissimus dorsi and teres major transfer in subscapularis insufficiency. The anatomic feasibility study of the latissimus dorsi (LD) with teres major (TM) muscle-tendon transfer to reconstruct an irreparable SS tendon tear by Elhassan et al. showed encouraging results [88].

#### 5.2.4. Subacromial spacer

One of the most recent treatment modalities proposed for an irreparable rotator cuff tears is the use of a subacromial balloon or spacer [89]. The most commonly used balloon system which contains an introducer and a preshaped spacer (available in 3 different sizes) made of poly(L-lactide-co-caprolactone), which is a copolymer of poly-lactide and -caprolactone. This is a biodegradable and widely used material that dissolves over a period of 12 months [45]. It is unclear, however, how long the spacer remains inflated. The spacer works by reducing subacromial friction through lowering the humeral head during abduction [89]. To enable insertion, the balloon is folded into a cylinder-shaped insertion tube, which is removed once the spacer is inserted into the subacromial space [89]. After a standard arthroscopy including debridement and bursectomy, the rotator cuff is assessed for reparability. Once deemed irreparable, the correct size of the spacer must be chosen. The biodegradable spacer is introduced through the lateral port and is inflated with saline to its maximal volume depending on the spacer size. As a final step, the delivery system is removed, and the shoulder is passively moved through a full range of movement to verify that the spacer is accurately placed, is stable in position, and does not interfere with shoulder mobility [89]. This balloon can be used in patients with irreparable tears of SST and IST. It is recommended to repair the subscapularis to create anterior-posterior coupling. Contraindications include glenohumeral arthropathy, active infection and allergy to device material.

Senekovic et al. published their 5 year follow-up of 24 patients who were treated with a balloon device. Of the participating subjects who reached the 5-year follow-up, 84.6% of the patients showed a clinically significant improvement of at least 15 points in Constant score, while 61.54% showed at least 25 points of improvement. Only 10% of the treated patients showed no improvement or worsening in the shoulder score comparing to their baseline. Further randomized controlled trials in larger cohorts are needed [90].

#### 5.2.5. Superior capsule reconstruction

The shoulder capsule is an important static stabilizer of the glenohumeral joint [91]. The anterior capsule serves to maintain glenohumeral stability anteriorly, whereas posterior capsule plays an important role with posterior stability [8, 91]. The superior capsule attaches to a

significant portion of the greater tuberosity, with an anatomic study indicating a range between 30% and 61% of total surface area [92]. As a result, it is often disrupted when complete tears of the supraspinatus or infraspinatus occur [41]. A recent biomechanical study determined that superior capsular defects led to increased glenohumeral translation in all directions, particularly with superior translation at 5 and 30° of abduction [91]. Mihata et al. developed arthroscopic superior capsule reconstruction (ASCR) [93] to restore superior stability of the shoulder joint of patient with irreparable cuff tears [93, 94].

Arthroscopic subacromial decompression and debridement of both the superior glenoid and rotator cuff footprint of the greater tuberosity is performed. If torn, the subscapularis tendon should be repaired and a partial repair of a torn infraspinatus and teres minor tendons is advised. The size of the superior capsular defect is evaluated. Then a graft 6–8 mm thick is prepared and inserted into the subacromial space through the lateral portal. It is then attached to the superior glenoid by using 2 suture anchors inserted into the superior glenoid. The lateral side of the graft is attached to the rotator cuff footprint on the greater tuberosity by using a compression double-row technique [93]. Finally, side-to-side sutures between the graft and the infraspinatus tendon and between the graft and the residual anterior supraspinatus tendon or subscapularis tendon are added to improve force coupling in the shoulder joint. Careful attention should be paid to overtightening of the side-to-side suture on the anterior side to avoid shoulder contracture after surgery [93].

In their group of 23 patients (24 shoulder), Mihata et al. [93] reported improvement of mean active elevation from 84 to 148 ( $p < 0.001$ ) and of external rotation from 26 to 40 ( $p < 0.01$ ). Acromiohumeral distance (AHD) increased from  $4.6 \pm 2.2$  mm preoperatively to  $8.7 \pm 2.6$  mm postoperatively ( $p < 0.0001$ ). There were no cases of progression of osteoarthritis or rotator cuff muscle atrophy. Twenty patients (83.3%) had no graft tear or tendon retear during follow-up (24–51 months). The American Shoulder and Elbow Surgeons (ASES) score improved from 23.5 to 92.9 points ( $p < 0.0001$ ). These encouraging results suggest that this reconstruction technique useful alternative treatment for irreparable rotator cuff tears. Human dermal allograft has been also successfully used in this procedure [72].

#### 5.2.6. Rotator cuff repair with patch

As previously mentioned, cuff repair in massive tears is a complicated task. Retear rates are high, and depending on the source may reach 34–94% [10]. What is interesting is that patients who undergo repair which subsequently fail, still show improved functional outcomes postoperatively [95–97]. However, their results are worse than in those where healing was achieved [98, 99]. In an attempt to decrease the failure rate and improve the outcomes of massive cuff tears repair, the use of patch grafts was introduced and popularized by various authors. Many varieties of patch materials have been developed and used clinically, including synthetic materials Polyester ligament (Dacron) [100], Gore-Tex soft tissue patch [101], Mersilene mesh [102], Teflon felt [103] and Carbon fibre patches [104], allografts freeze-dried rotator cuff [105, 106], quadriceps tendon [107], patellar tendon, achilles tendon [107], dermal matrix (Graftjacket) [107], tensor fascia late [108] and xenografts porcine dermal collagen [109, 110], porcine small intestinal submucosa [111]. Autografts such as the biceps

tendon [112, 113] and tensor fascia lata [114] have also been used. Patch reinforcement can be performed as augmentation (onlay) of a cuff repair, in which the rotator cuff is repaired to nearly normal status and patch is then either implemented into the repair construct or sutured over the top of the repaired tendon [99]. The other method is interposition (intercalary), wherein the graft bridges the gap between the irreparable cuff edge and cuff footprint on the humerus [99]. As the use of patches for massive cuff tears repair is a subject of a great deal of interest, much has been published throughout last 20 years. Unfortunately most of the reports are case reports or short term case series on a relatively small groups of patients. Each of these studies typically represents the experience of one surgeon or one institution and therefore, when taken alone, may not be an accurate reflection of patch use more broadly. Comprehensive reviews can provide valuable summarized data, giving clinicians a broader picture on this interesting topic. A recent review was performed by Steinhaus et al. in 2016 [99]. They reviewed results of 24 studies, published between 1986 and 2014. The frequency-weighted mean age of patients was 61.9 years with 35.4 months' follow-up. There were a total of 566 patients included. The most common surgical technique used across the 24 studies was open patch repair, representing 54.6% of cases (309 of 566), followed by mini-open in 170 cases and arthroscopic in 87 cases. The most common graft source was synthetic, representing 44.3% of grafts (251 of 566), followed by allograft in 188 cases and xenograft in 127 cases. The graft was used to bridge the gap between the retracted cuff and humerus (interposition) in 56.3% of patients (319 of 566), whereas it was used to augment the repair in 43.6% (247 of 566). Augmentation and interposition techniques showed similar improvements in range of motion, strength, and patient-reported outcomes (PROs), pain and activities of daily living (ADLs) whereas xenografts showed less improvement in PROs and ADLs compared with other graft types. The overall retear rate was 25%, with rates of 34% and 12% for augmentation and interposition, respectively, and rates of 44%, 23%, and 15% for xenografts, allografts, and synthetic grafts, respectively.

In summary, all studies showed improvements in clinical and functional outcomes, without much difference between augmentation and interposition techniques. Xenografts seem to do worse than allografts and synthetic materials. What is interesting and might be counterintuitive for many, is the fact that retear rate was lower with the interposition technique. Of course systemic reviews are only as good as the studies they are based on, so as promising as the results seem to be, there is no doubt that patch grafting needs well designed prospective comparison studies to truly assess its value in massive cuff tears treatment.

## 6. Leeds Cuff Patch

Our technique of choice in surgical treatment of irreparable rotator cuff tear was developed by the senior author. We utilize a non-absorbable polyester patch which is sutured over the torn rotator cuff. It thus provides reinforcement of incompletely repaired rotator cuff tears and those at high risk of re-tear due to poor quality soft tissue. It can be used both as a bridging graft and augmentation. Leeds Cuff Patch a synthetic patch that is indicated for reconstruction of chronic massive, full thickness rotator cuff tears where the retracted tear cannot be



mobilized back to the bony attachment site or where the cuff tissue has undergone degeneration. The patch implant is produced from polyethylene terephthalate (PET), commonly known as polyester. This is a non-absorbable biocompatible material that has been in use for the reconstruction of ligaments and tendons for over 25 years. The design of the patch comprises a base component with an integral reinforcement component. The base component has a 'open structure' that acts as a scaffold allowing tissue ingrowth. The reinforcement provides enhanced strength to the patch. The patch can be implanted with typical techniques and sutures as used for other tendon augmentation xenograft and allograft patches. The weak point of a repair with such products is between the suture and tendon. However, the integral reinforcement of the patch provides resistance to suture pull-through and thus addresses this common failure mode for such devices.

Conducting our own research, we compared outcomes of the Leeds Cuff Patch with other treatment interventions available (e.g. anterior deltoid rehabilitation exercises, arthroscopic rotator cuff repair, arthroscopic rotator cuff debridement) for patients with large or massive cuff tears.

We recruited 68 patients with large and massive rotator cuff tears: 29 in the Patch group and 39 as controls. The treatment decision was made based on patient choice and intra-operative findings: those patients who wished to avoid operative intervention underwent anterior deltoid rehabilitation; those with arthroscopically repairable tears received that treatment; those with arthroscopically irreparable tears but mobile cuff underwent open patch repair; those with substantial retraction of poor quality immobile tendon underwent debridement. All patients completed Oxford Shoulder Score (OSS), Shoulder Pain and Disability Index (SPADI), and Constant score at baseline, 6 weeks and 6 months following treatment.

The Patch group demonstrated improvement in all outcomes from baseline to 6 months (paired mean difference OSS 12.3, SPADI 18.8, Constant 13.9), as did the Control group (paired mean difference OSS 8.7, SPADI 18.8, Constant 11.1). When the patients with very poor quality rotator cuff were removed, the results were OSS 14.3 SPADI Constant 18.0. The arthroscopically repaired group showed very similar results to the remainder of the controls. Those with better quality tendon but still non-repairable had a clinically significant improvement in OSS compared with the non-patch group.

We are extending the follow-up period for this study to 2 years, and will also analyse MRI scans performed at baseline, 6 months and 2 years following surgery. This will provide both clinical and radiological outcomes of patch repair of large and massive rotator cuff tears, and be one of the first studies comparing patches with other treatment options for this group of patients.

## 7. Summary

There are a wide variety of options available to surgeon for the patient with a large to massive tear of the rotator cuff causing pain and loss of function. Most of these have been reported as having quite reasonable outcomes in the published literature. In the UK, less than 30% of upper limb surgeons, would consider a patch, and further research is required. Newer



procedures such as superior capsular reconstruction and balloon arthroplasty warrant further investigation. Reverse TSR gives excellent outcomes in the older patient, but for younger patients with large or massive rotator cuff tears, though there are a number of surgical options available, the evidence to support each needs strengthening with further research into this exciting area of shoulder surgery.

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