Felix H. Savoie III
Emilio Calvo
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Editors

The Failed Rotator Cuff

Diagnosis and Management

ISAKOS
International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine

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Preface

Successful repair of the painful rotator cuff tear results in excellent shoulder function. Unfortunately, while the repair is usually successful, failure of the repair with continued symptoms occurs far too often. Literature on the failed rotator cuff is sparse, and there is currently minimal information to guide the surgeon or patient on the best way to address this problem in a comprehensive way. This book attempts to cross multiple disciplines in assessing and managing the failed rotator cuff including diagnostics (lab and imaging), nutrition, soft tissue surgery, arthroplasty surgery, and rehabilitation.

The unique and important aspect of this is that it provides a complete global perspective on all aspects of dealing with patients who unfortunately have a failed rotator cuff repair. Members of the ISAKOS Shoulder Committee from all over the world have participated, reviewed, discussed, and written chapters to provide a comprehensive review of this specific issue. The perspective of our patients who have failed rotator cuff surgery is one of frustration and debilitation. For the surgeon who is attempting to treat this issue it is a difficult and time-consuming process. This textbook addresses all aspects in an effort to help bring global knowledge and experience in a straightforward and efficient manner to the reader.

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Part I

Basic Science

1 The Failed Rotator Cuff: Diagnosis and Management—Rotator Cuff Anatomy/Blood Supply

John W. Belk, Stephen G. Thon, Eric C. McCarty Jr, John B. Schrock, and Eric C. McCarty

1.1 Supraspinatus Muscle

1.1.1 Structure and Humeral Insertions

The supraspinatus originates in the supraspinous fossa and superior surface of the scapular spine. It courses laterally and inserts at the anteromedial aspect of the most superior impression on the greater tuberosity. As the supraspinatus travels towards its insertion, its tendon appears to fuse with the infraspinatus tendon and forms a single insertion. However, debate exists as to whether the supraspinatus and infraspinatus truly merge. Some suggest that by dissecting out connective tissue and the coracohumeral ligament near the insertion, it is clear that the supraspinatus and infraspinatus are distinct and do not merge [4]. Others assert that the supraspinatus interdigitates with the infraspinatus approximately 15 mm proximal to the greater tuberosity, as well as 5 mm proximal to a shared insertion on the greater tuberosity [5]. Another interdigitation is noted between the supraspinatus and subscapularis at the bicipital groove. This fusion of muscle fibers surrounds the long head of the biceps brachii and creates the appearance of a hood-like structure. The insertional footprint of the supraspinatus resembles the shape of a right triangle, which is wider anteriorly and grows more narrow posteriorly [4]. A recent cadaveric study of 113 specimens showed that the supraspinatus tendon always inserted into the anterior most area of the highest impression on the greater tuberosity, which is located more anteriorly with a much smaller footprint than previously described [4].

The supraspinatus muscular fibers have been described to run towards the anterior, tendinous portion of the muscle, while the deeper muscular fibers typically course more laterally towards its attachment at the highest impression on the greater tuberosity. Dissection of supraspinatus muscle fibers reveals the tendinous fibers, which are composed of two distinct portions. The anterior half is longer and thicker, while the posterior half is shorter and thinner [4].

1.1.2 Innervation

The supraspinatus is innervated by the suprascapular nerve, which courses laterally through the posterior cervical triangle and then travels across the superior border of the scapula into the suprascapular notch. Medial retraction of the supraspinatus tendon drastically changes the course of the suprascapular nerve through the scapular notch, which can present symptom-

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atically in patients with tears of the supraspinatus [6]. Compression or injury to the nerve at the suprascapular notch can lead to selective atrophy and weakness of the supraspinatus muscle [7]. In patients undergoing repair of massive rotator cuff tears, release of the suprascapular nerve at the suprascapular notch has been demonstrated to significantly improve pain relief, active forward flexion, and strength when compared to patients undergoing rotator cuff repair without nerve release (Fig. 1.1) [8].

1.1.3 Blood Supply

Arterial blood reaches the supraspinatus via the suprascapular artery. In some instances, the dorsal scapular artery is also responsible for delivering blood to the supraspinatus muscle [10]. It is hypothesized that the anterior circumflex humeral artery and the acromial branch of the thoracoacromial artery deliver blood to the supraspinatus tendon. The blood exits the supraspinatus via the suprascapular vein which drains into the external jugular vein and is returned to the heart. A distinct feature of the supraspinatus is the presence of a hypovascular zone. Also referred to the "critical zone," this area is located just proximal to the supraspinatus insertion and is characterized by significantly reduced blood flow relative to other aspects of the supraspinatus and surrounding rotator cuff muscles (Fig. 1.2) [11].

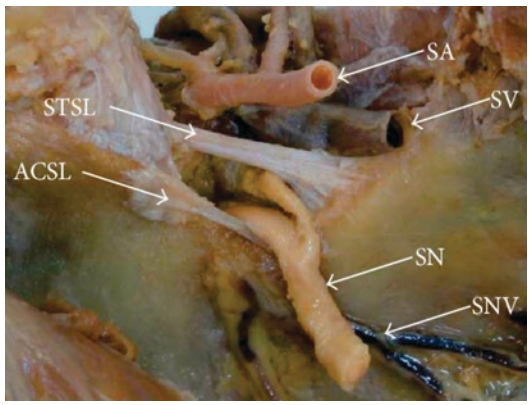

Fig. 1.1 Formalin-fixed cadaveric shoulder: suprascapular region. *SN* suprascapular nerve, *SNV* suprascapular notch vein, *SA* suprascapular artery, *ACSL* anterior coracoscapular ligament, *STSL* superior transverse scapular ligament, *SV* suprascapular vein. Reproduced with permission from [9]

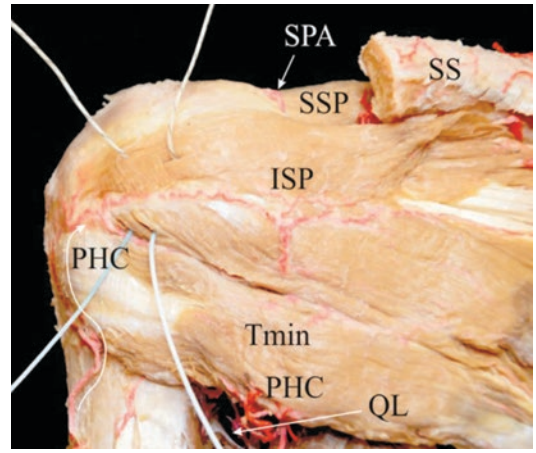

Fig. 1.2 Cadaveric illustration of a posterior left shoulder showing the position of the suprascapular artery and its supply to the supraspinatus. *SPA* suprascapular artery, *SSP* supraspinatus muscle, *SS* spina scapulae, *ISP* infraspinatus muscle, *PHC* posterior humeral circumflex artery, *QL* quadrilateral space, *Tmin* teres minor. Reproduced with permission from [12]

1.1.4 Variations

In general, the shape and attachments of the supraspinatus are very consistent. A few variations include insertions into the lesser tuberosity of the humerus or at the pectoralis major or minor as well as the superior transverse scapular ligament.

1.2 Subscapularis Muscle

1.2.1 Structure and Humeral Insertions

The subscapularis is the largest and most powerful muscle of the rotator cuff. It originates along the anterior aspect of the subscapular fossa on the scapula. A superior, tendinous portion and an inferior, muscular insertion comprise the two insertions of the subscapularis at the proximal end of the humerus [5]. The tendinous insertion, which is composed of a superficial and a deep layer, is broad and accounts for approximately 66% of the insertional footprint. The superficial layer is noticeably thicker and is composed of fused collagenous fibers with few stroma between cells. It bifurcates prior to attachment on the humerus, with one strand inserting at the superior aspect of the lesser tuberosity of the humerus and the other

inserting more laterally at the greater tuberosity, where it surrounds and interdigitates with the long head of the biceps tendon at the bicipital groove [13]. The thinner, deep layer is characterized by more ordered, parallel collagen fibers oriented longitudinally throughout the subscapularis. Deep fibers are densely packed and insert onto the lesser tuberosity of the humerus [13].

The muscular insertion of the subscapularis makes up approximately 33% of the insertional footprint and contains muscle fibers attached directly to the humerus via short tendinous fibers [14]. It attaches to the inferior portion of the lesser tuberosity and anterior aspect of the anterior humeral metaphysis. In some cases, the insertion reaches as inferiorly as the surgical neck of the humerus. Overall, the insertional length of the subscapularis from distal to proximal along the humerus ranges from 2.5 cm to 6.0 cm [15].

1.2.2 Innervation

The superior portion of the subscapularis muscles is innervated by the upper subscapular nerve and the inferior portion is innervated by the lower subscapular nerve. The upper and lower subscapular nerves insert into the muscle belly medial to the myotendinous junction with the upper subscapular nerve penetrating the muscle belly more proximal than the lower subscapular nerve [16]. The course of the lower subscapular nerve is longer as it eventually goes on to innervate the teres minor, this has been proposed as a site for traction injury during open shoulder surgery due to its increased length [16].

1.2.3 Blood Supply

The axillary artery travels laterally to the pectoralis minor and gives rise to the subscapular, anterior, and posterior humeral circumflex arteries. The anterior humeral circumflex artery diverges into medial and lateral ascending branches, with the medial ascending branches supplying blood to the subscapularis tendon and portions of the caudal bursa beneath the coracoid bursa [17]. A branch of the axillary artery also supplies blood to the subscapularis tendon. Cadaveric dissection has demonstrated that the anterior portion of the subscapularis muscle body is supplied by the subscapular, lateral thoracic, circumflex scapular, suprascapular, and axillary arteries. Posteriorly, subscapularis muscle tissue is supplied by the suprascapular, posterior circumflex humeral, and subscapular arteries [18]. Once blood reaches the subscapularis, it is drained by the circumflex scapular veins, which ultimately merge with the thoracodorsal vein. This merge creates the subscapular vein and gives way to the axillary vein, which eventually drains into the superior vena cava (Fig. 1.3).

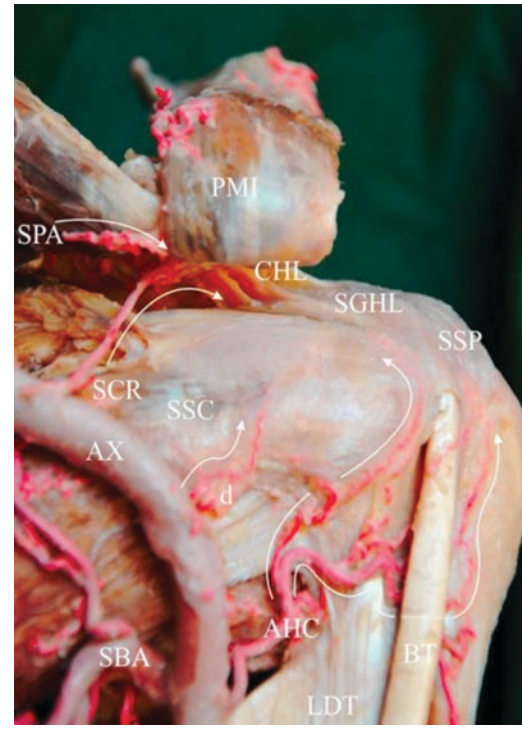

Fig. 1.3 An anterior view of a left shoulder specimen. The pectoralis minor muscle (PMI) has been released from the coracohumeral (CHL) and superior glenohumeral ligaments (SGHL) and ascended cranially. The subcoracoid artery (SCR) ascends from the axillary artery (AX) and courses into the coracohumeral ligament. A branch of the suprascapular artery (SPA) courses to the superior surface of the coracohumeral ligament. A direct branch (d) ascends from the axillary artery to the subscapularis (SSC) tendon. The anterior circumflex humeral artery (AHC) provides medial (*upward arrow*) and lateral (*upward arrow*) ascending branches. *SBA* Subscapular artery, *BT* tendon of the long head of the biceps brachii, *LDT* tendon of the latissimus dorsi. Reproduced with permission from [17]

1.2.4 Variations

Several variations of the subscapularis are documented in the literature. One anatomic variation is known as the subscapularis minor or secundus, which originates on the lateral border of the scapula and inserts at the crest of the lesser tuberosity [19, 20]. Other variations include subscapularis muscle insertions directly into axillary fascia, the pectoralis major, or the short head of the biceps brachii.

1.3 Infraspinatus

1.3.1 Structure and Humeral Insertions

The infraspinatus originates from both the infraspinatus fossa and the inferior surface of the spine of the scapula [21]. According to most anatomical texts, the four rotator cuff muscles have separate insertions from one another, each with its own footprint on the humeral tubercles. Some studies have described an interdigitation of the rotator cuff tendon fibers, forming a continuous insertion onto and around the greater and lesser tuberosities of the humerus [5, 22]. Although the muscular portion of the supraspinatus and infraspinatus appear separated from one another, the distal tendinous portions merge and are unable to be separated close to the insertion point [5]. The infraspinatus creates a trapezoidal footprint as it inserts onto the greater tuberosity. Prior studies have demonstrated distinct and separate insertion footprints of the different rotator cuff tendons although recent measurements and results contradict those findings and demonstrate an interconnected insertion zone for all tendons [5]. A cadaveric study with over a hundred specimens reported that the infraspinatus tendon curves more anteriorly around the proximal humerus than previously described, extending all the way to the anterolateral area of the highest impression of the greater tuberosity (Fig. 1.4) [4].

The infraspinatus is comprised of three distinct groups of fibers according to the direction and distribution of muscle fibers and is organized

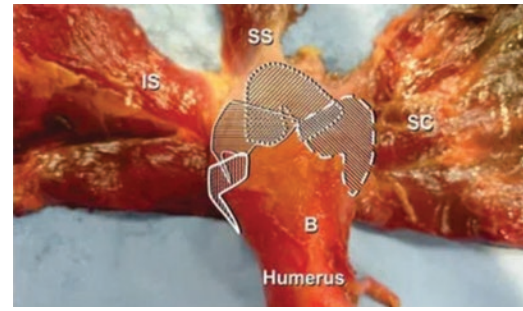

Fig. 1.4 External view of the complete rotator cuff unit still attached to humerus. Showing interdigitations between the RC tendons. *B* Long head of biceps. Reproduced with permission from [5]

in a superficial and deep plane [23]. A cranial and a caudal part make up the superficial layer and converge as the fibers move laterally, while a central part comprises the deep layer and runs laterally to insert on the medial two-thirds of the infraspinous fossa. The deeper medial portion has a large tendinous layer on the dorsal side, which narrows to form a thick central tendon as it continues laterally. This central tendon receives tendinous contributions from both the cranial and caudal part, and eventually terminates on the proximal humeral epiphysis (Fig. 1.5) [23].

1.3.2 Innervation

The suprascapular nerve innervates the infraspinatus although origins of the innervating branch to the superior transverse portion are variable [24]. They arise either from the main trunk of the suprascapular nerve after the supraspinatus nerves have branched off, or as branches from the supraspinatus muscle branches. Due to this innervation pattern, the superior portion of the infraspinatus may be more closely related to the supraspinatus [24]. Additionally, the suprascapular nerve has been shown to pass through the suprascapular notch 3.0 cm medially to the supraglenoid tubercle [25]. As it exits the suprascapular notch, it crosses the supraspinous fossa and provides motor branches for the supraspinatus muscle and receiving sensory branches. The suprascapular nerve then passes through the spinoglenoid notch, where it supplies motor branches to the infraspinatus muscle [26]. A blockage of the suprascapu-

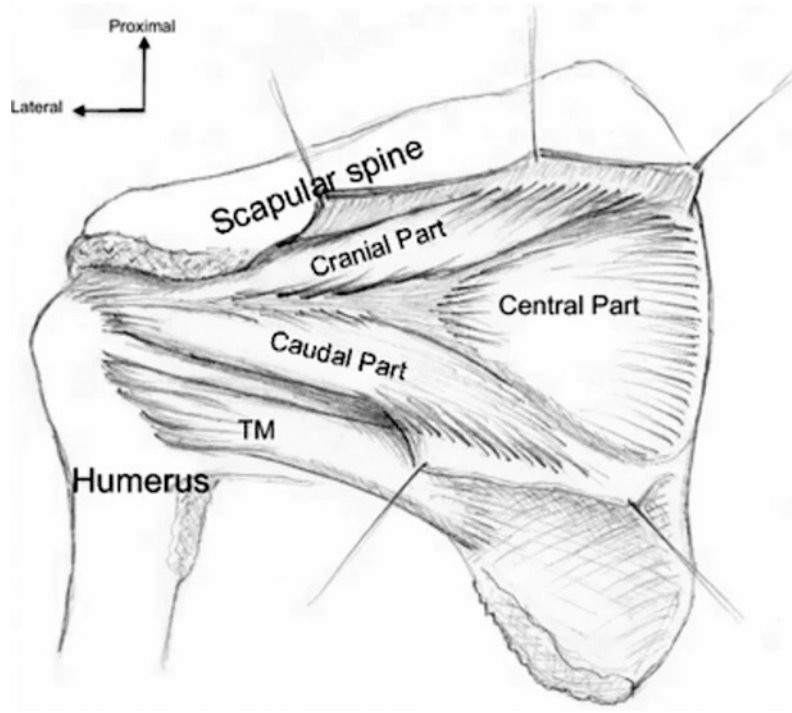

Fig. 1.5 Posterior aspect of muscular rotator cuff. ISP and TM units inserted medially on the infraspinous fossa and the inferior border of the scapula, respectively, and laterally on the humerus. Cranial, caudal, and central parts of the ISP are exposed. Note directions and distributions of the different groups of muscular fibers: cranial and caudal parts in a superficial plane, and central part in a deep plane. *TM* teres minor [23]

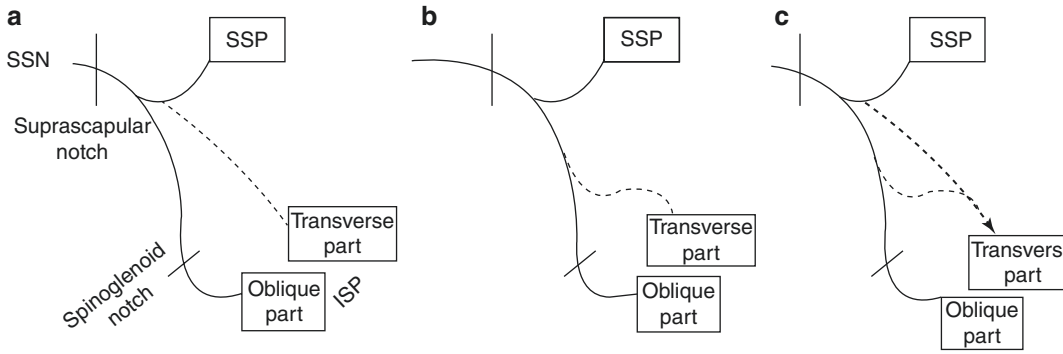

Fig. 1.6 Schematic illustrations represented origins of the branch to the transverse part of the infraspinatus. (**a**) Branches arise from branches to the supraspinatus muscle. (**b**) Branches arise from branches to the infraspinatus muscle. (**c**) Branches arise from branches to both muscles. *SSN* suprascapular nerve, *SSP* supraspinatus, *ISP* infraspinatus [24]

lar notch can lead to weakness and atrophy of both the supraspinatus and infraspinatus muscles, while a blockage of the spinoglenoid notch affects only the infraspinatus muscle (Fig. 1.6).

1.3.3 Blood Supply

The infraspinatus muscle receives its vascular supply via contributions of the suprascapular artery and the circumflex scapular artery [10].

1.3.4 Variations

The infraspinatus has been described as united with the teres minor, as well as having a connection with the posterior border of the deltoid [20].

1.4 Teres Minor Muscle

1.4.1 Structure and Humeral Insertions

The teres minor originates on the lateral border of the dorsal scapula and inserts on the posteroinferior greater tuberosity of the humerus, just inferior to the infraspinatus. Although commonly illustrated as a single muscle bundle, the teres minor is actually composed of two muscle bellies that insert at different areas along the greater tuberosity [27]. The insertion of the lower portion locates distally compared to the upper portion when the arm exceeds 90 degrees of elevation. More specifically, the pennate musculature and large intramuscular tendon in the upper portion has been hypothesized to be the primary generator of external force, with the lower portion acting as a depressor or stabilizer of the humeral head in cases when elevation exceeds 90 degrees [27].

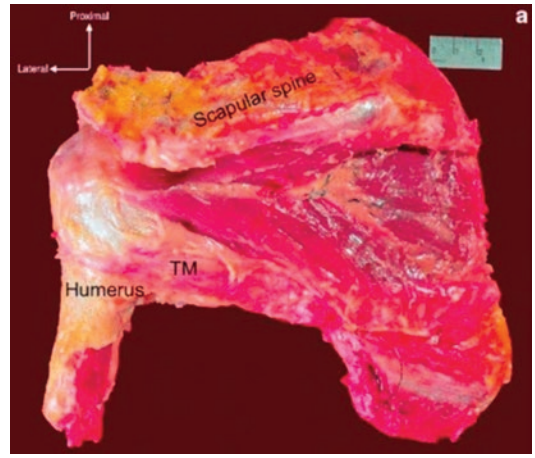

Fig. 1.7 Posterior aspect of muscular rotator cuff. TM inserts medially on the infraspinous inferior border of the scapula. *TM* teres minor [23]

1.4.2 Innervation

The teres minor is innervated by a branch of the axillary nerve and usually remains undamaged in most cases of rotator cuff injuries, likely because of its lack of "tendon mingling" with the infraspinatus. Although it plays a minor role in the healthy rotator cuff, the teres minor becomes a crucial external rotator in rotator cuff pathology (Figs. 1.7 and 1.8) [28, 29].

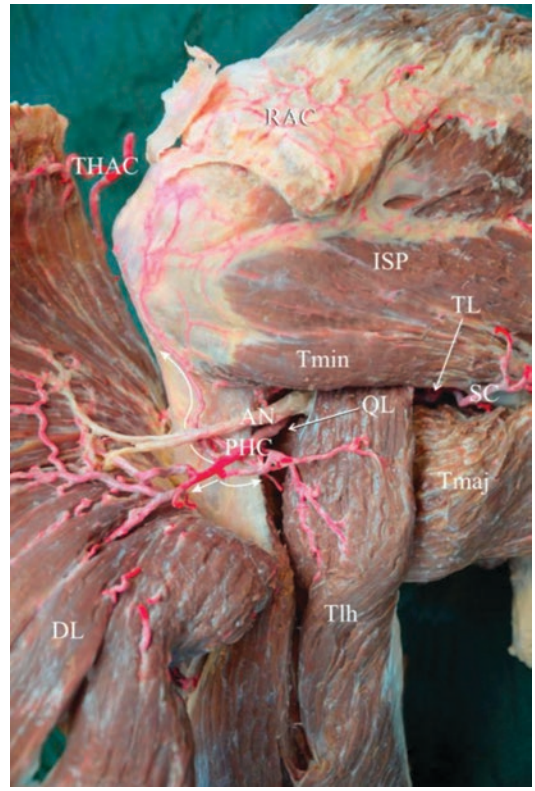

Fig. 1.8 A posterior view of the axillary nerve and its innervation of the teres minor. *AN* axillary nerve, *Tmin* teres minor [17]

1.4.3 Blood Supply

The teres minor is supplied primarily by the posterior circumflex humeral branch of the axillary artery. One study identified this branch as the posterolaterally oriented artery [30], while another referred to this section of the artery as the caudal bursa branches [17]. However, neither of these names have been routinely used in the literature.

1.4.4 Variations

The teres minor and infraspinatus are generally separated from one another in independent fascial sleeves; however, several cadaveric studies have found that in some cases, there exists a combined teres minor and infraspinatus fascia

compartment originating from the scapular spine superiorly and attaching inferiorly on the lateral border of the scapula and inferior glenoid neck [23, 31]. Interestingly, the locations of origin for the anterior and posterior circumflex humeral branches of the axillary artery have been inconsistently reported. In multiple cases, a separate origin for both the anterior and posterior circumflex humeral arteries has been observed in over 70% of specimens [32, 33] though a common origin trunk for these vessels from the axillary artery has also been reported in up to 67% of samples [34]. This variability has potential implications for fractures of the proximal humerus and should be considered as a possible area of study for teres minor pathology.

1.5 Conclusion

Rotator cuff injury is the second most common musculoskeletal pathology after lower back pain and is the most common shoulder condition for which patients seek therapy [35, 36]. More than 17 million Americans may be susceptible to shoulder impairment because of rotator cuff tendon disruption and eventual tearing [37]. Consequently, a well-developed understanding of rotator cuff anatomy is pivotal for both surgeons and therapists to improve reconstruction and recovery techniques, respectively. As healthcare professionals continue to learn more about the anatomy of the rotator cuff and rotator cuff pathology, indications for management of the injured rotator cuff will be further refined.

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2 Failed Rotator Cuff Repairs: Building an International Perspective

Geoffroy Nourissat, Anthony Kamel, John Swan, and Johannes Barth

2.1 Introduction

After rotator cuff repair (RCR), there is commonly significant clinical improvement (especially pain relief) in published series within the literature. However, significant improvement does not always imply clinical relevance. Function expectations differ amongst patients, which are related to age and their activities. Paradoxically, some patients have significant pain and disability, despite having a healed cuff repair, and other patients may report improved pain relief and functional outcomes despite the presence of a persistent tear or re-tear. Therefore, healing of the rotator cuff should not be considered as the most relevant primary outcome when measuring the success of RCR. Furthermore, the rate of revision after RCR is much lower than the rate of re-tear and is not always linked to the worst functional results. Finally, cultural factors may bias or impact the interpretation of RCR success or a failure.

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Thus, defining a failed RCR is complex. Furthermore, even if the rate of healing is limited, few patients require revision surgical management. Patients and surgeons can perceive RCR failure differently. Surgical goals vary between patients in terms of social and occupational activities.

2.2 Definitions in the Literature

Because of the high likelihood of good clinical outcomes and low morbidity, arthroscopic rotator cuff repair tends to be offered to many patients, even with limited symptoms. The surgery aims to treat the tear, prevent tear progression, and prevent accelerated muscle degeneration. From a surgical perspective, failure is commonly defined as a procedure that was unsuccessful and required revision surgery. There are several definitions published in the literature. Non-healing is the most recognized failure [22]. Cuff et al. [7] defined failed RCR as an American Shoulder and Elbow Surgeons (ASES) score <70, or a range of forward elevation <90°. Gasbarro et al. [9] defined failure as pseudoparalysis or a structural defect in the rotator cuff. For other authors, an insufficient improvement or worsening compared to the preoperative state indicates a failed repair [8].

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2.3 Subjective Failure

2.3.1 The Literature Reports Several Subjective Aspects of RCR Failure

2.3.1.1 Worsening of Preoperative Clinical Status

It is unclear why shoulder surgery can result in less than ideal postoperative conditions. Perioperative pain, stress, and some psychological and social factors can worsen clinical outcomes. Many studies explain why some non-surgical factors such as patient behavior and disability can negatively affect clinical outcomes [4, 6].

2.3.1.2 Patients Can Consider Persistent Pain as Failure

Postoperative pain after RCR commonly lasts up to 6 months in patients without complications or failure. Pain is multifactorial and it is difficult to identify predictive preoperative risk factors [3]. Many authors report that cutibacterium acne is a frequent cause of abnormal postoperative inflammatory pain.

2.3.1.3 Postoperative Stiffness

Stiffness is a less common postoperative complication since the development of arthroscopy shoulder surgery, better understanding of RCR indications, and improvements in anesthesiology. Of course, adhesive capsulitis [17] is still frequent after shoulder surgery. This is not considered a failure, but a complication as it recovers without surgery.

2.3.1.4 Loss of Strength

Many studies have reported that the true benefit of rotator cuff tear healing is principally recovery of shoulder strength. After RCR, with or without healing, global shoulder function improves by nearly 30% after arthroscopic surgery, after whatever procedure is performed [12]. Non-healing is correlated to loss of strength, but other conditions can also induce loss of strength, such as muscle atrophy or fatty infiltration that cannot recover post repair. [13].

2.3.1.5 Pseudoparalysis

In some cases, RCR induces a worsening of the status of the shoulder. Some patients with rotator cuff tear but good shoulder function can decompensate after total or partial RCR. This may be explained by Collin's theory, where some shoulders can function adequately without an intact posterosuperior rotator cuff, and if the RCR surgery modifies the global shoulder kinematics by disrupting the anteroposterior balance, then shoulder function can significantly decompensate. [5].

2.3.1.6 Inability to Return to Work

There are no studies demonstrating correlation between healing and return to work. Nové-Josserand reported 41.5% of patients were unable to return to the same work, regardless of the type of work or the nature of the tendon injury [19]. For Collin et al. [20], one-fifth of patients could not return to work after RCR, who were mostly females and heavy manual workers. Interestingly, they did not correlate RCR non-healing with the inability to return to work.

2.4 Objective Failure

Healing failure is considered throughout the literature as the most accepted objective criteria of failure of the procedure. In RCR, tendon healing is considered as the gold standard. But healing rates are highly variable. Several factors are well known, and in many cases, it is clear that healing is not the primary aim of the surgery. Repairing a massive rotator cuff tear with Goutallier stage 3 fatty infiltration in an active 70 year old patient complaining principally of weakness, but who has normal mobility and little pain can be performed. However, in this case, complete healing of the whole cuff in not the main importance. By contrast, the aim of repairing a traumatic rotator cuff tear in a young patient is to result in a well-healed rotator cuff. Several healing classifications are proposed, and there are several ways to identify non-healing. Ultrasound evaluation

performed by a trained consultant, on a flexible joint, can be performed as early as 3 months postoperatively, however, the healing process continues beyond 3 month, and tears can appear from 6 months to 1 year postoperatively [1]. There are multiple advantages to ultrasound assessment, such as cost-effectiveness; it can be repeated at different timepoints and has efficacy equivalent to MRI in defining healed tendon quality using Sugaya's classification ([1, 5, 20] et al., 2014, 2015). However, it is less effective in evaluation of muscle quality and cartilage lesions compared to MRI or CT scanning.

MRI can be performed to assess healing, using Sugaya's classification [11]. Sometimes, it is difficult to differentiate a heterogenous tendon from a torn tendon and MRI signal can take 18 months to become normal after RCR. A CT arthrogram has been considered for many years as the gold standard to assess RCR healing. However, it is an aggressive investigation, and it does not explore the superficial portion of the rotator cuff, which could be torn with an intact deeper layer. In our experience, a CT arthrogram is performed only for preoperative evaluation of a failed RCR, not for the primary diagnosis of a re-tear that can be performed with MRI or ultrasound.

Re-tears usually develop at the junction between tendon and bone [18]. In our experience, 50% of re-tears post-RCR in patients younger than 50 years old are anterior or posterior extensions of a healed RCR.

2.4.1 Table of Failure Criteria

Care must be taken in preserving the remaining tendon in cases of revision surgery. Primary repairs performed using the medial row technique are at higher risk of medial tendon tears. In such cases, there is inadequate tendon to fix to the bone as the tear occurs at the musculo-tendinous junction. In these cases, length and thickness of the tendon must be analyzed before attempting revision surgery [2, 10, 14, 16, 21, 15] (Table 2.1).

Table 2.1 Failure criteria

Type of failure	Subjective	Objective
Failure to heal	Clinical worsening	Healing failure
Symptomatic pain	Persistent pain	Lacking
Decreased mostion	Postoperative stiffness	Decreased motion
Weakness	Loss of strength	Functional deficits
Decompensation	Pseudoparalysis	Minmail active motion
Activity failure	Inability to return to work/sport	Variable

2.5 Conclusion

Failed rotator cuff repairs are multifactorial, and to date, the importance of these factors is unknown and the importance of these factors may also differ amongst different clinical presentations. Because of the variability of clinical presentations and of possible causes of failure, it is highly recommended that clinicians collect preoperative scores and data to aid in assessment of failure and future research to clarify and define failure. There is a clinical need for a simple validated index that would be practical to use in defining RCR failure.

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3 Biomechanical Consequences of Rotator Cuff Tears on the Glenohumeral Joint

Daniel P. Berthold, Lukas N. Muench, Felix Dyrna, and Knut Beitzel

3.1 Introduction

Massive, irreparable rotator cuff tears (RCT) remain a major challenge in shoulder surgery [1]. Due to pain, loss of range of motion (ROM), and insufficient function, these tears significantly affect the patients' quality of daily living [1]. Representing up to 40% of all rotator cuff tears, massive RCT are associated with persistent defects and poorer clinical outcomes [2, 3].

Understanding the biomechanics of native and defect shoulder kinematics is key when approaching rotator cuff surgery, especially in revision cases. A complex interaction between dynamic and static stabilizers of the glenohumeral joint is key for providing optimal range of motion and sufficient function (Fig. 3.1 and Video 3.1). Besides ensuring muscular balance and rotational function, the anatomy of the rotator cuff applies a compressive load to the glenohumeral joint throughout range of motion. The infraspinatus, teres minor, subscapularis, and the supraspinatus are acting as a muscular force couple, providing glenohumeral joint stability and contributing to humeral head centration.

3.2 Biomechanics of the Intact Glenohumeral Joint

The complex interaction between dynamic and static stabilizers of the glenohumeral joint is key for providing optimal range of motion and sufficient function. With the glenohumeral joint having the greatest range of motion of any joint, it comes along with an increased risk of joint instability [4]. The rotator cuff muscles, the deltoid, latissimus dorsi, and pectoralis major, as well as the scapulothoracic muscles, including the trapezius, levator scapulae, serratus anterior, pectoralis minor, and rhomboids, are considered

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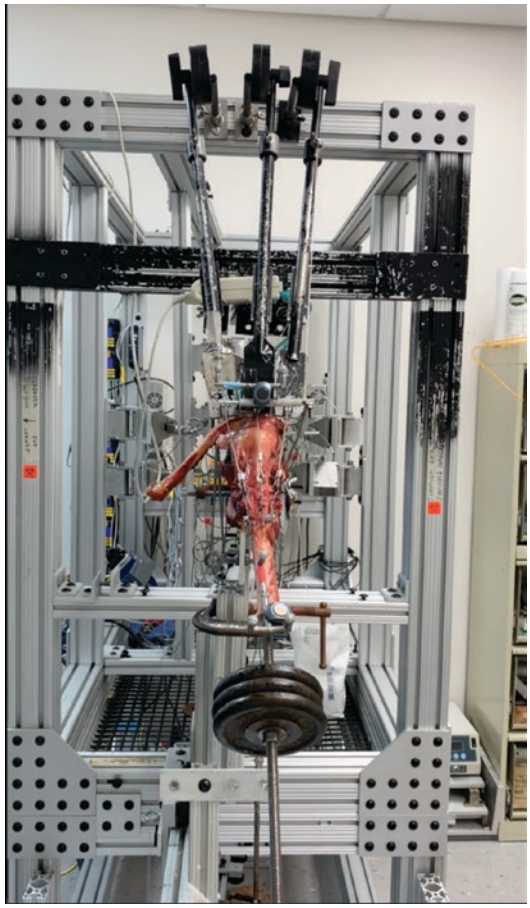

Fig. 3.1 Video showing abduction (60° with fixed scapula) on a dynamic shoulder simulator. An intact force couple allows for centered shoulder kinematics during abduction

important dynamic stabilizers [5]. In contrast, the static stabilizers comprise the joint capsule along with the glenohumeral ligaments, the glenoid labrum, negative intra-articular pressure and bony anatomy of the glenohumeral joint [5].

Close interaction between these stabilizers is critical to produce a biomechanically complex system ensuring the shoulder's ability for sufficient range of motion in multiple planes. Additionally, the importance of an intact scapulothoracic motion also needs to be mentioned, as the scapula serves as the origin or site of insertion for all rotator cuff muscles as well as the deltoid. In general, 17 muscles either have their origin or attach to the scapula, serving as the basis for glenohumeral motion. Thus, the humeroscapular interface should be considered when assessing the biomechanics of the glenohumeral joint.

3.2.1 The Concept of Concavity Compression

The function of the rotator cuff has been well described in the current orthopedic literature. When it comes to adequate glenohumeral abduction motion, synergistic and coordinated action between the rotator cuff and deltoid muscles is essential [6]. Besides ensuring muscular balance and rotational function, the anatomy of the rotator cuff applies a compressive load to the glenohumeral joint throughout range of motion [4, 7]. The anatomy and size of the glenoid fossa and the laxity of the glenohumeral joint play an important role in providing great range of motion but are also the most susceptible to joint instability [4].

In 1991, Lippit et al. advocated the concept of joint concavity compression in providing glenohumeral joint stability through full range of motion in the many functional positions where the glenohumeral ligaments are lax [4, 7]. Therefore, an intact rotator cuff is of great importance for the concept of concavity compression, as tears of the rotator cuff may contribute to glenohumeral joint instability, especially in superior humeral head migration. With the supraspinatus being the dominant muscle during the first 30° of abduction, the anterior and middle deltoid are considered to have their preferential muscle activity and loading from 30° to 90° of glenohumeral abduction [6, 8]. In patients with rotator cuff tears, this may lead to kinematic alterations, subsequently impairing the biomechanical synergy between deltoid and rotator cuff muscles [9]. A greater amount of force upon the middle deltoid may be expected in these patients, showing a major increase between 10° and 45° of abduction [10–12]. This may lead to an insufficient mechanical advantage of the deltoid, mostly due to the loss of balanced concavity compression and superior translation caused by tear progression [10].

Finally, greater deltoid forces are required to maintain joint stability and a decrease in abduction capability may be observed [10, 12, 13].

Dyrna et al. recently highlighted the required compensatory deltoid function to compensate for abduction motion loss in the presence of simulated rotator cuff tears in a dynamic biomechanical evaluation [10]. Creating combined supraspinatus and subscapularis tears resulted in the largest loss of glenohumeral abduction motion, despite the greatest increase in deltoid force [10]. However, isolated subscapularis tears resulted in increased anterior deltoid force, compensating for the loss of anterior joint compression without a reduction in abduction [10].

3.2.2 Muscular Force Couples and the Concept of the Suspension Bridge Model

The infraspinatus, teres minor, subscapularis, and the supraspinatus are acting as a muscular force couple providing glenohumeral joint stability and contributing to humeral head centration in the axial plane (Figs. 3.2 and 3.3; Videos 3.2 and 3.3) [14–17]. Thus, along with the three portions of the deltoid, which along with the inferior portion of the rotator cuff provide the force couple in the coronal plane, the anterior and posterior rotator cuff muscles are compressing the humeral head to the glenoid during dynamic abduction through range of motion [6, 17, 18].

Introduced by Burkhart et al. in 1993, the concept of the "rotator cable" and "suspension bridge" underlines the importance of an intact force couple [15]. The "rotator cable," a transverse band [19] running within the anterior supraspinatus at the entrance of the bicipital groove towards the posterior infraspinatus, is proposed to maintain function of the supraspinatus during tears occurring within the crescent tissue lateral to the cable, acting as a "suspension bridge" [15]. In patients with tears of the supraspinatus tendon, an intact force couple may allow for centered shoulder kinematics during abduction. Thus, as cuff tears may progress to the anterior or posterior portion of the rotator cuff [10], the force couple may be affected, which may further impair shoulder function during abduction motion [18].

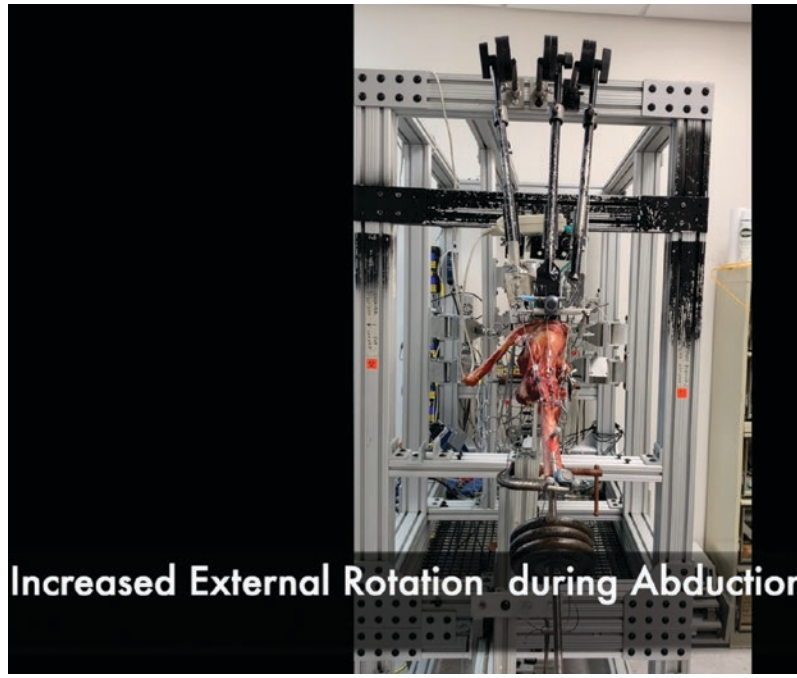

Fig. 3.2 Created subscapularis defect leading to impairment of shoulder function with increased external rotation during abduction

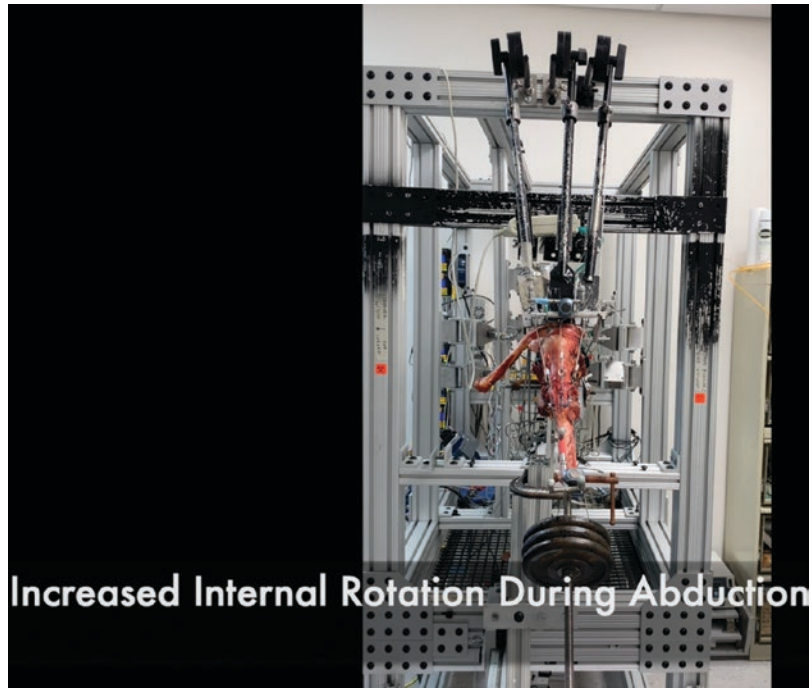

Fig. 3.3 Created infraspinatus defect leading to impairment of shoulder function with increased internal rotation during abduction

3.3 Biomechanical Consequences of Rotator Cuff Tears

The concept of concavity compression is of great importance to ensure glenohumeral stability throughout range of motion [5]. Thus, a sufficient function of the rotator cuff muscles is required to ensure compression of the humeral head into the glenoid fossa [20, 21]. Dysfunction or loss of rotator cuff integrity leads to changes in torque or joint-reaction forces, thus affecting glenohumeral stability [20, 21]. By displacing the glenoid contact superiorly, superior humeral head migration may be a result [10, 12], leading to painful subacromial impingement which often results in decreased range of motion.

During shoulder abduction, the supraspinatus muscle has been noted to be the dominant force at low abduction angles, with its contribution to full range of motion decreasing in higher abduction angles. Thus, the forces in the middle deltoid, equivalent to torque [22], increase significantly, in an attempt to restore full range of motion. An intact force couple is critical to balance the pull of the deltoid during abduction in the coronal plane. In large defects of the supraspinatus, an intact force couple may allow for stabilizing the humeral head by providing a stable fulcrum during abduction. To restore normal glenohumeral joint kinematics in massive cuff tears, greater forces within the force couple and the deltoid are required, which may subsequently lead to tear progression, either in the anterior or posterior direction [10].

Patients with stable fulcrum kinematics, who have tears of the superior portion of the rotator cuff, often demonstrate preserved essential force couples in the coronal and transverse planes, with good strength and normal motion [18]. In contrast, unstable fulcrum kinematics, such as massive tears of the superior and posterior cuff, may have uncoupling of the essential force couples leading to an inability to create a stable fulcrum of motion [18]. These patients often have active motion which consists of little more than a "shoulder shrug," according to Burkhardt et al. [18] Lastly, patients with massive tears that involve all of the supraspinatus, more than one third of the posterior cuff and at least one half of

the subscapularis, may present with a dysbalanced force couple in the coronal plane, which struggles to keep the humeral head centered in the glenoid. (Figs. 3.4 and 3.5; Videos 3.4 and 3.5) [18] Thus, the humeral head can end in a superior subluxation. However, these patients often have enough deltoid strength to allow them to elevate the shoulder, as the humeral head has contact on the undersurface of the acromion or the anterior acromiodeltoid origin (Figs. 3.6 and 3.7; Videos 3.6 and 3.7) [18]. Of interest, Burkhard and colleagues distinguished two types of patients with captured fulcrum kinematics characterized by the anteroposterior coverage of the humeral head by the acromion [18]. Patients with a "short awning" often have full forward elevation, while patients with a "long awning" may have an impingment on the anterior acromion with attempted elevation, which leads to restricted range of motion [18].

As torn tendons are not able to participate in load sharing, the tensile forces within the tendon increase on the remaining fibers, leading to the aforementioned concept of tear progression. This might also be encouraged by poor tissue quality, especially in already reconstructed tendons. Finally, progression of tears involving the force couple, may lead to pseudoparalysis [1, 23], especially in cases of concomitant subscapularis tears. Recent biomechanical studies hypothesized that an intact force couple does not only contribute

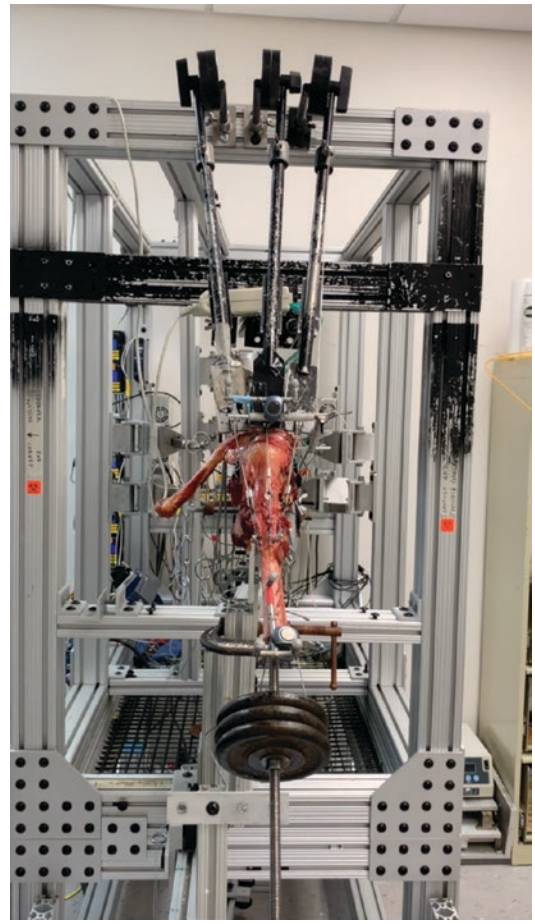

Fig. 3.4 Created massive rotator cuff defect (combined Supraspinatus, Infraspinatus, and Subscapularis defect) leading to impairment of shoulder function with loss of abduction

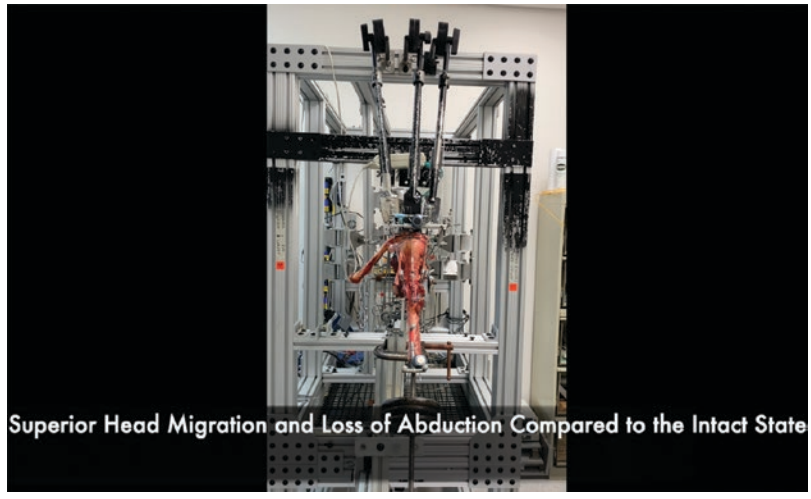

Fig. 3.5 Created irreparable posterosuperior defect leading to superior head migration and impairment of shoulder function

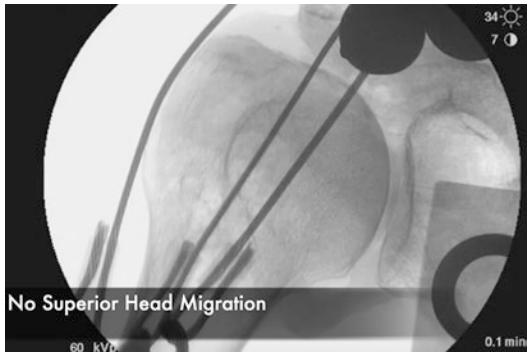

Fig. 3.6 Radiographs showing normal acromiohumeral distance during abduction on a dynamic shoulder simulator

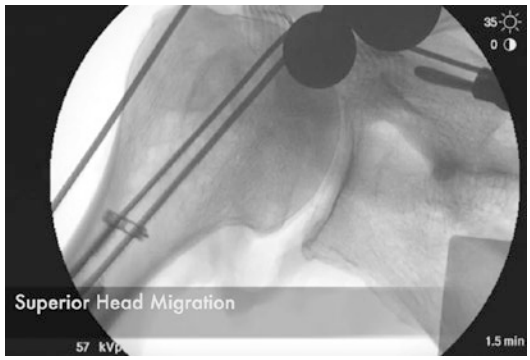

Fig. 3.7 Created irreparable posterosuperior defect leading to superior head migration and decreased acromiohumeral distance during abduction on a dynamic shoulder simulator

to internal and external rotation. More importantly, the subscapularis was further shown to play a role in early abduction during external rotation, in contrast to the infraspinatus contributing to abduction in internal rotation [5, 8].

Interestingly, when examining the strain within the rotator cuff muscles, Bey et al. found that the strain increased in positions of greater abduction [24]. Besides, the compressive strain of the articular side of the tendon was found to have lower values when compared to the bursal side, which may lead to progressive tears at the articular surface [25].

Besides, it has to be noted that the latissimus dorsi and the pectoralis major muscle also contribute to the complex interaction between the force couple, the rotator cuff, and the deltoid. The moment arm of each muscle varies within range of motion, resulting in different torques with each joint position [26]. Thus, complex coordination between the latissimus dorsi, the pectoralis major, deltoid, and rotator cuff are needed to provide a smooth shoulder function [5, 27–30].

Finally, massive tears of the supraspinatus tendon may cause traction on the suprascapular nerve due to tendon retraction [31]. This may enhance early atrophy and fatty infiltration of the remaining rotator cuff (supraspinatus, infraspinatus).

Recent literature suggests that abnormal joint loading as a consequence of rotator cuff tears may lead to bony alterations such as erosion of the glenoid, humeral head, or, in case of severe rotator cuff arthropathy, to an acetabularization of the acromion [32]. This may be especially observed in the setting of massive rotator cuff tears and may be followed by an anterosuperior escape and mechanical conflict between the humeral head, the superior glenoid and acromion [33]. In addition, as massive rotator cuff tears may induce severe osteoarthritis, the collapse of cartilage and bony structures may lead to a release of enzymes with further impairment of the surrounding tissue, thus leading to pain and limited shoulder function [32].

However, the complex mechanism of glenoid erosion is not well understood. Abnormal joint loading may lead to changes in peak glenoid pressure within the glenoid. Rather than being orientated to the superoinferior axis of the glenoid, the pressure might be oriented within the posteroinferior region, thus leading to erosion of the glenoid, described as a type B glenoid according to Walch et al. [34, 35]

3.4 Conclusion

Understanding the biomechanics of native and defect shoulder kinematics is key when approaching rotator cuff surgery, especially in revision cases. A complex interaction between dynamic and static stabilizers of the glenohumeral joint is of great importance to ensure full range of motion and adequate function of the shoulder girdle. However, RCTs may lead to a dysbalance between

those dynamic and static stabilizers, which may result in decreased range of motion and shoulder function over time. Superior humeral head migration and altered intra-articular joint pressure can lead to severe humeral head or/and glenoid osteoarthritis, which is often followed by severe pain and insufficient joint function. However, the location of the rotator cuff tear may be important in shoulder kinematics rather than the size of the tear. In general, most of the rotator cuff tears involve the supraspinatus and some portion of the posterior rotator cuff. In these cases, a normal transverse plane force couple allows for normal function. However, if the posterior rotator cuff is damaged, a stable fulcrum may not be established, which could lead to the aforementioned effects.

By restoring the integrity of the muscular force couple or preventing superior humeral head migration by reconstructing the structures of the superior capsule, the consequences of RCTs may be reduced or enhanced. However, in cases refractory to this, reverse shoulder arthroplasty may be indicated, in order to reduce immobilizing pain and increase shoulder function.

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4 The Failed Rotator Cuff: Diagnosis and Management—New Concepts in Biology of Repair

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4.1 Introduction

Despite advances in surgical techniques, recurrent tears of the rotator cuff following repair remain a major challenge [1]. A series of arthroscopic rotator cuff repairs has demonstrated that postoperative healing of the tendon usually occurs between 71% and 89% of cases [2, 3]. However, this rate of tendon healing may decrease to only 47% or 50% of cases in the treatment of massive rotator cuff tears [2, 3]. Consequently, (re)-tear size can directly affect tendon healing and subsequent shoulder function [2–4]. Even though a "hypovascular zone" within the supraspinatus tendon has been hypothesized to lead to initial degenerative tears with further implication to poor tendon healing following repair, the complexity of the healing process has not yet been fully understood [5].

The cells contributing to natural tendon healing have been found to originate from loose connective tissue surrounding the tendon fascicles and tendon body [6]. In response to the injury, these cells proliferate and migrate toward the tear site, in order to form collagenous healing tissue [6–8]. As the endogenous healing potential of the tendon appears to be limited, augmentation techniques using biologic adjuvants have recently garnered more attention, including the application of growth factors, platelet-rich plasma (PRP), or mesenchymal stem cells (MSCs) [9, 10]. Despite bone marrow being the traditional source for MSCs used for biologic augmentation of tendon injuries over the last years, recent studies have highlighted subacromial bursal tissue to be an alternative, easily accessible, inexpensive source for MSCs, demonstrating superior proliferation potential, tissue engraftment, and survival, when compared to bone marrow-derived MSCs [6, 10–13].

4.2 Biologic Adjuvants for Repair Augmentation

4.2.1 Platelet-Rich Plasma

Platelet-rich plasma (PRP) is derived from autologous peripheral blood that is centrifuged to

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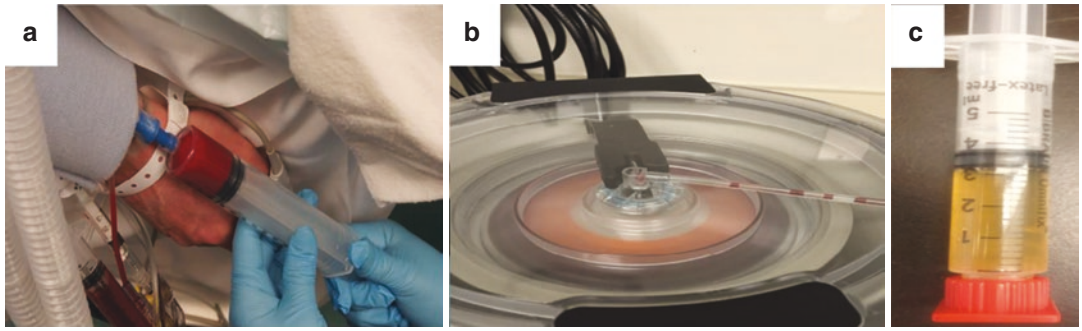

Fig. 4.1 Demonstrating harvest and processing of platelet-rich plasma (PRP). Venous peripheral whole blood is drawn (**a**) and then processed using a fully automated three-sensor technology system based on flow cytometry and light absorption (**b**) to obtain approximately 3 mL of PRP (**c**)

isolate a higher concentration of growth factors contained within alpha-granules of the platelets (Fig. 4.1) [14]. Due to the potential of promoting tendon healing along with the relatively low risk profile, this biologic adjuvant is appealing in the treatment of rotator cuff tears [14, 15]. Generally, there are two types of PRP based on the concentration of white blood cells: leukocyte-poor and leukocyte-rich PRP. As leukocytes are important for wound healing and tissue restoration, they may also induce an excessive inflammatory response [16].

4.2.1.1 Basic Science Evidence

In vitro studies have demonstrated that tenocytes exposed to PRP have increased cell proliferation and matrix synthesis, potentially leading to improved tendon regeneration or healing [15, 17]. In addition, application of PRP was found to induce the differentiation of tendon stem cells into active tenocytes, exhibiting high proliferation rates and collagen production capability [18]. However, the final PRP-composite is influenced by numerous patient-specific factors, including age, sex, diet, and activity level [19]. Preparation-specific factors comprise the type of collecting tube as well as speed and number of cycles during the centrifugation process [15, 16]. Even in separate samples harvested from the same patient, PRP has been shown to vary widely, making generalization of clinical and in vitro findings difficult [16].

4.2.1.2 Clinical Outcomes

Despite strong in vitro results regarding its stimulating effects on tenocytes and myocytes, clinical outcomes following PRP application have been inconsistent. Recent meta-analyses of randomized controlled trials have reported mixed results, with some showing decreased failure-to-heal rate for small- to medium-sized tears as well as decreased re-tear rates for large tears treated with PRP [20, 21], and others finding no difference in outcome scores and structural healing rates [22, 56]. A study by Malavolta et al. found that PRP application did not significantly improve clinical outcomes, pain, and structural healing in 51 prospectively randomized patients undergoing arthroscopic single-row rotator cuff repair at 5-year follow-up [39]. In contrast, Randelli et al. performed a prospective, double-blinded, randomized controlled trial and reported short-term benefits following repair augmentation using PRP, including significantly lower pain scores 1 month after surgery and greater functional improvement at 3-month follow-up [51]. However, there was no difference in clinical outcome measures at 6, 12, and 24 months, postoperatively [51].

The use of PRP for clinical application is limited to the variability in the final composite and the heterogeneity of studies, compromising direct comparisons between studies. This includes differences in underlying tendon pathology, repair technique, postoperative rehabilitation, PRP

composition, and comorbidities such as smoking status and diabetes [15].

4.3 Cell-Based Therapies

Concentrated bone marrow aspirate (BMAC) and subacromial bursa-derived cells (SBDCs) have been described as viable sources of cell populations with MSC and progenitor characteristics for the use in regenerative orthopedic surgery [11, 13, 40, 44, 45, 47, 49]. However, it should be considered that these minimally manipulated cell preparations have to be distinguished from laboratory-prepared cell populations undergoing cell sorting and culture expansion [15]. In contrast to culture-expanded bone marrow-derived MSCs, BMAC only comprises a very low concentration of MSCs by formal criteria [28], which has been shown to range only from 0.001% to 0.01% of total cells [50]. These minimal criteria proposed by the International Society for Cell Therapy include the adherence to tissue culture plastic, the ability to form colonies, positive fluorescence-activated cell sorting (FACS) analysis for MSC-specific surface markers, and the ability of multilineage differentiation [28]. Thus, it has been recommended to abandon the term "mesenchymal stem cell" for these minimally manipulated cell preparations, which are allowed for clinical application [15]. As a result, the term "connective tissue progenitors" (CTPs) has been proposed, which more accurately describes the heterogeneous population of tissue-resident proliferative stem and progenitor cells [47, 49].

4.4 Concentrated Bone Marrow Aspirate (BMAC)

Bone marrow still remains the most commonly used source of MSCs for biological augmentation, as its application in patients with rotator cuff injuries has shown promising results including decreasing re-tear rates and improved healing outcomes [9, 10, 29]. However, Muschler et al. found that progenitor cells only averaged about 1 per 30,000 nucleated cells in BMA obtained from the iliac crest [46].

Although aspiration of bone marrow from the iliac crest is still considered the gold standard [35, 42, 49, 58], complications such as hematoma and nerve palsy have been reported [31]. While the proximity of the axillary nerve and artery make the proximal humerus amenable to similar risks, the ability to obtain the sample under direct visualization during rotator cuff repair makes this an ideal location. Mazzocca et al. first described the proximal humerus to be a more desirable source of MSCs for rotator cuff repair due to its ease of attainment (Fig. 4.2) [40]. In addition, BMAC has been shown to contain more growth factors with anti-inflammatory and anabolic effects as well as up to three times more nucleated cells when compared to PRP [57]. However, harvesting BMAC remains an expensive procedure with debatable cost-effectiveness [15].

4.4.1 Basic Science Evidence

Basic science evidence for the use of BMAC in rotator cuff healing augmentation is limited. In a rabbit model, Liu et al. studied the healing potential of supraspinatus tendon repairs augmented with PRP and BMAC [38]. The authors found that repairs augmented with BMAC alone or with a combination of BMAC and PRP demonstrated superior biomechanical properties compared to repairs augmented with PRP alone or pure saline solution [38]. Treatment with BMAC enhanced tendon-to-bone healing along with superior collagen fiber continuity and orientation compared to the control group and presented with significantly higher levels of growth factors compared to PRP [38].

Additionally, Kim et al. investigated the effects of a combined BMAC and PRP application on tendon-derived stem cells and found enhanced proliferation and migration of tendon-derived stem cells, while preventing aberrant chondrogenic and osteogenic differentiation [36].

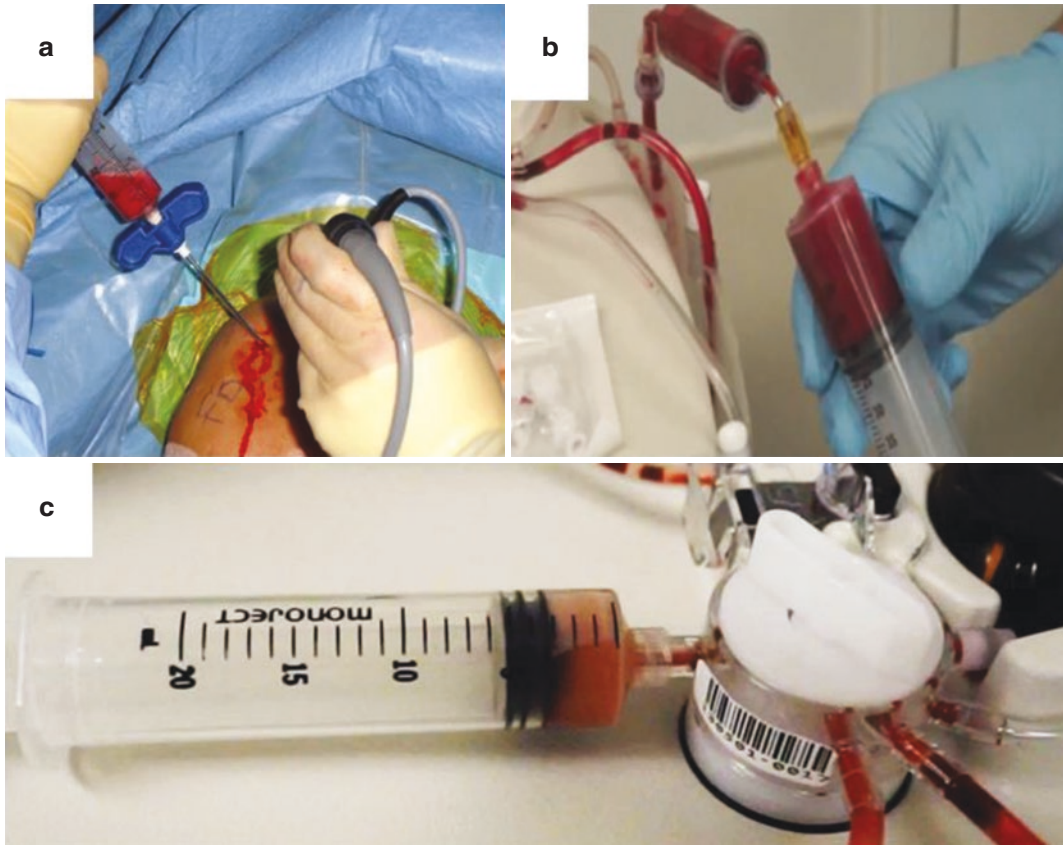

Fig. 4.2 Demonstrating harvest and processing of bone marrow aspirate (BMA). BMA is obtained from the proximal humeral head during arthroscopic rotator cuff repair using a non-fenestrated trocar (**a**). The harvested BMA, consisting of blood, bone marrow, and arthroscopic fluid is transferred to a centrifugation system (**b**) and concentrated (**c**)

4.4.2 Clinical Outcomes

Concentration of a harvested aspirate can easily be performed with only minimal manipulation of cells, allowing for subsequent clinical application in the setting of rotator cuff repair (Fig. 4.2). However, only a few studies with small case series have investigated the effectiveness of bone marrow aspirate for augmenting single-row rotator cuff repairs, with most reporting on bone marrow stimulation techniques, rather than direct application of BMAC [9, 29, 43, 53]. Hernigou et al. reported long-term results of primary rotator cuff repairs augmented using cBMA showing improved healing rates on MRI compared to a non-augmented control group [9]. At 10-year follow-up, 87% of augmented repairs remained intact compared to 44% of repairs in the control group [9].

In 14 patients with a minimum follow-up of 1 year, Ellera Gomes et al. described improved clinical outcomes along with tendon integrity in all patients following augmentation of mini-open transosseous suture repair for full-thickness rotator cuff tears [29]. However, current literature does not allow for drawing definite conclusions regarding the clinical efficacy of BMAC applications, which is mainly due to inconsistent relationships between successful rotator cuff healing and clinical outcomes scores as well as disparities in underlying pathologies, repair techniques, lack of control groups, and patient demographics [15].

In conclusion, reported clinical outcomes of BMAC applications should be interpreted with caution [9, 10, 15, 29, 35, 37]. Further, the actual clinical efficacy of BMAC remains a matter of debate and may rather be explained by its high concentration of growth factors, having anabolic and anti-inflammatory effects [15, 41]. Further, the clinical efficacy of autologous BMAC is dependent on the concentration of necessary progenitor cells [33]. While certain patient characteristics, such as alcohol abuse [32] and smoking [26] can negatively affect BMAC quality, optimizing surgical technique is essential for a successful treatment.

4.5 Subacromial Bursa-Derived Cells (SBDCs): The Future?

Although bone marrow is still considered the most commonly used source of MSCs for biologic augmentation, recent literature has shown MSCs to be present in subacromial bursal tissue, which is often discarded during arthroscopic surgery to ensure visualization of the rotator cuff tear, suggesting its use as an easily accessible, inexpensive, and viable augment for arthroscopic rotator cuff repair [6, 9–13, 29, 35]. Previous studies found that the cells forming collagenous healing tissue at the tear site originate from originate from loose connective tissue surrounding the tendon fascicles and body, especially the paratenon [7, 8, 55]. As the rotator cuff tendon does not seem to be enclosed by a typical paratenon, the surrounding bursal tissue may be one of the main contributors to endogenous tendon healing. Thus, in the presence of tendon injury and degeneration, these cells may be stimulated to migrate toward and induce healing at the tear site. This may be further supported by the suggestion of Uhthoff et al. that the extension of subacromial bursa should rather be considered a reparative response than a degenerative change [54].

Morikawa et al. described a novel, non-enzymatic, mechanical method for isolating SBDCs for clinical use [45]. According to their technique, subacromial bursa is obtained from over the rotator cuff tendon using an arthroscopic grasper device [45]. The sample is then mechanically digested for 60 s using sterile tenotomy scissors until the tissue resembles a finely minced, liquified particulate (Fig. 4.3) [45].

4.5.1 Basic Science Evidence

In vitro characterizations of human SBDCs have shown that these cells fulfill all characteristics of MSCs, including similar surface antigen expression profiles and multilineage differentiation [11–13]. Furthermore, Utsunomiya et al. reported superior proliferation and differentiation potential of SBDCs compared to other tissues within the shoulder [13]. In an immunodeficient murine patellar tendon defect

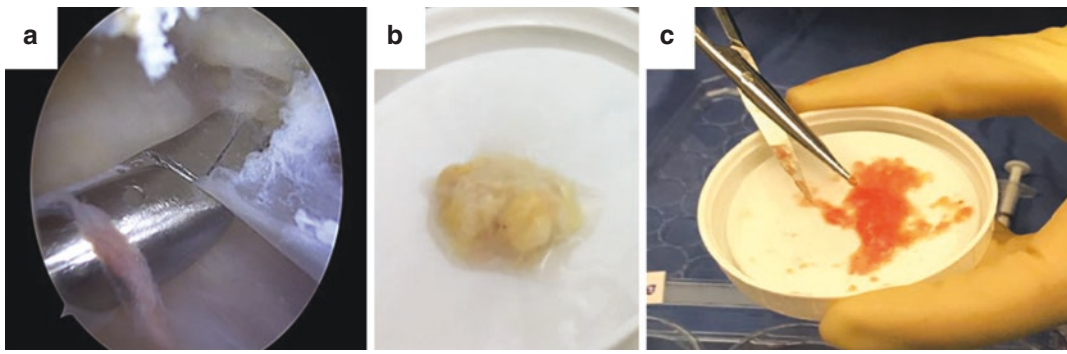

Fig. 4.3 Demonstrating the harvest and processing of subacromial bursal tissue. Subacromial bursa is obtained from over the rotator cuff tendon using an arthroscopic grasper device (**a**). The sample (**b**) is then chopped using sterile tenotomy scissors until becoming a finely minced, gooey particulate (**c**)

model, SBDCs showed superior engraftment to host tendon along with survival when compared to bone marrow-derived MSCs (bMSCs) [6]. Further, Morikawa et al. demonstrated superior differentiation and proliferation potential of SBDCs compared to BMAC [44].

Several studies have suggested that the subacromial bursa may play an influential role in bone-tendon healing [34, 54, 55]. Uhthoff and Sarkar reported that rotator cuff healing was most noticeable along the subacromial bursal wall in rotator cuff biopsy specimens and recommended against radical removal of bursa, as total debridement of the bursa may remove a primary source of neovascularizing signals and fibroblastic cells necessary for biological repair of the torn tendon [54]. Further evidence of the biological activity of native bursa was reported by Hirose et al. who determined that spontaneous healing occurred along the bursal side of the rotator cuff tendon in a rabbit model and that the cells that infiltrated the defects were observed to be continuous with the epitenon of the bursa [34]. Yoshida et al. identified the cellular origins of rotator cuff healing after labeling tissue in a murine model, reporting robust involvement of bursal-sided tendon cells with minimal contribution from the enthesis [55]. These studies suggest that subacromial bursa exhibits biological activity within in vitro rotator cuff repair models.

4.5.2 Clinical Experience and Future

While there is currently no proof regarding the long-term efficacy of bursa augmentation during rotator cuff repair, Hernigou et al. have reported on the clinical results of MSC adjunctive therapy in arthroscopic rotator cuff repair [40]. Patients in the study group received MSCs from BMAC, while those in the control group did not. At 10 years follow-up, 87% of patients in the MSC group had intact rotator cuffs compared with 44% in the control group. Similar clinical outcomes for bursa-augmented repairs is lacking. However, Morikawa et al. showed that the proliferation and differentiation capabilities of MSCs derived from subacromial bursa are at least the same if not superior to those from BMAC [20]. These data suggest that subacromial bursa is a viable, easily accessible source of MSCs that may be a promising biological augment for rotator cuff repairs. However, clinical outcomes following rotator cuff repair augmented with subacromial bursa are yet to be reported.

Additionally, it remains unclear whether there are any metrics that can predict the potential success of subacromial bursa in augmenting rotator cuff healing, including the relation of patient demographics and rotator cuff pathology to the healing potential of subacromial bursa. Further studies are necessary to examine the effects of local and systemic disease on the biological viability of this tissue. Understanding variations in subacromial bursa tissue and how they relate to biological factors involved in healing may assist surgeons in predicting tendon healing and determining both repair type and the need for possible augmentation. Clinical and radiographic outcomes studies are needed to understand the role of bursal augmentation in arthroscopic rotator cuff repair.

4.6 Further Considerations

Preliminary basic science and clinical evidence has suggested that various nutrients, including vitamin D, proteins, amino acids, and trace minerals may have a positive effect on tendon growth and healing, mainly by engaging with the metabolism of collagen [27]. As collagen forms the major extracellular protein in tendons and muscles, dietary interventions to improve collagen synthesis may be helpful in restoring tendon integrity [27].

In a rat model, Angeline et al. found that a diet-induced vitamin D deficiency had negative effects on early healing at the rotator cuff repair site, showing a significant decrease in load to failure along with less bone formation and collagen fiber organization [23]. However, clinical data regarding the effect of vitamin D supplementation on postoperative rotator cuff healing remains inconsistent. Ryu et al. demonstrated that low serum vitamin D levels were not related

to preoperative tear size, extent of tendon retraction, or fatty infiltration of the cuff muscles [52]. More importantly, the authors found that there were no significant relationships with postoperative structural integrity and functional outcomes after arthroscopic rotator cuff repair [52]. Contrary, Oh et al. showed that serum vitamin D levels had a significant negative correlation with fatty muscle degeneration and a positive correlation with isokinetic muscle torque [48]. Further, vitamin D deficiency has been reported to be associated with a greater risk of postoperative surgical complications following rotator cuff repair [30].

Additionally, recent studies have identified matrix metalloproteinases (MMPs) to be critical in maintaining and remodeling the extracellular tissue matrix after rotator cuff repair [24, 25]. The tetracycline family of antibiotics has been demonstrated to inhibit MMPs by a mechanism being independent of their antimicrobial activity, with its local or systemic administration demonstrating reduced severity of tendon degeneration associated with increased MMP activity [24, 25]. Bedi et al. further found that doxycycline-mediated inhibition of interstitial collagenase (MMP-13) enhanced early healing after rotator cuff repair in a rat model, resulting in improved collagen organization and greater strength of the healing enthesis [24]. Although this may offer a novel biologic pathway of repair augmentation, clinical studies regarding the effectiveness of doxycycline administration in the setting of rotator cuff repair are still lacking [24].

4.7 Summary

Despite advances in surgical techniques, recurrent rotator cuff tears following repair remain a major challenge [1]. As the endogenous healing potential of the tendon appears to be limited, augmentation techniques using biologic adjuvants have recently garnered more attention, including the application of growth factors, PRP, or MSCs [9, 10]. Although bone marrow still remains the traditional source for MSCs used for biologic augmentation of rotator cuff repair, recent studies have highlighted subacromial bursal tissue to be an alternative, easily accessible source of MSCs [6, 10–13]. Despite strong in vitro results regarding its stimulating effects on tenocytes and myocytes, clinical outcomes following PRP application have been inconsistent. Additionally, reported clinical outcomes of BMAC applications should be interpreted with caution, with the actual clinical efficacy of BMAC still remaining a matter of debate [9, 10, 15, 29, 35, 37]. In vitro characterizations of human SBDCs have shown strong results [11–13], demonstrating superior differentiation and proliferation potential compared to BMAC [44]. Thus, SBDCs may be a promising biological augment for rotator cuff repairs; however, clinical outcomes following repair augmentation are yet to be reported.

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5 Reasons for Structural Failure of Rotator Cuff Repair

Nahum Rosenberg

Repair of tear of the rotator cuff (RC) tendons/muscles aims to restore the structural integrity and subsequentially to improve the RC biomechanics and reduce pain and stiffness in shoulder. This means that mechanical repair of the RC should improve function in shoulder with torn RC. Therefore, it is logically to assume that a failure to maintain integrity of RC repair should essentially lead to a functional deterioration in the affected shoulder. But surprisingly the functional outcome does not always correspond to the mechanics of the repaired RC. Several reports present evidence of satisfactory functional outcome even after re-tear of RC repair, which is comparable with patients with healed repaired RC [1]. Therefore, the current understanding of the "RC repair failure" is not complete. In order to pursue the further recognition of the term "Failure" in this matter, first of all the term of "RC repair failure" should be clarified and may be that the terms "structural failure" and "functional failure" should be distinguished. After the exact definition of these terms it might be easier to proceed for the future understanding of the inconsistency between the mechanical and functional outcome after RC repair surgery.

The integrity of muscle-tendon-bone unit in the RC is maintained by the specific mechanical properties of each of the components and can be estimated by the values of Young's modulus [2] which represent the stiffness of the tissue and measured from the stress-strain curves representing the slope of the linear ascending part of the curve, i.e., the plasticity range of material deformation before the structural distraction of the material occurs (tear of muscle or tendon, fracture of bone). The spectrum of stiffness of the RC components extends from the least stiff muscle (E 8–17 kPa), via more stiff tendon (E 30–50 kPa) and up to highly stiff insertion site of the RC into cortical bone of proximal humerus (E 15–25 gPa) [3, 4]. The tendon in general reversibly comply to an external load in this elasticity range, due to the reorganization of the collagen fibers from the "wavy" pattern at rest to their alignment according to the load applied, by a spring-like mechanism [5] (Fig. 5.1). Beyond this elasticity range, the tendon integrity fails and a tear is generated. The elasticity range becomes narrower following scar generation, after tendon repair, therefore the repaired tendon is more vulnerable to mechanical loads, even in the physiological range of the force generated by the muscle on the tendon.

Clearly the scar tissue of the repaired RC tear, even after theoretical accomplishment of healing process, has inferior viscoelastic properties and should be prone to failure after excessive forceful contraction of the RC [6].

The healing process of the repaired RC tendon should be completed in 12 months via the three

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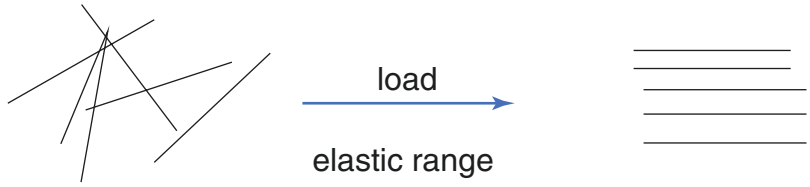

Fig. 5.1 A simplistic schematic representation of the "spring mechanism" in the elastic range of load on tendon when the fibers (straight lines) become gradually uncrimped

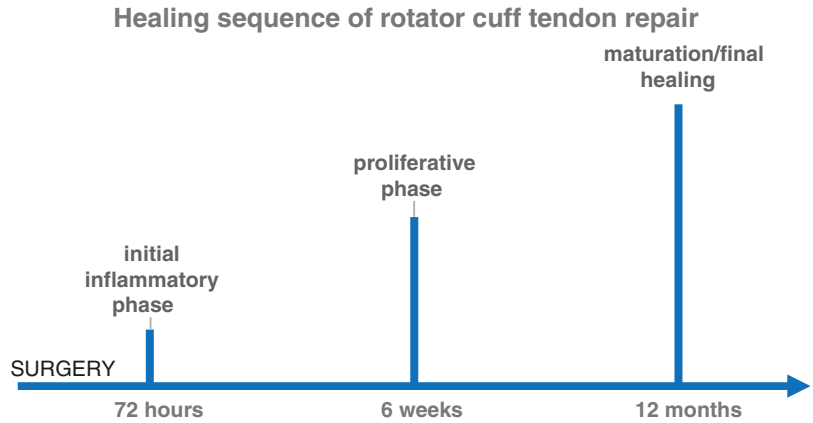

Fig. 5.2 Schematic representation of the local healing process' timing after rotator cuff repair

main physiological phases (Fig. 5.2): initial inflammatory phase (24–72 h) with inflammatory cells recruitment from the local hematoma, then 6 weeks of proliferative phase with enhanced rate of local collagen 3 synthesis by the tenocytes, and then, up to 12 month after surgery, the remodeling/maturation phase that starts with 4 weeks of consolidation stage, when collagen 1 synthesis increases, and followed by fibrous replacement, when a scar tissue is generated as a final healing result [7]. Therefore, even in the optimal conditions, the tendon healing process of the repaired RC may last up to 12 months, and if not completed, the repair will fail.

But even if the tendon repair is fully healed, the mechanical properties of the repaired site are usually inferior to the normal tendon due to the impaired elasticity of the generated scar tissue that might fail even in physiological range of load on the RC [6]. This means that the RC repair failure is related to the insufficient time period of the healing process progress, to the lack of optimal healing environment for the eventual scar generation and to the magnitude of the mechanical load on the repaired RC. Accordingly, extrinsic mechanical impact on the repair site, intrinsic microvascular impairment due to the local tissue degeneration during the healing process or overload on the RC, even following full healing of the repaired tendon, might cause a re-tear of the RC [7]. But despite the presented facts no clear advantage of a delayed immobilization of the shoulder after RC repair regarding the re-tear rate has been found [8].

Most of the RC tears involve the supraspinatus tendon at its hypovascular area, 10–15 mm proximal to the insertion into greater tuberosity of the proximal humerus [2, 9]. The surgical repair of the torn tendon is based on approximation of the leading edge of the torn tendon into the bone on the greater tuberosity to generate a new insertion interface. The main reason for the RC re-tear is the impaired tensile properties of scar tissue following the repair in this anatomical site [10]. The success of healing of this interface depends on an adequate overlap on the tendon—bone interface. To achieve this, several "double row" techniques of tendon suturing into the bone exist aiming to increase the footprint of the tendon edge on the bone and to avoid the generation of a gap at the

tendon—bone interface. Additionally, this type of repair is biomechanically stronger and showed better healing rates [11]. Indeed, the re-tear rate is reduced following implementation of the "double row" repair [12] and showed improvement of 35% in healing rate, as reported on 3 years follow-up following an objective evaluation by MRI [13].

Tendon tear healing requires adequate physiological load and blood supply [14]. Because the chronic tears in RC occur mainly in the hypovascular zone and the tension of the repair sutures can be compromised at the tear edges, with fatty infiltration (above grade 1 according to Goutallier classification on MRI), the essential tendon healing blood supply and mechanical properties of the tear edges might be insufficient in a degenerative tendon; therefore, the chronicity of the tear is a risk factors for a repair failure [11, 15]. Additionally retraction of a chronic tear, especially up to the level or medial to the glenoid, may generate a high, non-physiological tension on the tendon—bone interface at the repair site that can further compromise the local blood supply. This might be the reason for the higher failure rate after repair of retracted degenerative RC tears, even after technically successful surgical repair. It has been shown that the rate of re-tear doubles after repair of massive tears in comparison to small tears (73% vs. 34%) [16] .

The diversity of the reported outcome data on the RC repairs in the different studies, i.e., different tear size, quality of tear edges, and different surgical techniques, causes uncertainty regarding the exact rates of re-tear after RC repair (a wide range between 20% and 90% in different reports with a reported mean rate of 26%) [16–18].

According to the accumulated data, which was presented in a systematic review of literature, the risk factors for RC repair structural failure are the tear size and additional local surgical procedures involving biceps tendon and acromioclavicular joint, done along with the tendon repair [19]. Indeed, as described above, large degenerative tears are pathophysiologically prone to fail after surgical repair. RC tendon degeneration is age related; therefore, the factor of age of the patient has been revealed to be a risk factor for the repair failure because after the age of 50 years the possibility of degenerative tear in the RC tendon is higher and subsequentially the chance of re-tear of the repair is also higher due to the inferior mechanical properties of a torn tendon [19, 20]. Naturally, the factor of age indirectly reflects the local structural factors related to RC tear, i.e., tissue degeneration which is age related.

Several additional interesting factors may play a role in RC repair structural failure. One of these is the general bone mineral density that negatively affects tendon healing probably due to pull out of the suture anchors from insertion in the greater tuberosity of the proximal humerus [21]. Additional potential indirect factor is the neuropathy of suprascapular nerve that might lead to degenerative changes and subsequentially a tear in the supraspinatus muscle [22]. This factor might become important in young patients with RC tears and has an impact on the repair outcome, which is considered to be favorable in young patients, but the repair might unexpectedly fail due to RC degeneration, which is not related to the age. Should be noticed that a direct relation between supraspinatus neuropathy and RC re-tear hasn't been proven [23].

To summarize, the main risk factors for structural failure of the RC repair are the tendon intrinsic characteristics (level of degeneration of the tear edges) and the tear size. The rate of the re-tear can be reduced by a double raw repair technique, but the functional outcome following RC repair is not clearly related to the structural failure of the RC tendon repair.

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6 Imaging of Failed Rotator Cuff Tears

Alessandra Scaini, Marcello Motta, and Giuseppe Milano

6.1 Introduction

Managing failure after rotator cuff repair (RCR) is challenging. About 25% of patients that undergo RCR complain about persistent or recent pain and disability, with a re-tear rate ranging from 30 to 90% in massive tears [1, 2]. Not all symptomatic patients exhibit a re-tear, and post-operative imaging is usually recommended in order to find out the cause of persistent symptoms, since clinical examination is often unclear [3]. Imaging is useful mainly to define the status of rotator cuff and of the long head of biceps tendon (LHBT), but also to analyse other possible causes of pain such as post-operative synovitis, subacromial impingement, hardware migration or other bone-related problems.

Post-operative rotator cuff imaging consists of radiographs, followed by second-level exams, like ultrasonography (US), magnetic resonance imaging (MRI), magnetic resonance arthrography (MRA) or computed tomography (CT) [4].

Interpretation of shoulder imaging after RCR is often difficult because of surgical alterations of native anatomy and hardware artefacts; tendon morphology is changed, and diagnostic criteria are dissimilar than preoperative imaging. Imaging findings should always be related to clinical presentation to properly understand their clinical relevance.

6.2 Imaging Modalities

6.2.1 Radiography

The first level of imaging is radiographic exam, which includes an anteroposterior view, an axillary view and a lateral or trans-scapular (Y) view [5, 6]. This simple exam can detect the presence and the position of metallic hardware (including eventual misplacing or migration), osseous complication such as glenohumeral arthritis, humeral head subluxation, subacromial spurs, fractures, os acromiale and status of greater tuberosity [5, 7].

6.2.2 Ultrasonography (US)

Many studies used US to evaluate RCR, describing sensitivity between 85 and 100%, a specificity from 89 up to 100% and an accuracy of 89% for tendon integrity [8–10].

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Ultrasonography is a valuable tool, because it is not subject to artefacts from suture anchor and allows dynamic assessment with low costs [4, 5]. However, it is an operator-dependent technique and the specificity and predictive value rely on experience of the operator and equipment [2]. Furthermore, US interpretation is not without pitfalls due to changed and heterogeneous appearance of the tendon structure. Cuff defects-like appearances persist up to 5 years after surgery in 20–50% of the cases and tendon fibres appear disorganized and abnormal for 5 years with an image of thickening [1, 11, 12]. Tendon healing may appear hyper or hypoechoic, and increased peri-tendinous vascularity decreases about 6 months after surgery [13].

In addition, US cannot provide a comprehensive evaluation of the shoulder other than rotator cuff status.

6.2.3 Magnetic Resonance Imaging (MRI)

MRI has a primary role in post-operative imaging of the rotator cuff; while it is the gold standard for rotator cuff tears, its accuracy is very reduced in post-operative setting, because of artefacts and post-surgical changes, especially when MRI protocol to reduce artefact is not used.

A thorough evaluation of the shoulder, and not only the status of rotator cuff, is mandatory to find out potential causes of failure or other sources of residual symptoms.

There is a relative paucity of data regarding MRI in post-operative settings. Although several classifications on different findings are available, no clear evidence exists on which is the most accurate and reliable, and which sequences are the best suitable (Table 6.1). According to the current literature, only the presence of structural integrity (and in particular assessment of full-thickness re-tear) has a high intra- and inter-observer reliability [5, 14, 15].

The most relevant concern is about the assessment of tendon integrity, with a reported sensitivity from 86 to 100% and a specificity between 92 and 97% [3, 16–18]. Several classifications have been proposed, which dichotomize the presence of a re-tear (yes or no) or stage the re-tear in terms of size (small, medium or large) or thickness (full or partial) [3, 16, 18–22]. Currently, the 5-type classification reported by Sugaya et al. is the most commonly used and many dichotomizations of Sugaya's classifications have been reported with the highest reliability over all [2, 15, 23–25] (Table 6.2). Assessment of partial-thickness re-tear as bursal- or articular-sided tears showed poor intra- and inter-observer reliability [26]. Some studies also evaluated tendon thickness, with poor reliability [26, 27].

Another finding is the location of re-tear, which may be on the greater tuberosity or close to the musculotendinous junction. Cho et al. distinguished Type 1 lesions (if no repaired cuff

Table 6.1 Parameters evaluable on MRI of repaired rotator cuff [15]

Structural integrity
Tendon thickness
Signal intensity
Location of re-tear
Size of re-tear
Number of tendons involved
Tendon retraction
Footprint coverage
Tear length
Musculotendinous joint position
Muscle atrophy
Fatty infiltration
Status of the long head biceps tendon
Joint effusion
Bone marrow oedema
Acromiohumeral distance
Cysts of the greater tuberosity

Table 6.2 MRI classification of repaired rotator cuff tendons as proposed by Sugaya et al. [24]

Type	Imaging appearance
I	Repaired cuff with sufficient thickness, homogeneously low T2 signal intensity
II	Repaired cuff with sufficient thickness, partial high signal intensity area within the tendon
III	Insufficient cuff thickness without discontinuity
IV	Minor discontinuity on more than one slice, suggesting a small tear
V	Major discontinuity suggesting a moderate or large tear

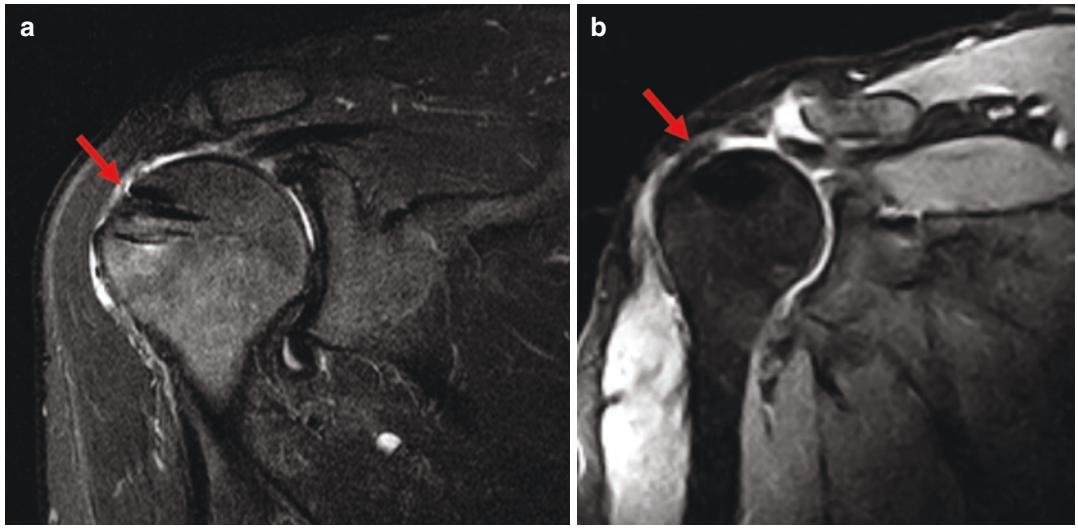

Fig. 6.1 Re-tear location according to Cho et al. [28]. (**a**) MRI coronal T2-weighted image of failed rotator cuff repair. In Type 1 lesions, no repaired cuff tissue remains on the greater tuberosity (red arrow). (**b**) MRI coronal STIR image of failed rotator cuff repair. In Type 2 lesions, repaired cuff tissue remains at the re-insertion site (red arrow)

tissue remains on the greater tuberosity) and Type 2 lesions (if the repaired cuff tissue remains at the re-insertion site) (Fig. 6.1). They also reported more Type 1 lesion after single-row repair, whereas suture bridge technique was related to Type 2 [28]. Khazzam et al. reported fair intra-observer- and poor inter-observer reliability in describing the location of re-tear [26].

Extent of tendon retraction is measured on coronal images using Patte classification as in preoperative imaging [29, 30].

Many parameters are related to a qualitative description of the tendons and muscles. Fatty infiltration is evaluated on sagittal Y-shaped T1 or T2 sequence, and constitutes one of the most important predictive factors for successful outcomes [31]. Fuchs et al. demonstrated that Goutallier's grading system is reproducible on MRI, and this is currently the most commonly used classification for fatty infiltration.

Muscle atrophy is usually evaluated on sagittal or Y-shaped images, where several measures are analysed according to different classifications [32–38]. Cross-sectional area (CSA) of supraspinatus, infraspinatus, teres minor and subscapularis muscles may be calculated and according to Zanetti et al. [32], muscle atrophy is present when CSA of a single muscle is more than 2 standard deviations below the average of all muscle areas. The tangent sign is another criterion to assess muscle atrophy of the supraspinatus. Specifically, the supraspinatus muscle is considered atrophic when its superior profile in the supraspinatus fossa is tangent or lies below the line that runs from the superior border of the scapular spine to the superior margin of the coracoid [32]. Thomazeau et al. graded atrophy according to the occupational ratio, which is calculated by dividing the CSA of the muscle for the CSA area of the fossa [34] (Fig. 6.2).

Recent studies revealed that there are immediate post-operative changes in CSA related to the lateral excursion of muscle belly during the repair [39–41]. Surgical repair itself changes measures of atrophy and fatty infiltration, by lateralizing the muscle belly and reducing the retraction of the tendon. Thus, preoperative retraction could be responsible of false presentation of atrophy in the two-dimensional (2D) view, called *pseudoatrophy*; to solve this problem recent studies tried to measure muscle volume with MRI three-dimensional (3D) reconstructions [41, 42].

Reversibility of fatty infiltration and muscle atrophy after repair is controversial. Several authors reported that they are irreversible phenomena, while others noted an improvement after

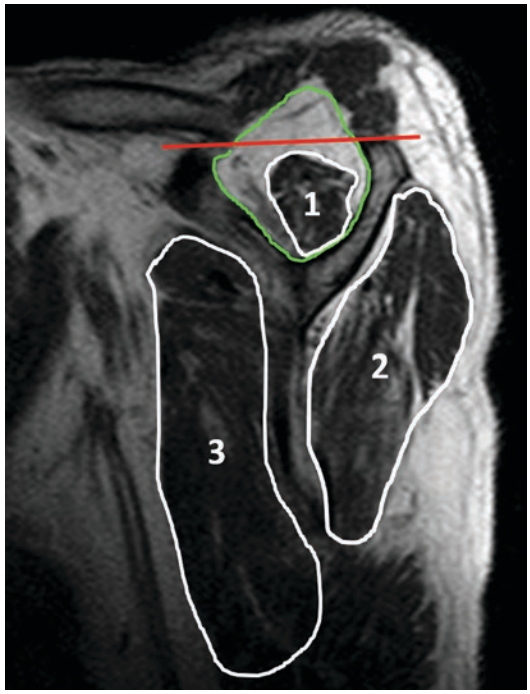

Fig. 6.2 Measuring cross-sectional area on parasagittal T2-weighted sequence. Quantification of supraspinatus muscle (1), supraspinatus fossa (green line), combined measurement of the infraspinatus and teres minor muscles (3), and subscapularis muscle (4). Tangent line is coloured in red

successful repair [37, 43, 44]. Current baseline assessment consists of preoperative measures on 2D MRI, albeit in light of the above-mentioned considerations, some authors suggested that using early post-operative imaging could reveal true baseline muscle atrophy [39, 42, 45].

Developing of new repair / reconstruction techniques, such as patch augmentations and superior capsular reconstruction (SCR), requires new imaging knowledge for proper evaluation. Usually, grafts appear with low-signal intensity on MRI proton density (PD) sequences, but currently there are few studies concerning imaging of SCR [46, 47].

6.2.4 Magnetic Resonance Arthrography (MRA)

Addition of intra-articular contrast medium may enhance accuracy and sensitivity of MRI for detecting rotator cuff re-tears; in particular, the contrast agent emphasizes partial-thickness re-tears of the articular side [48, 49]. Moreover, contrast is useful to discriminate granulation tissue, post-operative inflammation and scarring from a re-tear, wherever this distinction is not easy in standard MRI. Re-tear clearly appears as a fluid filled gap [50], but some authors suggested that MRA overestimates failures by increasing the appearance of pseudo-tears [51].

6.2.5 Computed Tomography (CT)

The high radiation exposure related to CT scan it as second choice over MRI. Therefore, CT should be considered as an alternative second-level imaging modality in those cases where MRI is contraindicated (i.e. in presence of pacemaker) or when artefacts from metallic hardware cannot be reduced on MRI [7]. Several protocols should be used to decrease metallic artefacts during acquisition and reconstruction of CT scans [52, 53].

6.3 Expected Findings

Post-operative imaging presents many different interpretation issues. Only 10% of the patients, including asymptomatic patients, has a "normal" tendon appearance [54]. The anatomy could be altered by surgery, and it is crucial to know what kind of surgery was performed. Furthermore, imaging features of tendon healing and peritendinous tissue reaction after rotator cuff repair should be understood to discriminate expected findings from pathologic findings.

6.3.1 Artefacts

Metal artefacts reduce diagnostic accuracy and reliability of post-operative MRI after RCR [55].

Presence of metal anchors and metal debris related to burring is usually responsible for low-signal artefacts located beneath the acromion (Fig. 6.3). Ferromagnetic materials as iron, nickel, cobalt cause significantly more severe artefacts

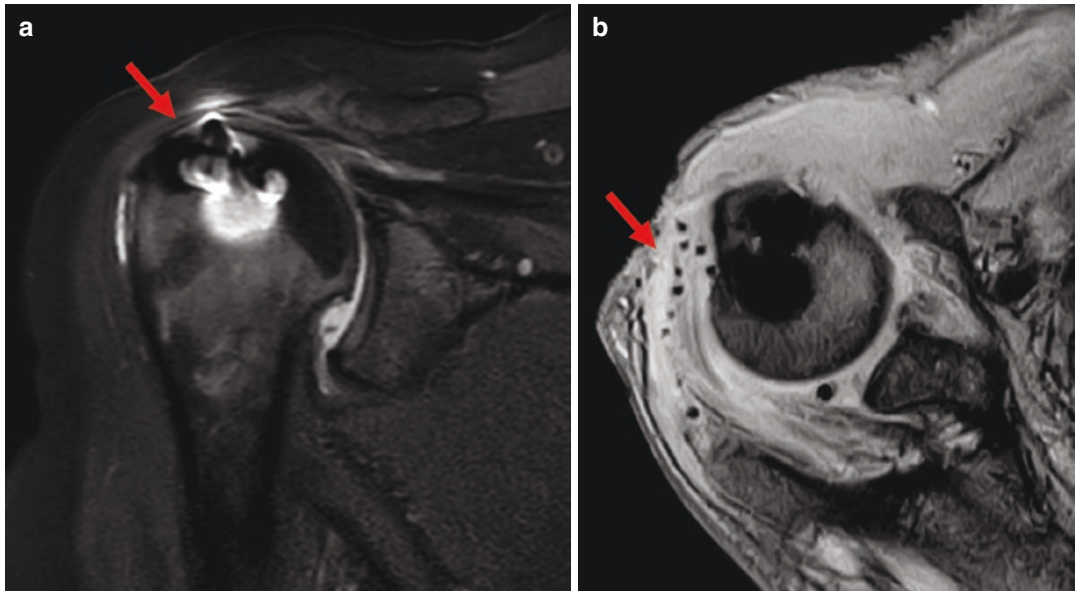

Fig. 6.3 Metal artefacts reduce diagnostic accuracy and reliability of post-operative MRI after RCR. (**a**) MRI coronal STIR image of failed rotator cuff repair. Presence of metal anchors is responsible for low-signal artefacts located beneath the acromion (red arrow). (**b**) MRI axial T2-weighted image of failed rotator cuff repair. Metal debris (red arrow) are related to burring

compared to titanium and zirconium, which are paramagnetic metals [56]. Several MRI parameters can be settled to optimize the quality of imaging. Scanning at lower magnetic field, using a larger matrix size, thinner slices, and lower time-to-echo reduces metal distortion. During the past years, several MRI techniques were proposed to manage metal artefacts, like multiple-acquisition with variable resonance image combination (MAVRIC), the WARP sequence and the metal artefact reduction sequences (MARS) [57, 58].

Sequences with fat suppression can be troubling in presence of metal artefacts. It could be addressed using short tau inversion recovery (STIR); while gradient recalled echo sequences (GRE) are not recommended [56, 59].

6.3.2 Osseous Findings

Subacromial decompression, acromioplasty or distal clavicular resection could be part of the surgical treatment. Characteristic findings include a flattened acromial undersurface, lack of the anterior acromion and a marrow fibrosis that appears with a decreased signal. Scar tissue with an intermediate signal replaces this structure in few weeks [60].

While marrow fibrosis is usually detected after acromioplasty, marrow oedema around acromioclavicular joint is strictly related to pathology in the acromioclavicular joint. Misdiagnosis of this pathology could be responsible of post-operative poor outcome [61].

In relation to humeral side, a surgical trough appears in the insertion zone on the greater tuberosity. Some osteolysis or cystic changes can be sometimes observed around the anchors (Fig. 6.4) [2, 62].

Bone marrow oedema-like signals are also associated with post-operative findings and should not be evaluated as pathologic findings [51].

6.3.3 Soft Tissue Findings

Absence of subacromial peri-bursal fat is usually associated with RCR. A mild-to-moderate joint effusion is common with a leakage of fluid into the subacromial space, which may persist for

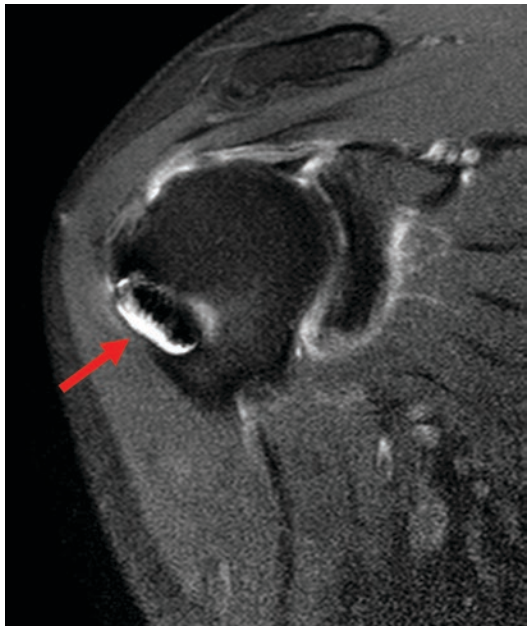

Fig. 6.4 MRI coronal STIR image of failed rotator cuff repair. Osteolysis or cystic changes can be sometimes observed around the anchors (red arrow)

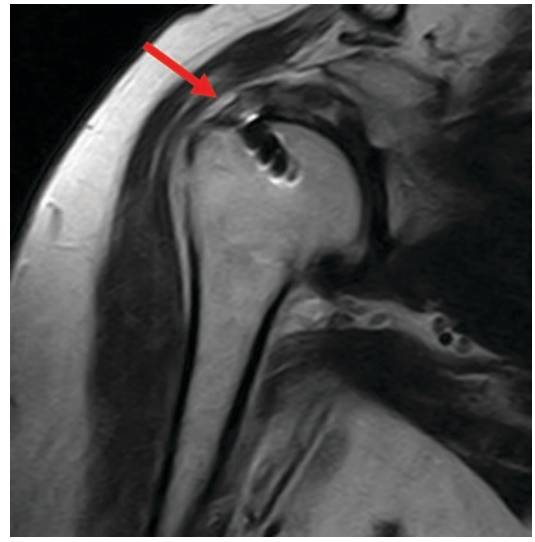

Fig. 6.5 MRI coronal T2-weighted image of healed rotator cuff (red arrow). Some signal changes in the repaired tendon can be referred to previous tendinopathy. These morphologic alterations might last for several years after surgery but have no influences on clinical outcome

years. This effusion through articular and subacromial spaces does not represent an indirect sign of re-tear, because the repair is no more watertight and can be related to opening of rotator interval [63]. Only 12.5% of repaired tendon have a normal MRI signal intensity. In the early post-operative period, the repaired tendon appears disorganized with hyperintense granulation tissue, whose appearance mimics re-tear on short-echo-time sequences [2]. Remodeling phases gradually improve MRI tendon images from 3 to 12 month, but these morphologic alterations might last for several years after surgery [4, 64]. Furthermore, signal changes can be referred to previous tendinopathy. These alterations can be considered normal findings in post-operative imaging and have no influences on clinical outcome, but reduce agreement on tendon healing [65] (Fig. 6.5).

Also delamination may be responsible for signal alteration and intratendinous split. Craig et al. reported that areas of delamination do not heal after the repair but have no effect on patient-reported outcomes [2]. Gagnier et al. reported that 20–50% of patients have a visible tendon defect for years, and this defect may not be clinically significant [66].

Footprint coverage less than 50% or tendon defect on the insertion are often considered as indirect signs of failure, but recent studies indicate that from 20 up to 50% of patients exhibit a tendon defect over the insertion area, including successful repaired rotator cuff [67, 68]. Therefore, increased signal intensity, even if suggestive for a gap, should not be considered as re-tear if it is not correlated with clinical findings.

6.4 Pathologic Findings

The most important concern in symptomatic patient after RCR is the development of a re-tear. Despite this, there are many causes for persistent pain and reduced function, which can be considered as a failure.

6.4.1 Recurrent Tear

As previous explained, defining a true re-tear is a challenge and should be paired with clinical

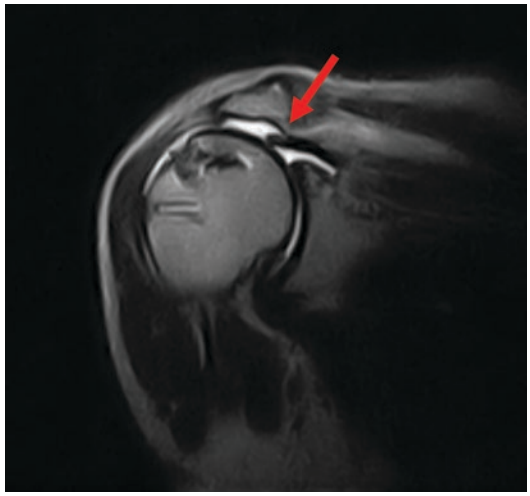

Fig. 6.6 MRI coronal T2-weighted image showing rotator cuff re-tear due to non-healing. Supraspinatus tendon (red arrow) appears atrophic, fibrotic and with irregular structure

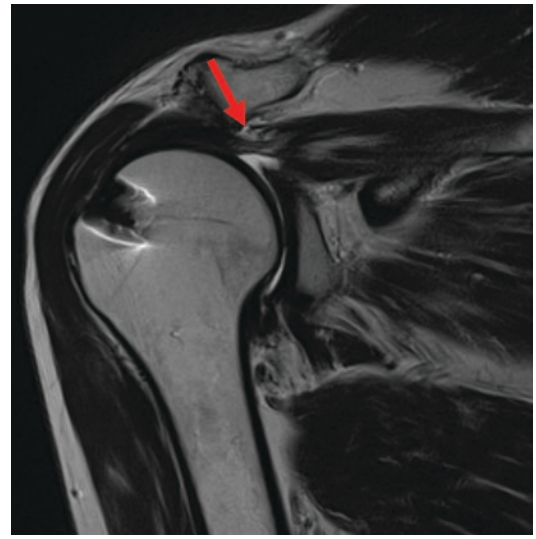

Fig. 6.7 MRI coronal T2-weighted image showing a failure in continuity of rotator cuff repair. An elongation of the tendon (red arrow) accompanied by a retraction of the muscle from the insertional area and without a tendon gap is visible

presentation. A comparison with preoperative MRI may be useful.

Most of re-tears typically occurs during the first 3 months after surgery. Rotator cuff failure before 6 months is defined non-healing type and usually appears with irregular structure, fibrosis and poor neo-angiogenesis (Fig. 6.6). Failures after 6 months are defined as recurrent tears and have degenerative or traumatic origin [69, 70].

A re-tear is usually visible on MRI as a presence of fluid-like or hyperintense signal on a T2-weighted image into the tendon thickness. Secondary signs of re-tears are medial retraction of proximal tendon and muscle edge, progression of fatty infiltration and muscle atrophy. In rare cases it is possible to see a failure in continuity, which is an elongation of the tendon with scar tissue accompanied by a retraction of the muscle from the insertional area and without a tendon gap [71] (Fig. 6.7).

6.4.2 Displacement of Suture Anchors

Hardware failures are related to anchor malpositioning or anchor displacing (Fig. 6.8). Metal anchors are detected also on radiographs, while pinpoint the location of non-metallic anchors (i.e. PEEK or biodegradable anchors) requires MRI. Malposition may result in cartilage damage, reduced range of motion and usually

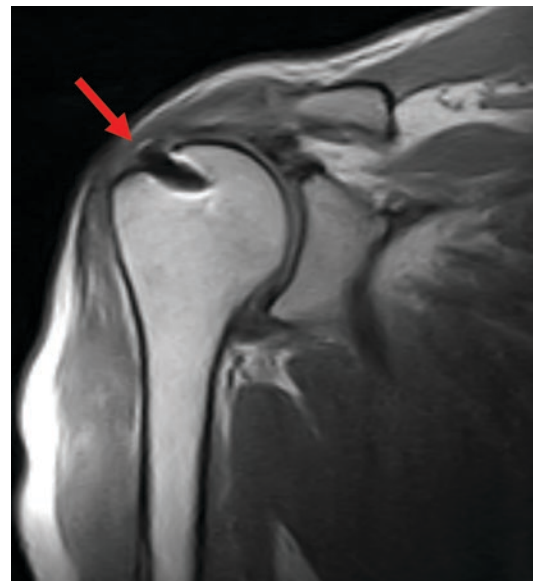

Fig. 6.8 MRI coronal T1-weighted image of failed rotator cuff repair showing a proud suture anchor (red arrow) in the subacromial space

requires revision surgery. Same symptoms are present even in case of anchor displacing, which may exacerbate becoming a loose body into the joint.

Persistent bone marrow oedema and bony resorption around the hardware are suspicious for inflammatory reaction to the implant.

6.4.3 Infection

Thick synovia and significant joint effusion are suspicious for infection in case of suggestive clinical signs. Diagnosis is confirmed by culture of joint fluid and imaging like US can serve as guide for needle aspiration.

6.4.4 Iatrogenic Injuries

Detachment of the deltoid from the acromion is a devastating injury that is identified on MRI by the retraction of the deltoid filled by fluid. Atrophy of muscle with progressive fat replacement is present in chronic lesions [5].

Other complications visible on imaging studies are acromial fractures (often related to aggressive acromioplasty) and post-arthroscopic glenohumeral chondrolysis [1].

6.4.5 Diagnostic Errors

Incomplete preoperative diagnosis leads to incorrect treatment with poor post-operative outcomes. Most frequently, hidden lesions are lesions of the rotator interval, instability or tendinopathy of LHBT, and subscapularis tears. Undetected os acromiale may become symptomatic after acromioplasty (Fig. 6.9). All these injuries are visible in a careful observation of MRI scans, while suprascapular neuropathy is only suspected on MRI by secondary atrophy of the innervated muscle and must be diagnosticated by electromyography [5].

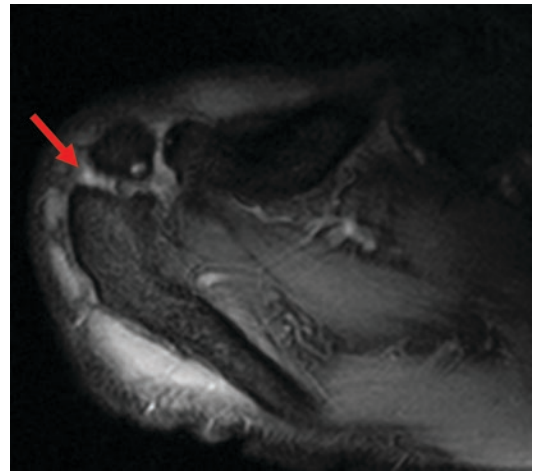

Fig. 6.9 MRI axial STIR image showing an os acromiale (red arrow)

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7 Special Techniques in Evaluation of the Failed Rotator Cuff

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7.1 Introduction

Imaging of the shoulder joint, in particular for rotator cuff pathology, has improved tremendously over the past few years. Beyond plain radiographs, imaging capabilities that clinicians can rely on include MRI, MR arthrogram, CT scans, ultrasound scans, vascular Doppler studies, and more recently US Elastography. This chapter will focus on imaging capabilities and possibilities in failed cuff repairs. While it is known that failure to heal occurs in about 20% of cases [1], what is needed is to define a common understanding of failure of cuff repair, what is accepted as failure to heal as opposed to re-tear, and understand the various causes. The presence of high signals, thinning and even gaps in post repair tendons may not constitute a pathological state as patients remain relatively asymptomatic. Hence, an understanding of "normal" changes that might occur in tendons after cuff repair, and how these changes may change over time, is necessary.

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Plain radiographs remain useful despite modern imaging, and we discuss here the role of radiographs in cuff pathology and re-tears. Advanced imaging like ultrasounds and MRI serve to help clinicians navigate these questions: *Is there a re-tear? Where and how big? What are the possible causes? Is it reparable and if so, can imaging help my surgical options?*

7.2 Definition of Failed Cuff Repair

What is understood as failure of cuff repair as a surgical event? Desmoineaux defined it as the need for revision surgery in the short- and mid-term, without defining these time periods [1]. Quoting a 10-year study, Collin et al. cited a revision rate of about 7% after cuff repair (35 out of 511 patients) [2]. Cuff et al. [3] chose to define failure more objectively, defining failed cuff repair as an American Shoulder and Elbow Surgeons (ASES) score lower than 70 or a range of forward elevation below 90°. However, this may not have correlation with structural cuff integrity nor clinically important improvements, albeit subjectively, that patients may experience after surgery. A more coherent definition could be the presence of pseudo-paralysis, the lack of improvement or worsening of symptoms compared to pre-op, coupled with a structural defect in the cuff, which was proposed by Gasbarro et al. [4].

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Thus, the understanding or perception of cuff failure may be different to different people involved [1]. To the patient, clinical events like prolonged post-op pain and stiffness, persistent weakness or pseudo-paralysis, and even the Popeye sign, may be viewed as failures. The inability or delay in return to work and sports may be disappointing and viewed as a failure to meet patients' expectations. To the surgeon, failure is more objective, such as the occurrence of infection, worsening of symptoms and scores, failure of the repaired tendon to heal, or the recurrence of a tear.

Recurrence of tears, as opposed to the presence of gaps, occur in 11–68% of patients after cuff repair [5, 6]. A repaired tendon is not always water tight. If during post-op MR arthrography contrast is seen communicating into the subacromial space, it may represent a normal postoperative appearance [7]. Relatively asymptomatic patients may demonstrate tendon thinning, partial-thickness, or even full-thickness tendon tears on MR images. In their study, Zanetti et al. [8] found that symptomatic postoperative patients tended to have larger rotator cuff defects (>11 mm).

7.3 Changes seen after Cuff Repair

Repaired rotator cuff tendons demonstrate a wide variety of appearance in MRI and ultrasound. Even in asymptomatic patients, "normal" morphology of the tendon has similar appearance to non-operated tendon in only 10% of the cases [9]. Morphology is influenced by temporal interval since surgery, technical variance in surgical repair and most crucially, the presence of complications [10, 11].

There is considerable overlap between the spectrum of expected atypical appearance and imaging morphology suspicious for tendon re-tear. An adroit method to interpret these findings is to utilise an established visual grading system, in MRI as suggested by Sugaya et al. and modified for ultrasound by Barth et al. [12, 13] (Table 7.1).

In both grading systems, grade I is interpreted as completely normal, grade II and III as a spectrum of normal to partial tears, grade IV as small tear, and grade V as major tears. This interpretation is more established in the peripheral grades (I and V) but remains controversial in the middle (grades II to IV). Partial tears are known to be indistinguishable from intact repaired tendons, making the differentiation of grade II and III less helpful [14]. On MRI, increased signal may reflect not just tendinopathy and low-grade partial tears but also postoperative inflammation, suture material or granulation tissue formation (Fig. 7.1) [15]. Studies tracking temporal evolution of MRI signal intensity and ultrasound echotexture of repaired tendon found that most severe signal and echotexture alteration are found in early post operation; often but not always, these tendons may demonstrate eventual normalisation after 1 year in MRI and after 6 months in ultrasound [16, 17].

Table 7.1 MRI and ultrasound grading system for interpretation of post repair cuff tendons

Tendon Grade	Sugaya (MRI grading using oblique coronal, oblique sagittal and transverse T2-weighted spin echo sequences) [5]	Barth (Ultrasound grading using frontal, sagittal, and transverse B-mode images) [4]
I	Sufficient thickness compared to normal cuff and homogeneously low signal intensity	Sufficient thickness (>2 mm) with normal echostructure as normal tendon hyperechoic and fibrillar on each image
II	Sufficient thickness compared with normal cuff and partial high signal intensity area	Sufficient thickness (>2 mm) with partial hypo-echogenicity or heterogenicity
III	Insufficient thickness with less than half thickness compared with normal cuff but without discontinuity	Insufficient thickness (<2 mm) without discontinuity
IV	Presence of minor discontinuity in 1 or 2 slices on both oblique coronal and sagittal sequences	Presence of minor full-thickness discontinuity of which borders are well visible
V	Presence of major discontinuity in more than 2 slices of both oblique coronal and sagittal sequences	Presence of major discontinuity of which borders are not visible

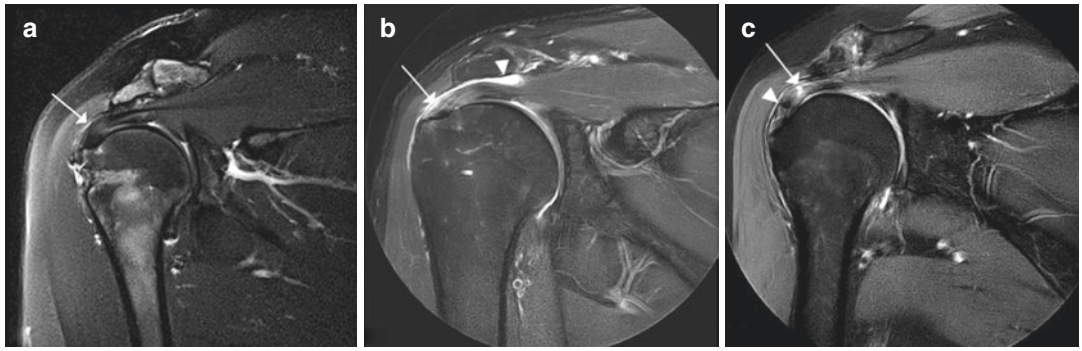

Fig. 7.1 MRI signal changes in asymptomatic patients after cuff repair. Coronal oblique T2-weighted fat suppressed MRI images of the shoulder post supraspinatus tendon repair in three different patients. (**a**) Repaired tendon demonstrates dark signal without defect (arrow) compatible with Sugaya grade I. (**b**) Repaired tendon demonstrates diffusely raised signal without defect compatible with Sugaya grade II. Adjacent bursal fluid distention (arrowhead). (**c**) Repaired tendon demonstrates raised signal with small fluid-filled defect that is less than 1 cm, compatible with Sugaya grade III. Focal dark signal within the tendon represents repair sutures (arrowhead)

Studies investigating the significance of tendon thickness are also contentious. Tham et al. performed serial ultrasounds for patients post repair and found no predictable changes in tendon thickness nor association with symptoms [18]. Temporal charting of MRI changes post repair by Crim et al. also revealed no consistent pattern pertaining to tendon thickness [16]. Both studies however presented an increase in footprint width over time suggestive of tendon-to-bone healing. This stands as a precaution against misinterpreting poor footprint coverage as surgical failure in the 6 weeks to 3 months postoperative imaging [16]. There are also contrasting studies that demonstrate progressive decrease in tendon thickness on sequential ultrasound post repair, but none have been able to correlate with symptoms or function [17, 19].

Small residual defects in the repaired cuff of up 1 cm in size are often seen in both MRI and ultrasound of asymptomatic patients, ranging from 21% to 48% in prevalence [8, 20]. Possible explanations provided include reparative scars and non-watertight repair that convert debilitating tears to "functional cuff tears" [8, 20]. Not all portions of a tendon tear may be repaired due to limitations of tissue quality and in these instances, the unrepaired defects remain [11]. It is also interesting to note that in a study with 5-year follow-up, some of these defects diagnosed earlier by ultrasound eventually demonstrated healing, lending strength to the hypothesis of reparative scars [21]. These findings reiterate our understanding that post-op imaging should not be performed any earlier than 6 months, before which time tendon appearances are undergoing changes. In the early post-op period, signal changes in the tendon, thinning and even small gaps may not be abnormal.

"Normal" post-op changes after cuff repair can thus be summarised as such: in the early phase (3–6 months), there could be appearance of "gaps", high signal changes, hypervascularity, and disorganised fibrillar pattern in the tendon. In the late phase (at around 12 months), the fibrillar pattern becomes more organised, there is reduced vascularity and less high intensity signal changes.

7.4 Role of Radiographs in Failed Rotator Cuff Tears

Imaging of rotator cuff pathology frequently employs advanced imaging like MRI, CT scans, ultrasonography, or bone scans [22]. Yet, there is agreement among musculoskeletal radiologists that the initial imaging evaluation of the majority of musculoskeletal pathologies, including rotator cuff injuries, should begin with routine radiography [23], despite findings of plain radiographs being seemingly non-specific. Radiographs are widely available, relatively cheap, technically easy to perform, acceptable as a screening tool,

and are able to provide adequate information about fractures and arthritis of the shoulder. But what information can plain radiographs give us about rotator cuff pathologies, especially in the failed cuff repair?

Standard views to take:

1. **True Shoulder AP (Grashey) view**: This is taken with the beam pointing 45 degrees laterally, oblique to the torso but in the true plane of the glenohumeral joint, in contrast to the conventional AP wherein the beam and cassette are perpendicular to the torso and hence oblique to the glenohumeral joint (Fig. 7.2).
2. **The Supraspinatus Outlet view**: The supraspinatus view is preferred to view the morphology of the acromion and classify it. This view is done with the cassette on the affected shoulder and the torso about 40 degrees oblique to it, with the beam tilted 10 degrees caudally (Fig. 7.3). This view is useful to visualise the

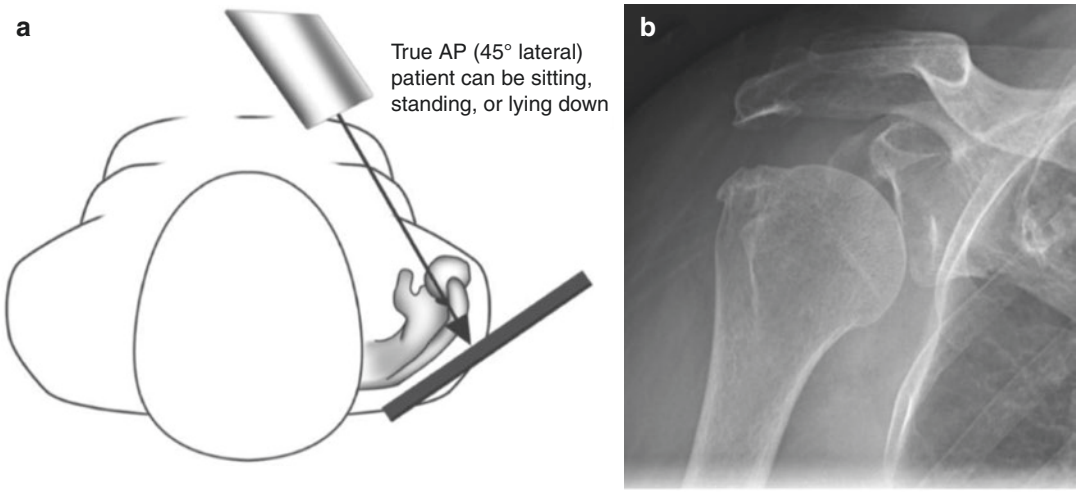

Fig. 7.2 True AP shoulder view. (**a**) Patient positioning for a true shoulder AP view and (**b**) is an example

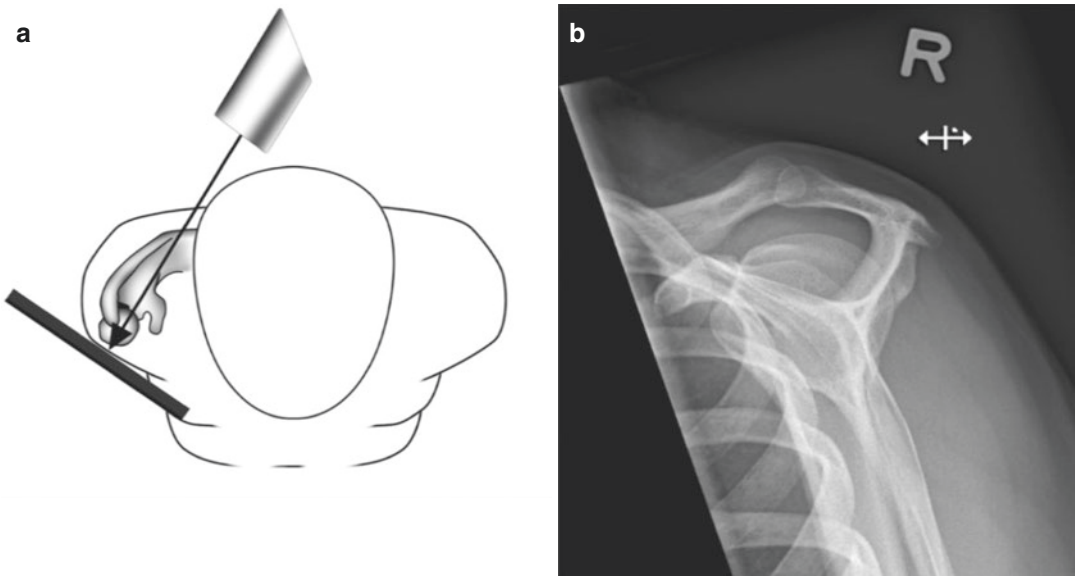

Fig. 7.3 Supraspinatus outlet view.(**a**) Patient positioning for the supraspinatus outlet view and (**b**) is an example showing type I acromion

keeled acromion [24], acromial spurs [25] and classify morphology of the acromion [26].

Radiographic features to note:

1. **Metal artefacts:** The presence of metallic anchors is evidence of previous cuff surgery performed and could shed light on possible causes of failed cuff repair (Fig. 7.4). Metal anchors could have pulled out of the bone, alluding to possible low bone density [27], though this is not common. The presence of metal artefacts determines which further imaging is required [28], in which case ultrasound (or CT scan) may be required. Most current anchors are non-metallic, and MRI can be performed without any modifications.
2. **Osteophytes**: The presence of osteophytes may be subtle but should be looked for. These tend to occur in longstanding cuff tears [29] and may be progressive leading to cuff arthropathy. Kyoung et al. have compared the true AP view with conventional AP in 160 consecutive shoulders. Using five signs of rotator cuff tears (greater tuberosity (GT) sclerosis, GT osteophyte, subacromial (SA) osteophyte, GT cyst, and humeral head osteophyte), they found the true AP view is more sensitive in detecting pathognomonic findings of rotator cuff tear compared to the conventional AP view [29].
3. **Acromiohumeral interval and Moloney's lines (Superior migration of the head)**: True shoulder AP radiographs also permit measurement of the acromiohumeral interval (AHI) and congruence of Moloney's line, which can be used to identify superior migration of the humeral head (Fig. 7.5). The AHI is measured from the inferior most level of the acromion to the superior most point of the humeral head. In a landmark study in 2011, X-rays of 109 shoulders were studied, which showed that an AHI <6 mm is a sign of rotator cuff rupture almost systematically involving longstanding total infraspinatus tear [30]. The authors state that AHI equal to or greater than 6 mm is of no diagnostic relevance. The accuracy of AHI to predict cuff tears is increased when studied with Moloney's line [31]. In a study of 116 X-rays of shoulders with ultrasound-proven rotator cuff tears, abnormal AHI (<8 mm) was seen in 89.7% of severe rotator cuff tears. There was also positive correlation between disruption of Moloney's line with tears of the infraspinatus, subscapularis, and long head of biceps tendons. However, there was a wide inter-observer variability when measuring AHI on AP radiographs alone [32]. The use of AHI in the studies above were suggestive of the diagnosis of cuff tears. But can AHI be used to predict re-tears and hence, be of used in radiography of failed cuff repairs? Shoulder MRI of 83 patients who had undergone cuff repair were studied with an overall re-tear rate was 57.8% [33]. Independent prognostic factors of re-tear were degree of tendon retraction and AHI (6.8 mm in re-tear vs 8.7 mm in intact) on preoperative MR images.
4. **Critical Shoulder Angle, Acromial Index:** The CSA, first described by Moor et al. [34],

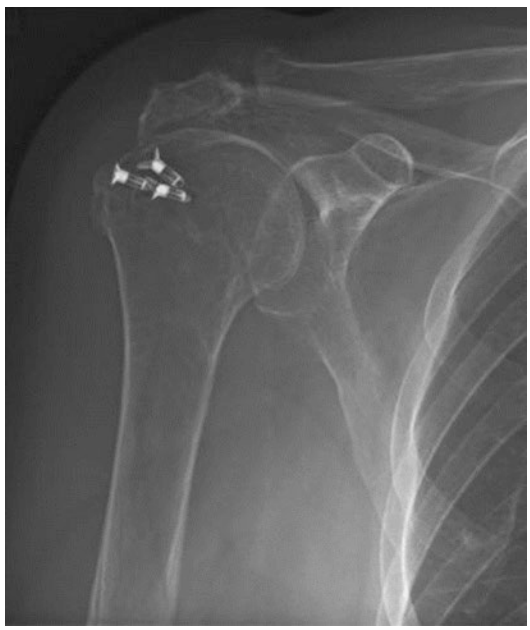

Fig. 7.4 Radiographs of patient with recurrent tear. The shoulder AP radiograph shows metal artefacts in the humeral head, which is high riding with an acromial humeral interval (AHI) <6 mm. There are mild degenerative changes. These changes on the plain radiograph suggest a recurrent tear of the tendon

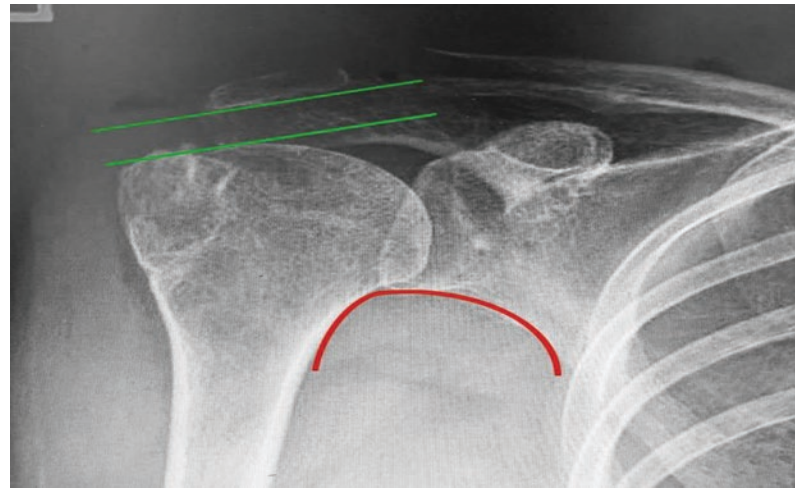

Fig. 7.5 Acromiohumeral interval (AHI) and Moloney's line. AHI is the distance between the green lines and Moloney's line is marked in red

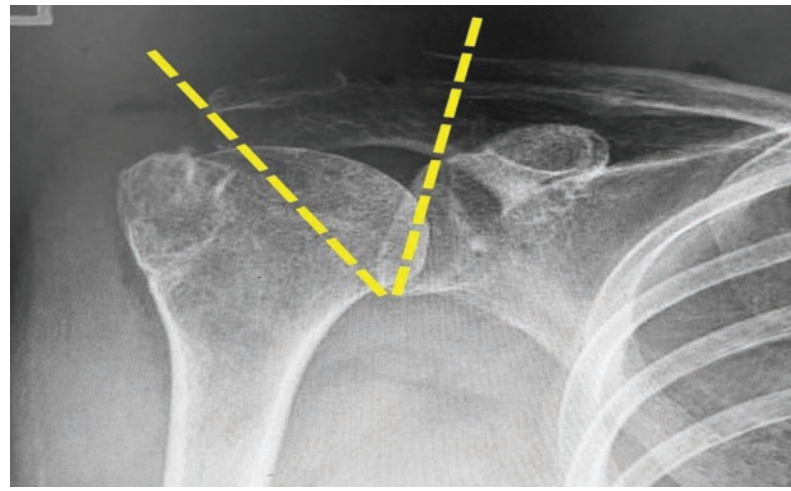

Fig. 7.6 Critical shoulder angle (CSA). The CSA is the angle subtended between these lines; a line from the lateral edge of the acromion to the inferior glenoid and a line in the plane of the glenoid

combines the measurements of the inclination of the glenoid and the lateral extension of the acromion (Fig. 7.6). It has been shown to be a predictor of the occurrence of cuff tears [35]. A CSA greater than 35 degrees is associated with cuff tears, and a CSA less than 30 degrees is associated with glenohumeral osteoarthritis. While CSA may have a role in the pathogenesis of cuff tears, it does not appear to affect functional outcomes after 24 months [36] nor does it affect re-tear rates [37]. The acromial index (AI), which describes the lateral extension of the acromion (Fig. 7.7), has similarly been shown to be associated with full-thickness cuff tears [38] but does not influence outcomes nor re-tear rates [36].

5. **Bone mineral density (BMD) and cortical thickness of humeral shaft:** Another factor to study from the true shoulder AP view is cortical thickness of the humeral shaft, used as a surrogate of BMD of the humeral head [39]. Tingart et al. described the combined cortical thickness (CCT) of the proximal humerus as a reliable and reproducible predictor for localised BMD (Fig. 7.8). The CCT determined from conventional AP shoulder radiographs correlated well with BMD measured after cutting the proximal

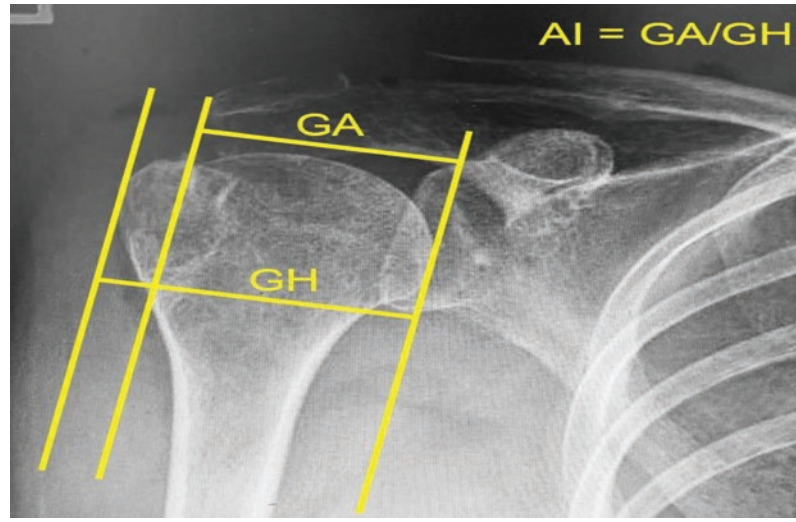

Fig. 7.7 Acromial index (AI). The AI is obtained by dividing (GA) the distance from the plane of the glenoid to the lateral edge of the acromion, over (GH) the distance from the plane of the glenoid to the lateral aspect of the humeral head

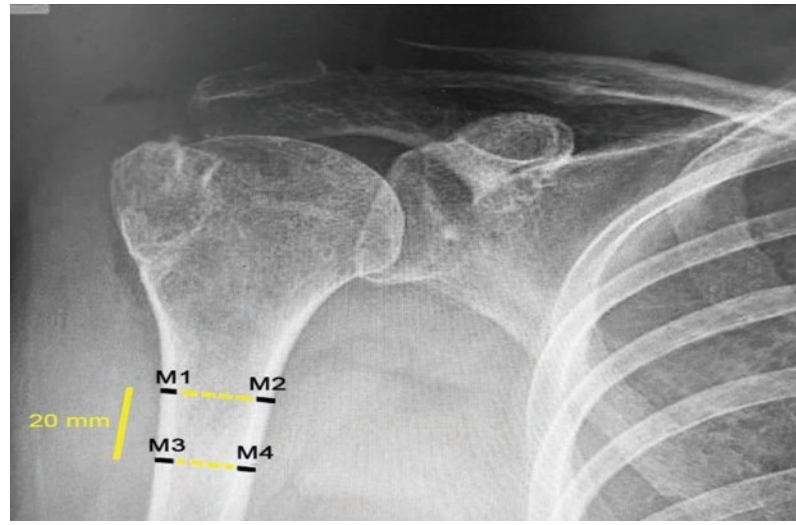

Fig. 7.8 Combined cortical thickness (CCT). CCT is the mean of medial and lateral cortical thicknesses at two levels. The first level is measured where the endosteal borders are parallel and the second level is measured 20 mm distal to that. M1 and M2 are the medial and lateral cortical thicknesses at the first level, while M3 and M4 are the medial and lateral cortical thicknesses at the second

humerus diaphysis, with CCT <4 mm being highly indicative of a low BMD. Chung et al. found that the failure rate of rotator cuff healing correlated with BMD, with high rates of failure in patients with osteopenia and osteoporosis [40]. A lower BMD may thus compromise the strength of rotator cuff repair by suture anchor loosening or pull-out before adequate tendon-to-bone healing can occur [27]. In a study by Lee et al., CCT of pre-op radiographs were measured; functional scores after cuff repair were significantly higher in those with higher CCT at 6, 12, and 24 months [41].

6. **Acromial morphology:** Although Bigliani's classification system of acromial morphology utilising the standard outlet radiograph has become an accepted method for evaluating patients with rotator cuff disease, its reproducibility is questionable. In a study of 40 patients' outlet views [42], viewed 4 months apart by six reviewers, including two shoulder surgeons, a musculoskeletal radiologist, an orthopaedic surgery sports

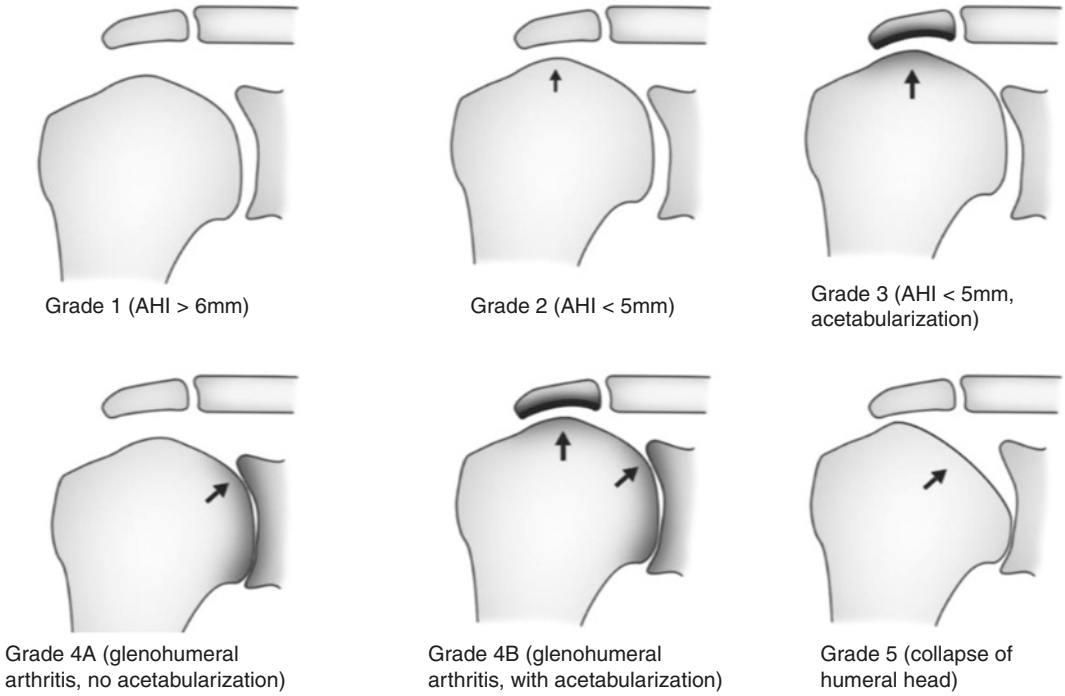

Fig. 7.9 The Hamada classification of massive cuff tear and cuff arthropathy. Grade 1: Preserved AHI or greater than 6 mm. Grade 2: AHI of 5 mm or less. Grade 3: AHI < 5 mm with acetabularization of the acromion. Grade 4A: Glenohumeral arthritis without acetabularization, AHI < 7 mm. Grade 4B: Glenohumeral arthritis with acetabularization, AHI ≤ 5 mm. Grade 5: humeral head collapse and cuff tear arthropathy (CTA)

fellow, and two orthopaedic residents (PGY-2 and PGY-5), all six observers agreed only 18% of the time on classifying each film as type I, II, or III acromion. Inter-observer reliability among the six observers ranged from 0.01 to 0.75 (mean 0.35, fair), and intra-observer repeatability ranged from 0.26 (fair) for PGY-5 residents to 0.80 (excellent) for the fellowship-trained surgeons, with a mean of 0.55 (moderate).

7. **Arthritis of the glenohumeral joint**: Cuff tear arthropathy develops in about 4% of patients with massive cuff tears [43]. Risk factors for cuff arthropathy include advanced age, smoking, hypercholesterolemia, family history, large cuff tear, and history of trauma [44]. The onset of cuff arthropathy in failed cuff repair heralds a different approach and requires a replacement arthroplasty option as opposed to revision cuff repair. The Hamada classification [45] divides patients with massive rotator cuff tears and cuff arthropathy based on the acromiohumeral interval (AHI) and can provide a mechanistic explanation to the findings seen on the radiograph (Fig. 7.9) (Table 7.2).

7.5 After the Radiographs, MRI, CT, or Ultrasound? A Radiologist's Perspective

In the American College of Radiology Appropriateness criteria, imaging work-up for shoulder pain post-rotator cuff repair is recommended as—either MR arthrogram, MRI of the shoulder without IV contrast, or ultrasound, should be performed when initial radiographs are normal or inconclusive [46]. Radiographs are helpful to evaluate alignment while guiding the appropriate further investigation based on the types of indwell-

Table 7.2 Summary of radiographic features to note in failed cuff repair

Views to take	Features to note
True AP view	• Metal artefacts: Evidence of cuff surgery and determines further imaging to be done • Osteophytes (GT osteophytes, sclerosis, cysts, humeral head, and subacromial cysts): Common in post cuff repair • Superior migration of the humeral head (Acromiohumeral interval and Moloney's line): Seen in massive cuff tears and may be indicative of re-tears • Critical shoulder angle and acromial index: Postulated to be involved in pathogenesis of cuff tears but not predictive of re-tears • Combined cortical thickness: Low BMD postulated to be associated with increased failure rates of cuff repair • Onset of arthritis and cuff arthropathy: Influences therapeutic options in re-tears
Supraspinatus outlet view	• Metal artefacts • Osteophytes (GT osteophytes, sclerosis, cysts, humeral head, and subacromial cysts) • Acromial morphology: Involved in pathogenesis of cuff tears but not predictive of re-tears and low reproducibility

ing hardware and their associated imaging artefacts [47]. MRI or ultrasound scans are targeted at assessing for complications of repair including re-tear, as well as other concomitant conditions resulting in pain such as adhesive capsulitis.

In our centre, imaging post-cuff repair is usually done when patients are symptomatic, presenting with prolonged pain, weakness, scores that are not improving or worsening, or after any new trauma. If such imaging is done routinely, as previously discussed, caution is required when interpreting imaging within 3 months post-repair as appearances may appear more sinister due to acute reactive changes [16, 17]. It is recommended that any routine imaging like MRI or ultrasound be done at least 6 months after cuff repair.

CT scans are not common in the usual work-up for failed cuff repairs, but can show the osseous changes similar to a plain radiograph with greater spatial resolution, including visualisation of bony tunnels in a transosseous rotator cuff repair, location of suture anchors with respect to tendon insertion, muscle atrophy, and fatty infiltration. There may be apparent muscle enlargement with lateralisation of the muscle-tendon unit after a repair. Effusion can be detected by the presence of fluid in the glenohumeral joint. Heterotopic ossification may be visualised with greater resolution compared to a plain radiograph. CT scans can be used to plan for revision of a failed rotator cuff repair to an arthroplasty [28].

With the use of intra-articular contrast in CT arthrogram, the thickness of the rotator cuff tendon can be assessed. Leakage of contrast from the glenohumeral joint into the subacromial space would be indicative of a rotator tear. However, the absence of contrast leakage across a tendon may not exclude a failed repair as this may represent scar tissue. Likewise, the presence of contrast leakage across a tendon may not represent a failed repair as the repair may not be watertight across the footprint. Delaminated tears can be detected by layering of contrast. Absence of subacromial peribursal fat may be a sign of a previous bursectomy. The articular cartilage can be assessed and this, in the setting of a failed rotator cuff repair, may affect the decision between an attempt at revision of a failed rotator cuff repair or an arthroplasty [28].

7.6 The Diagnostic Value of Imaging: Is there a re-tear?

The aim of postoperative imaging in symptomatic patients is to investigate for complications. Complications that can be detected on imaging

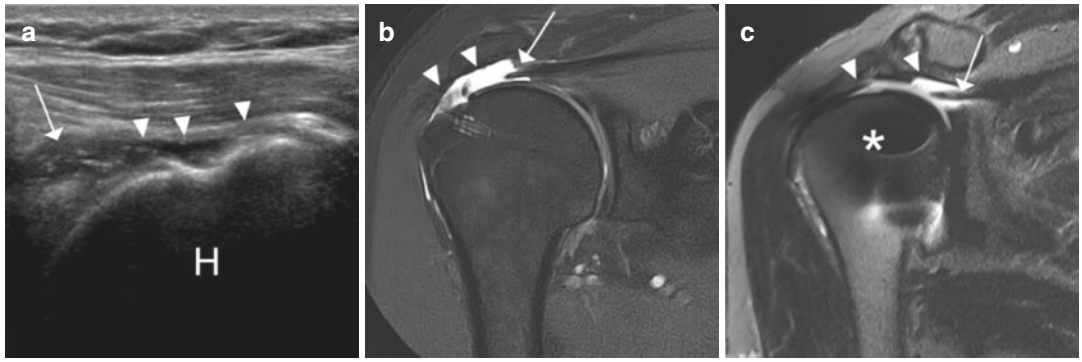

Fig. 7.10 Recurrent tears seen on imaging. (**a**) Longitudinal B-mode ultrasound and (**b**) coronal oblique T2-weighted fat suppressed MRI images of the same patient post supraspinatus tendon repair demonstrates a large fluid defect (arrowheads) in keeping with re-tear/Sugaya grade V. The tendon stump is retracted medially (arrows) and appears like a type 1 re-tear. *H* humeral head. (**c**) Coronal oblique T2-weight fat suppressed MRI with metal artefact reduction protocol of another patient reveals a re-tear of the repaired tendon (arrowheads) with retracted of the tendon medially (arrow) and a stump of tendon at the footprint, making it a type 2 re-tear. Metal susceptibility artefacts (*) from metal anchor within the humeral head

include recurrent tendon tear, suture displacement, subacromial spur formation, infection, adhesive capsulitis, deltoid detachment, heterotrophic ossification, and acromial fracture [11, 28]. Any fluid-filled full-thickness defect within the tendon (approximating Sugaya and Barth grade IV and V) in a symptomatic patient that is not seen on preoperative imaging is **suspicious for a re-tear** [10, 28]. Defects larger than 1 cm or with medial retraction of proximal tendon (approximating Suyaga and Barth grade V) are more likely to **represent re-tears** [8, 10]. Muscle atrophy and fatty infiltration may also provide clues to re-tear, as studies show patients with failed repair are found to have substantial progression of muscle degeneration [11].

Two patterns of cuff repair re-tears have been described (Fig. 7.10). Type 1 re-tears occur due to failure at the bone-tendon junction, while type 2 re-tears occur medially, approximately 2 cm medial to the tendon insertion at the myotendinous junction, resulting in a cuff of remnant tissue still attached to the greater tuberosity. It is theorised that Type 1 re-tears occur early in the postoperative phase and are secondary to the mechanical failure of bone-tendon fixation, whereas type 2 re-tears occur secondary to failure of biological healing [48].

7.7 The Forensic Value of Imaging: Why Did the Repair Fail?

Re-tears are known to occur between 11% and 68% of patients after cuff repair [5, 6]. Broadly speaking, causes of failed cuff repairs can be classified into three categories: (1) failure of healing, (2) technical errors, and (3) traumatic failure [49]. However, it is important to note that the majority of failed cuff repairs are multifactorial in aetiology and numerous factors can be identified as contributing to the failure of any one cuff repair. Imaging can help uncover possible causes of the failure of cuff repair. These include:

1. **Size of original tear**
   Le et al. [50] found the greatest predictive factor for recurrence of tears to be the size of the original tear, specifically, the anteroposterior and mediolateral dimensions of the tear, with tears with a larger anteroposterior dimension and higher grade tears to be at greater risk.
2. **Poor tissue quality**
   Recurrence of tears is related to failure of tendons to heal, and this in turn is due to poor tissue quality [15]. But can tissue quality be assessed by imaging? One surrogate of tissue quality could be thinning of the repaired tendon.

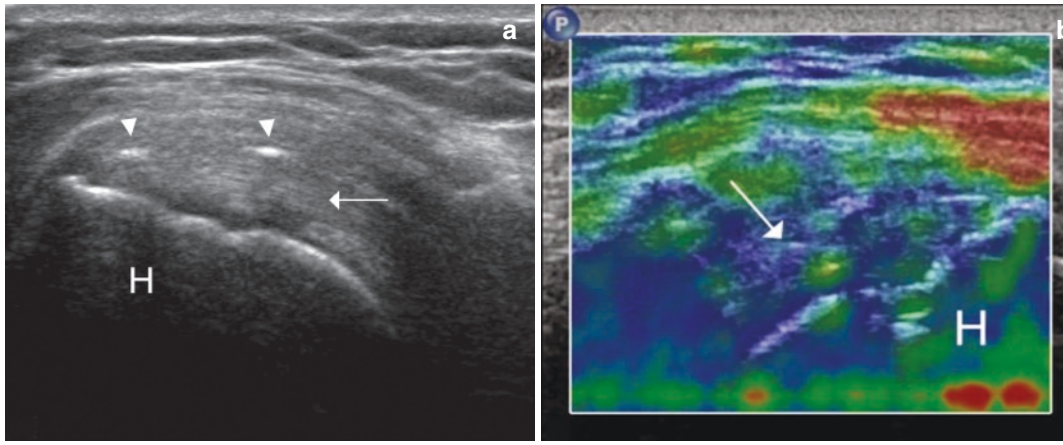

Fig. 7.11 Ultrasound elastography. (**a**) Longitudinal B-mode and (**b**) longitudinal axial-strain elastography ultrasound images of a normal supraspinatus tendon post repair (arrows). The tendon demonstrates fibrillated echotexture with adjacent repair sutures (arrowheads). Absence of focal red colour overlay within the tendon on elastography signifies no abnormal softening of the repair tendon. *H* humeral head

Thinning of tendons and disorganisation of collagen fibres, presence of granulation tissue, increased levels of glycosaminoglycans, fibrocartilaginous metaplasia, calcification, fatty infiltration, and necrosis of the tendon margin with cell apoptosis, along with biochemical changes, are all histopathological hallmarks of degeneration that occur in cuff tears [51].

In a study of 63 patients above 70 years of age who underwent cuff repair, Zhang et al. found smoking and thinner cuffs (<4 mm) were found to be associated with poorer two-year outcomes in terms of Constant and Oxford Shoulder scores independent of age, comorbidities, duration of symptoms, and tear sizes [52]. This suggests that in elderly patients, tendon thickness of 4 mm could determine good to poor outcomes. However, the critical tendon thickness below which the tendon quality is detrimental and re-tears are likely to happen, is still unknown.

Blood supply to the repaired tendon could be another factor to affect tissue quality and hence tendon healing. Vascular flow in and around the repaired tendon has been investigated with contrast-enhanced power Doppler ultrasound [53, 54]. The repaired tendon itself is typically avascular. The peritendinous region demonstrates the most hypervascularity, which is more prominent immediately post repair and decreases with time. This is postulated to represent conduit of blood flow in the peritendinous region, which is thought to promote healing. However, there is currently no convincing data correlating tendon or peritendinous vascularity with clinical outcomes or re-tear rate [17].

Newer axial-strain or shear-wave ultrasound elastography techniques (Fig. 7.11) are potentially useful adjuncts to assess tendinopathy and tendon healing by quantifying differential stiffness of tendons [55]. Early investigations into the temporal evolution of the repaired tendon demonstrate high elastic modulus immediately post repair, which subsequently decreases as tendon heals [56]. This may provide more information about tendon quality, but further studies for validation is required.

3. **Muscle Atrophy and Fatty Degeneration**
Chronic cuff tears undergo muscle atrophy with time and subsequently, undergo fatty infiltration. These changes profoundly affect the functional outcome after cuff repair [57]. Poor clinical outcomes after surgery were correlated with increasing muscle atrophy and fatty infiltration [58]. Cuff repairs that healed reported no progression or even improvement of the muscle atrophy, while in failed repairs, there was reported substantial progression of muscle atrophy and fatty

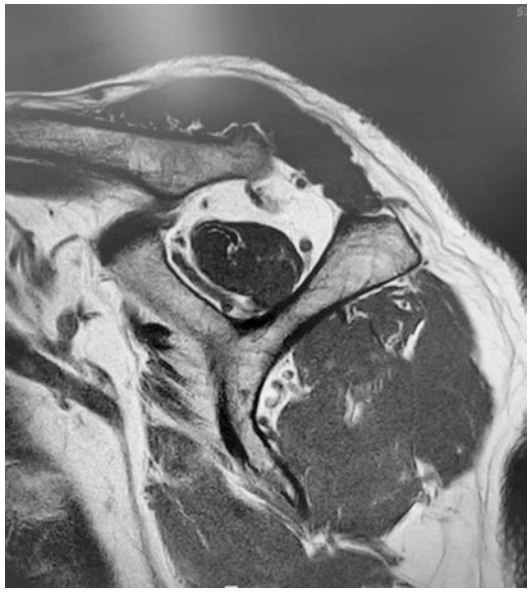

Fig. 7.12 Muscle atrophy on MRI sagittal views. In this example of a recurrent cuff tear, the sagittal views of the MRI show significant atrophy (Goutallier 3) of the supraspinatus and infraspinatus muscles with fatty infiltration

infiltration [57]. Thus, the quality of the cuff muscles and fatty infiltration needs to be evaluated before revision surgery is decided, underscoring the importance of imaging in the work-up of the failed cuff (Fig. 7.12). There could exist a "point of no return" where the atrophic changes the muscles have undergone are irreversible [57] in which case revision repair may be unsuccessful. As per Savoie et al., this point could be Goutallier stage 3 [59].

4. **Implant failure and suture breakage**
   While the incidence of suture breakage causing cuff failure is low, it is noted earlier that healing rates of tendon correlated with bone mineral density, with higher rates of failure in patients with osteopenia and osteoporosis [40]. In patients with low BMD, the anchor could loosen or pull-out before adequate tendon-bone healing could take place, compromising the strength of the cuff repair and possibly leading to failure (Fig. 7.13) [27].

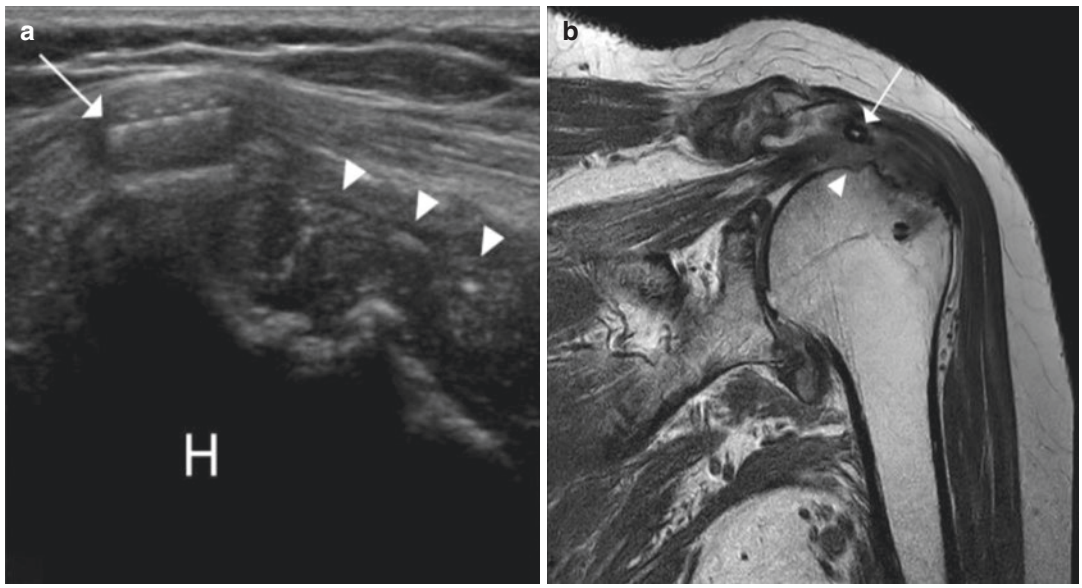

Fig. 7.13 Failed cuff repair due to implant pull-out. (**a**) Longitudinal B-mode ultrasound and (**b**) coronal oblique PD-weighted MRI images of the same patient post supraspinatus tendon repair. Fractured tendon anchor (arrows) is dislodged into the subacromial space. Granulation tissue formation within the defect of the supraspinatus tendon (arrowheads) in keeping with re-tear

7.8 The Prognostic Value of Imaging: What Can Be Done?

Imaging plays an important role in the work-up of the failed cuff repair. From plain radiographs to advanced imaging such as MRI, CT scans, or ultrasounds, imaging is instrumental in aiding the clinician in diagnosing the causes of failed cuff repair, the possible causes of failure of tendon healing, and subsequently, the surgical options available based on the evidence gathered so far. Figure 7.14 proposes a treatment algorithm based on clinical and radiological findings. A thorough clinical history and examination is the initial step. Evidence for diagnoses of infections and capsulitis are gathered at this stage and other investigations with appropriate treatment may need to be started, if indicated.

The initial question would be answered with plain radiographs, which assesses for evidence of arthritis (Hamada stage 4 or more). If there is gross arthritis in the presence of failed cuff repair, then a reverse shoulder arthroplasty is warranted [43]. If there is no or minimal arthritis, then what would drive the decision-making is the presence and size of re-tears and the severity of muscle atrophy with fatty infiltration. If there are changes such as signal intensity, small gaps, and thinning of the tendon with no discernible tear >10 mm (Sugaya 1–3), then the patient would benefit from physiotherapy and may benefit from PRP injections [1, 60], stem cell injections [60], and biological augments [60], as such changes may be partly physiological and not necessarily pathological [8, 10, 11, 20].

Tears >10 mm in a symptomatic failed cuff repair warrant surgical intervention [58]. Revision surgery can be done with good results, with a view to perform biceps tenotomy/tenodesis if not done already and revision acromioplasty [1]. The role of biological augments in this group of patients with failed cuff repairs is controversial [60]. In larger tears (3–5 cm) with minimal muscle atrophy (up to Goutallier 3), a partial repair can be attempted, with possible use of patches and balloon spacers. In massive tears (>5 cm) with significant muscle atrophy (Goutallier 3 and

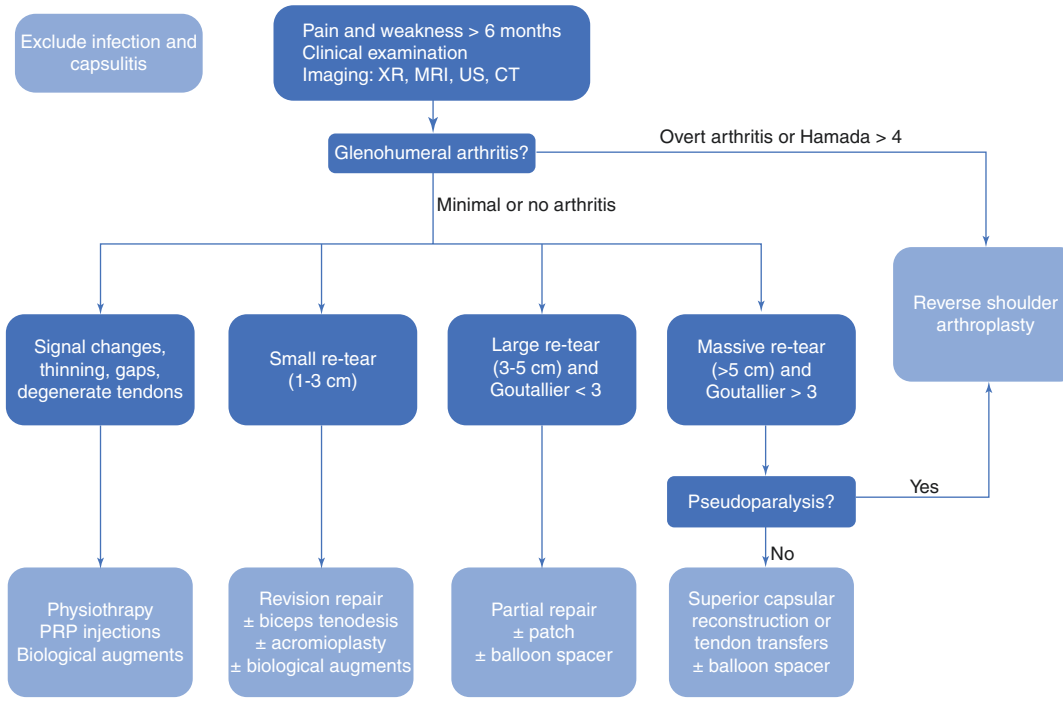

Fig. 7.14 Suggested algorithm based on clinical findings and imaging studies

above), the decision rests on the presentation of pseudo-paralysis. If there is some degree of elevation and rotation is present but weak, consider a superior capsular reconstruction or the appropriate tendon transfer. If pseudo-paralysis is evident, then a reverse shoulder arthroplasty is thus indicated [1].

The radiological criteria of irreparable rotator cuff tears are a fixed high-riding humeral head, an AHI <5 mm, a non-functioning deltoid muscle, and severe rotator cuff muscle atrophy and fatty infiltration [61].

7.9 Conclusion

Imaging plays a vital role in the postoperative evaluation of the failed rotator cuff. Findings that are diagnostic for abnormalities before surgery may actually be expected changes in the postoperative setting and may not correlate with worsened symptoms clinically [61]. Plain radiographs can shed information on pathogenesis of tears and may have bearing on recurrence of tears. Advanced imaging like MRI, CT scans, and ultrasounds are the key modalities in diagnosing tear recurrences, reveal possible causes of failure, and guide surgeons on surgical options available. The role of the radiologist who understands the expected postoperative findings after rotator cuff repair and correlates these changes with the surgery performed would be critical to the team and would add immense value to patient care.

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8 Biomechanics of Failed Rotator Cuff Repair: How to Optimize Anchor and Suture Placement

Eiji Itoi and Nobuyuki Yamamoto

8.1 Introduction

Surgical techniques for rotator cuff repair have improved from single-row repair to double-row repair including transosseous-equivalent repair as new surgical devices and suture anchors have been developed. When we repair a rotator cuff tear, we expect the healing of the cuff tendon to the bone. However, re-tears are reported to occur in 11%–94% of repairs [1–3]. It is well known that re-tear rate is much higher (25%–70%) in large to massive tears than in small to moderate tears [4, 5]. In order to reduce the re-tear rate, we need to know what the causes of re-tears are. The causes of re-tears can be divided into three groups from the structural viewpoint: (1) pullout of suture anchors from the bone, (2) breakage of the sutures, and (3) the tendon pulling through the sutures. Cummins and Murrell investigated the mode of failure after rotator cuff repair in 342 consecutive patients who underwent primary rotator cuff repair using suture anchors [6]. The predominant mode of failure was tendon pulling through sutures (86%). This was also confirmed in a biomechanical study, showing that 94% of failure occurred at the tendon [7]. The suture anchor pullout was far less common, ranging from 2.4% to 4.5% [6, 8]. Suture materials are so strong that suture breakage is not a clinical concern [6]. Thus, most failures occur at the tendon-suture interface, causing the tendon to pull through the sutures. We cannot change the quality of the tendon tissue. In order to secure the construct of suture bites through the tendon, there are various techniques introduced with increased number of sutures or using tapes instead of sutures to make the contact area wider and the contact stress lesser. In this chapter, we describe how to avoid a re-tear after rotator cuff repair focusing on suture placement, anchor insertion, and assessment of bone strength.

8.2 How to Optimize Suture Placement

In the 1990s, the sutures were already much stronger than the tendon tissue. As a result, how to bite the tendon to create the strongest construct has been a major issue. The modified Mason-Allen, the most commonly used technique during open procedure, is known to be the strongest construct against the tendon tissue [9]. In order to avoid suture breakage during surgery, the sutures have become even stronger these days. The modified Mason-Allen technique is easy to perform during open procedure, but it is more complicated during arthroscopic procedure [10–12]. Another method to decrease a risk of tendon

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cutout is to increase the number of sutures or to make the suture wider to decrease the stress at the suture-tendon interface. Doubling the number of sutures and suture anchors is known to improve the biomechanical parameters [13]. For the purpose of decreasing the stress at the suture-tendon interface, suture tapes have been developed. Liu et al. compared a No. 2 suture (FiberWire®; Arthrex) versus a tape (FiberTape®; Arthrex) using the same repair construct of transosseous-equivalent double-row repair [14]. The average ultimate failure load of tape repair was 217 N, which was significantly greater than that for suture repair (144 N). These biomechanical data seem to be quite favorable for cuff repair. Zhang et al. also reported that a custom-made mesh suture with 1.7-mm diameter showed a significantly greater ultimate failure load than polydioxanone suture II/0 (PDS® II/0; Ethicon) or FiberWire® suture 0 (Arthrex) [15]. However, the clinical outcome of 150 consecutive patients treated with either sutures (100 patients) or tapes (50 patients) did not show any significant difference [14]. The re-tear rate of tape repairs (16%) was almost the same as that of suture repairs (17%). The authors mentioned that there were more factors at play than initial repair construct strength regarding healing of the rotator cuff tendon.

8.3 Biomechanics of Repair Construct

There are three types of repair constructs for rotator cuff tears based on the number of rows of suture anchors: single-row repair, double-row repair, and triple-row repair. The double-row repair construct is further divided into two types: standard and transosseous-equivalent (TOE) double-row repairs. There are several systematic reviews comparing the single-row versus double-row [16–18]. Based on these reviews, tendon healing is better in double-row repair than single-row repair although the clinical outcomes are the same. Regarding the triple-row, the data are too limited to make any decisive conclusion at this point [18].

Among the double-row repairs, TOE repair is more widely used than the standard repair. There are several biomechanical studies of various configurations of TOE repairs with or without augmentation stitches [15, 19–25]. Most reports showed that various types of reinforcement sutures at the medial-row level or doubling the number of sutures between the medial- and lateral-row anchors made the repair constructs stronger than the standard TOE repair, [19, 24, 25] but others showed that there was no biomechanical difference between those with and without medial-row reinforcement [26]. A single-row repair using triple-loaded anchors was reported to be better in gap formation compared to a TOE repair using double-loaded anchors although no difference was observed in the ultimate failure load [20]. A consensus on the desirable repair construct is yet to be achieved.

When performing a TOE repair, medial-row sutures are tied over the tendon and then pulled laterally to the lateral-row anchors. Maguire et al. compared two types of TOE repairs: TOE repair with tied medial-row sutures versus untied ones using ovine shoulders [21]. There were no significant differences in the ultimate failure load, contact area, and gap formation between them. On the other hand, Wu et al. reported that the ultimate failure load was significantly greater in the TOE repair construct with tied medial-row sutures than untied ones in human cadaveric shoulders [27]. In this study, all failures occurred at the tendon-to-bone attachment, or the so-called type 1 re-tear, and no type 2. Thus, it is still controversial whether we should tie the medial-row sutures or not. A finite element model analysis revealed that the tied medial-row sutures showed a significantly higher stress concentration in the cuff tendon around the medial-row sutures than untied ones (Figs. 8.1 and 8.2) [28]. We measured the strain of infraspinatus tendon after TOE repair with and without tying the medial-row sutures and compared them with the normal tendon using human cadaveric shoulders [29]. We found that the strain of the proximal tendon was significantly higher with tied medial-row sutures than that with untied ones or the normal tendon. On the other hand, the strain of the distal tendon

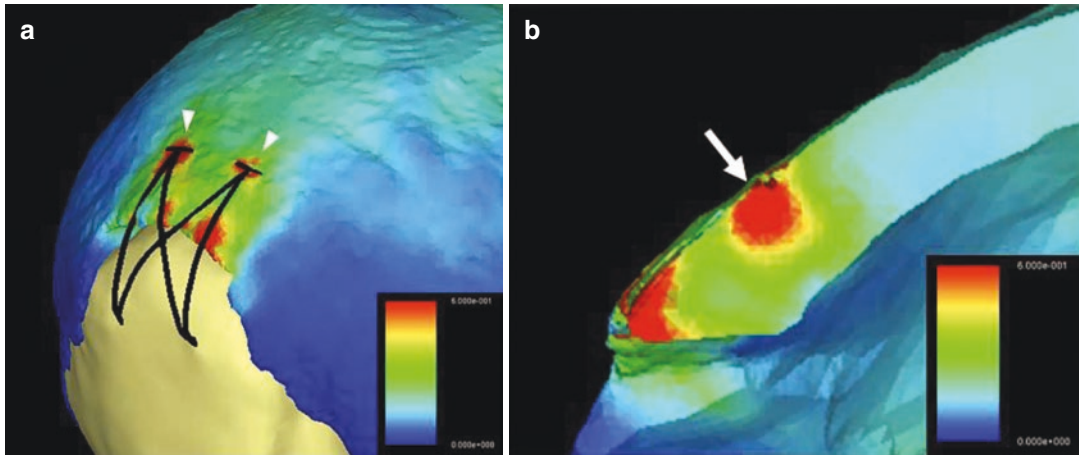

Fig. 8.1 Stress distribution in the knotted TOE repair. In the anterolateral view (**a**), a high stress concentration is observed on the bursal side of the tendon around the knots (arrow heads). In the coronal cross-section of the supraspinatus tendon (**b**), a high stress concentration is observed around the medial-row sutures in the bursal half of the tendon (arrow). Reprinted from Sano et al. [28], with permission from IOS Press

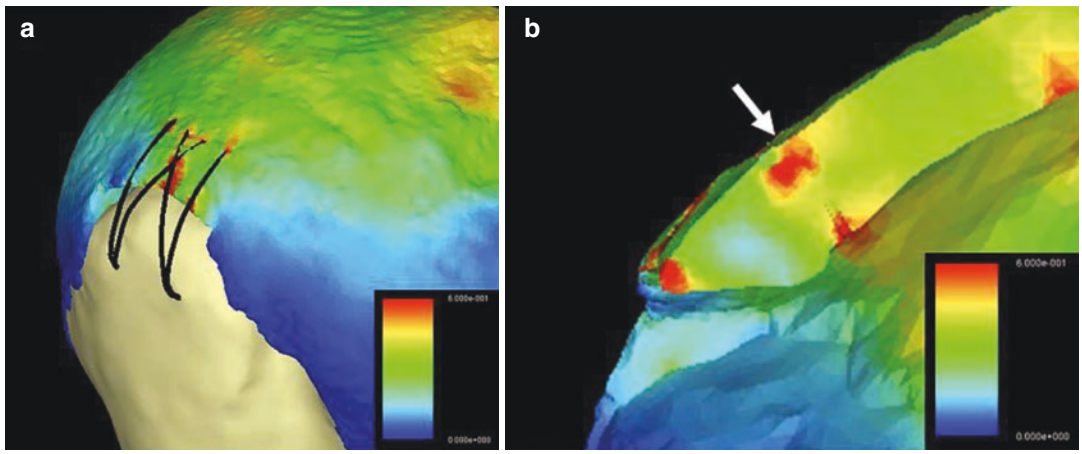

Fig. 8.2 Stress distribution in the knotless TOE repair. In the anterolateral view (**a**), little stress concentration is observed on the bursal surface of the tendon. In the coronal cross-section of the tendon (**b**), a stress concentration much lower than that in the knotted TOE repair was observed around the medial-row sutures in the bursal half of the tendon (arrow). Reprinted from Sano et al. [28], with permission from IOS Press

with and without tying the medial-row sutures showed significantly lower strain than the normal tendon. As a result, there was a greatest strain gap between the proximal and the distal tendons at the level of medial-row sutures when they were tied. This might be related to a failure at the medial-row level, known as a type 2 re-tear. After TOE repairs with tied medial-row sutures, 74%–80% of re-tear was reported to be type 2 [12, 30]. A recent biomechanical study showed that the ultimate failure load was significantly higher in the TOE repair construct with untied medial-row sutures than tied ones [31]. As the authors of this study used a silicone rubber to simulate the rotator cuff tendon, all failures occurred at the medial-row level, simulating a type 2 re-tear, which was different from the other previous biomechanical studies. They concluded that the repair construct without tying the medial-row sutures was expected to help reduce the preva-

lence of type 2 re-tear. We perform TOE repairs without tying the medial-row sutures. In our series of 23 TOE repairs, there was one failure (4%), which was type 1 (unpublished data). Untying the medial-row sutures might be helpful to avoid a type 2 re-tear. This needs to be further confirmed in large-scale clinical studies.

8.4 How to Optimize Anchor Insertion

The deadman theory is well known as a guidance how to insert a suture anchor [32]. According to this theory, both θ_1 (inclination of the suture relative to suture anchor) and θ_2 (inclination of the suture through the tendon relative to the bony surface) should be equal to or less than 45° (Fig. 8.3). There is no controversy on θ_2. There is consensus that the suture passing through the cuff tendon should be around 45° when the tendon is pulled proximally and comes to equilibrium.

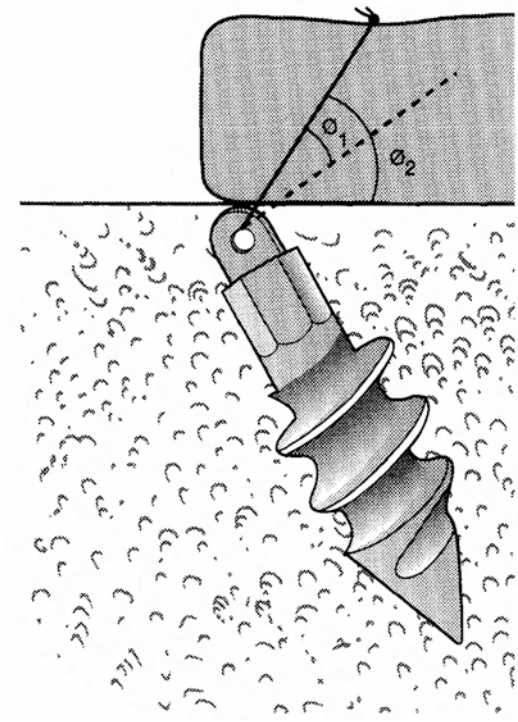

Fig. 8.3 Deadman theory. Both θ_1 and θ_2 should be equal to or less than 45°. Reprinted from [32], with permission from Elsevier

However, θ_1 has been controversial. Based on the deadman theory, it is widely believed that an anchor should be inserted at 45° to the bony surface to achieve the greatest pullout strength. Contrary to this belief, all the biomechanical studies showed the opposite result: the pullout strength was the weakest when inserted at 45°. There has been a heated debate about θ_1 [32–40]. On the one hand, inserting a tent peg at 45° to the ground or perpendicular to the tent rope is what we usually do and what we intuitively believe is correct. On the other hand, the biomechanical studies have shown that it is not true. How can we explain this discrepancy between what we do with a tent peg and what the biomechanical studies have shown? A clear difference between a tent peg and a suture anchor is the friction. The friction between a tent peg and the ground is very small, whereas the friction between a suture anchor and the bone is quite large. We hypothesized that the friction might influence a relationship between the insertion angle and the pullout strength. We performed biomechanical studies using both the threaded and thread-less anchors to prove our hypothesis [41–43]. In these studies, we found that when the friction was very low such as the tent peg, the greatest pullout strength was obtained when it was inserted perpendicular to the suture (tent rope) or 45° to the surface (ground) [41, 43]. However, when the friction was very high such as a suture anchor, the anchor should be inserted perpendicular to the bony surface or 135° to the line of pull to achieve the maximum pullout strength regardless of bone strength [41, 42]. Whenever we insert a suture anchor to the bone, it should be inserted perpendicular to the bony surface.

Another issue related to suture anchor is the safe distance between two suture anchors. It has anecdotally been believed that two suture anchors should be separated at least 10 mm apart from achieving the best performance. However, there is no evidence to prove this belief. We measured the minimum distance of suture anchors without decreasing the pullout strength using both a metal screw-type anchor (TWINFIX™, 5.0 mm Ti; Smith & Nephew, Andover, MA) and a PEEK coil-type anchor (HEALICOIL™ PK, 4.5 mm;

Smith & Nephew, Andover, MA) [44]. We measured the pullout strength of a pair of suture anchors inserted perpendicular to the surface of Sawbones and parallel to each other with a center-to-center distance of 4, 6, 8, and 10 mm. We found that the pullout strength was significantly lower with the center-to-center distance of 4 mm, but no difference among 6 mm and above. We concluded that 6 mm (center-to-center) was the minimum distance of suture anchors without decreasing the pullout strength in both the metal screw-type anchors and PEEK coil-type anchors.

8.5 Assessment of Bone Strength

Bone strength correlates well with the pullout strength of suture anchors [45]. Because of this, we need to assess the strength of the bone to predict a risk of anchor failure. We compared two groups of patients who underwent rotator cuff repair: 15 patients with no anchor failures (stable anchor group) and 5 patients with anchor failure during or immediately after the surgery (failed anchor group) [46]. Preoperative CT scanning had been performed using a bone mineral reference phantom in all the patients. Based on the CT data, 3D finite element model was created to estimate the pullout strength of a suture anchor (TWINFIX™, 5.0 mm; Smith & Nephew Endoscopy KK, Tokyo, Japan). The failure load in the failed anchor group was 70.3 ± 25.6 N (mean ± standard deviation), which was significantly lower than that in the stable anchor group (119.0 ± 28.3 N; $p < 0.0001$). The receiver operating characteristic curve showed that the optimum cut-off value of the failure load was 75.4 N. When the bone strength is estimated to be too weak to hold the suture anchors, we repair the cuff without using suture anchors. Transosseous repair with mini-open, open, or arthroscopic technique is one solution. Several arthroscopic transosseous repair technique have been reported such as a customized drill guide, [47] ArthroTunneler (Tornier Inc., Edina, Minnesota), [48] the anterior cruciate ligament (ACL) guide (Acufex Director ACL system; Smith & Nephew, Andover, MA), [49] Taylor Stitcher (TS) bone tunneler (NCS Lab Srl, Modena, Italy), [50] and Omnicuff (Mininvasive Ltd., Magal, Israel) [51]. We take CT scan in elderly patients to estimate the failure load. If the failure load is calculated to be less than 75.4 N, we use mini-open transosseous repair with Endobuttons™ (Smith & Nephew Endoscopy KK, Tokyo, Japan) between the sutures and the lateral cortex of the humerus. The knots are tied over the Endobuttons™. Based on this estimation, we have used mini-open transosseous technique with Endobuttons™ in 8 patients (8%) out of 101 primary rotator cuff repairs. So far, we have experienced no anchor failures (unpublished data).

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Part II

Soft Tissue Procedures for the Failed RCR

9 Debridement and Long Head of the Biceps Tenotomy in Revision Rotator Cuff Tears

Daniel P. Berthold, Lukas N. Muench, Augustus D. Mazzocca, and Knut Beitzel

9.1 Introduction

Several treatment options are available for shoulders surgeons when facing massive, irreparable defects of rotator cuff tendons, especially in the case of revision surgery. The surgical approaches include debridement, [1] tenotomy of the long head of the biceps, [2–5] partial repair, [3, 6–8] tendon transfers, [9–13] rotator cuff augmentation/grafting or reconstruction with various kinds of patches, [12, 14–23], subacromial balloon spacer, [18, 24, 25] or reverse total shoulder arthroplasty [12, 18, 26–30].

Historically, one of the most commonly used options in the late 1990s included debridement of the edges of the necrotic tendon along with decompression of the subacromial space and acromioplasty [31]. With more sophisticated treatment options emerging in the past decade and yielding good functional outcomes, debridement and tenotomy of the long head of the biceps may have lost its momentum. However, debridement and tenotomy, often labeled as a salvage procedure or limited goals surgery [32], are significant potential downsides in terms of costs, reliability, morbidity, and come along with low complications profiles and activity limitations [33]. Recently, data from Ho et al. demonstrated good mid-term outcomes of arthroscopic debridement for irreparable rotator cuff tears, thus being suggested as a reasonable option for a difficult-to-treat patient population [33].

9.2 Indications

Choosing the appropriate treatment option highly depends on patient age, comorbidities, activity level, and extent of the disability [34]. First of all, a detailed physical examination and accurate radiographic imaging are key for a correct assessment of the severity of the injury. Patients with severe rotator cuff deficiency often present with severe pain including poor sleep quality and decreased shoulder function, resulting in decreased ability to perform activities of daily living [2, 35, 36]. A complete physical examination including examination of the glenohumeral joint, sternoclavicular joint, cervical spine, and

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ipsilateral upper extremity along with a complete neurovascular exam is necessary to assess the presence of concomitant injuries. A detailed neurovascular examination should be performed to rule out any rare diseases to the brachial plexus or brachiocephalic vessels. Radiographic analysis usually shows a decreased acromiohumeral distance along with severe muscle atrophy, fatty infiltration, and retraction of the rotator cuff muscles [37–40].

When the patient presents with a rotator cuff re-tear, it has to be considered if revision rotator cuff reconstruction is feasible or not. If the re-tear is deemed repairable, rotator cuff reconstruction should be performed to restore the native joint kinematics. If the re-tear is considered massive and irreparable even with advanced arthroscopic techniques, partial repair, tendon transfer, arthroplasty, and graft augmentation have been proposed [13, 18, 25, 30, 41–48]. When advanced fatty infiltration of the rotator cuff muscles including loss of tendons and significant superior head migration are present, debridement, acromioplasty, and tenotomy might be indicated in the elderly patient [2]. The advantages of these less invasive interventions comprise significantly decreased costs, less morbidity, fewer activity limitations, and lower complication profiles [33]. Additionally, patients with irreparable rotator cuff tears presenting with retained overhead elevation without significant osteoarthritis or evidence of pseudoparalysis may not meet the criteria for reverse shoulder arthroplasty [3]. Thus, debridement and tenotomy might also be indicated in these patients to preserve the remaining force couple and to treat any pain source in the shoulder [7]. Further, this technically less-demanding procedure does not adversely affect any necessary, future salvage procedure. Additionally, if a rotator cuff reconstruction is not feasible in elderly patients having significant medical comorbidities which preclude undergoing a major surgery such as reverse shoulder arthroplasty, arthroscopic debridement might be more suitable in these patients.

9.3 Technical Aspects of Debridement and Tenotomy

Lesions of the long head of the biceps are often associated with massive, irreparable rotator cuff tears and can be a source of chronic shoulder pain [2, 4, 49]. The lesions include tendinitis and hypertrophy, subluxation, delamination, or dislocation from the medial rim of the bicipital groove [2, 49]. Historically, Walch et al. first described an arthroscopic approach for long head of the biceps tenotomy as a simple procedure in patients with massive, irreparable cuff tears [50]. Since then, various approaches for tenotomy as well as tenodesis of the long head of the biceps have been described.

Compared to biceps tenodesis, biceps tenotomy is less technically demanding, has lower morbidity and has been shown to achieve similar functional outcomes [5]. However, the patient needs to be educated about the possibility of a Popeye deformity, which might come along with subjective fatigue and discomfort. Biomechanically, a slight decrease in overall flexion may be expected.

9.4 Surgical Technique

Debridement and long head of the biceps tenotomy can be performed using open, mini-open or all-arthroscopic techniques, with the trend shifting towards arthroscopic techniques. The authors' favored technique is performed all-arthroscopic. After induction of general anesthesia, the patient is positioned in beach-chair position. Previous, inappropriately placed arthroscopic portals should be re-established and not re-used. The arm is placed in a movable arm holding device and landmarks are being marked.

The surgical procedure starts with a diagnostic arthroscopy of the glenohumeral joint using a standard posterior portal. With the arthroscope in the posterior portal, a standard anterior portal is established through the rotator interval under direct

visualization using a spinal needle. Subsequently, a systematic diagnostic arthroscopic evaluation is performed, and the preoperative indication is confirmed. If the rotator cuff is deemed unrepairable (Fig. 9.1), complete bursectomy and arthroscopic debridement can be performed. These include lavage, synovectomy, removal of moderate osteophytes, debridement of degenerative labrum pathology and rotator cuff tissue, as well as the removal of loose bodies. Acromioplasty or distal clavicle excision can be considered, but care has to be taken to avoid overaggressive acromial or clavicle resection, which may result in instability. The goal of acromioplasty should be to convert the shape of the acromion from type III to type I according to Bigliani [51, 52].

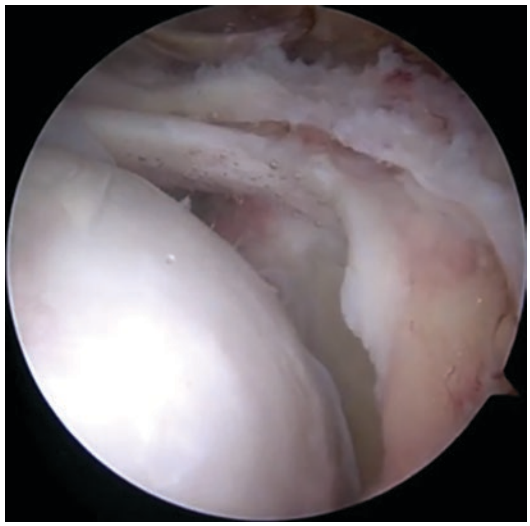

Fig. 9.1 Figure displaying a retracted, irreparable supraspinatus tear

Biceps tenotomy is performed by releasing the tendon at its origin on the superior glenoid labrum, allowing the distal end of the tendon to retract into the bicipital groove. Care has to be taken to carefully debride the insertion of the long head of the biceps on the supraglenoid tubercle to limit all future pain sources. Debridement of chronic, partial, or massive rotator cuff tears may reduce pain symptoms by the elimination of a potential inflammation source [53]. The extent of the debridement hereby depends solely on the extent of the pathology and has to be performed and adapted carefully by the surgeon.

If necessary, any scar tissue or adhesions should be removed carefully. If the patient presented with restricted shoulder function due to a stiff shoulder pathology before surgery, circumferential debridement should be considered. Retained sutures (Fig. 9.2), misplaced or dislocated anchors should carefully be removed. If metal anchors were used, they should be considered to be left intact in the bone, as removal

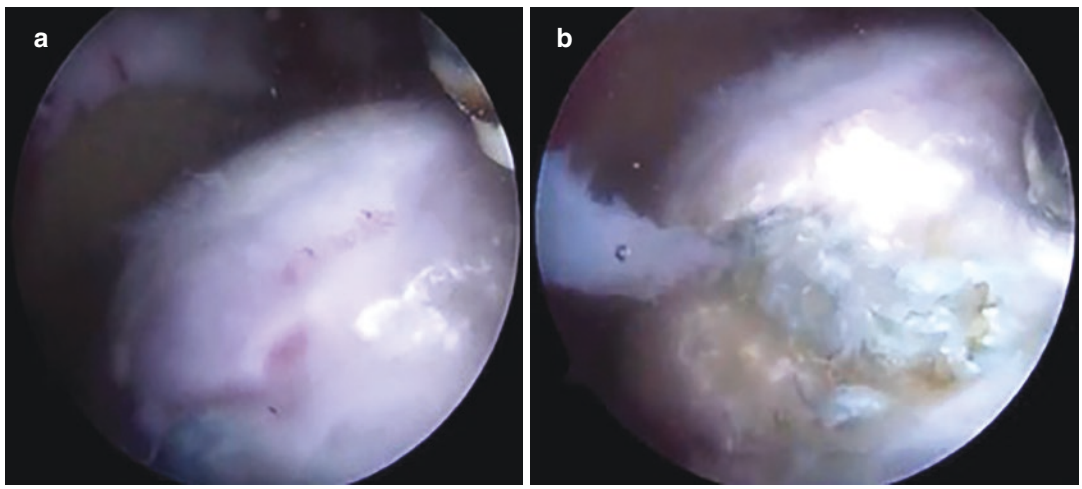

Fig. 9.2 Figure displaying arthroscopic debridement of retained sutures (**a** and **b**) after previous failed rotator cuff repair

may increase the risk of large bone defects within the bone.

If present, small to moderate osteophytes can be removed using an arthroscopic shaver or burr. This procedure aims to remove any potential source of impingement or range of motion restriction of the joint. The most common form of osteophytes is located on the inferior side of the humeral head, making additional use of a low anterior (or posterior) portal necessary. Care has to be taken to avoid any damage to the axillary nerve, by maintaining the instrument intra-articular. If the patient presents flaps of cartilage on the humeral head or the glenoid, these should also be debrided, as they may cause slight pain or might significantly progress over time.

Loose bodies can be removed using an arthroscopic grasper or rongeur. Loose bodies are often located on the axillary pouch or in the subscapularis recess and can be a source of pain by causing locking or blocking symptoms. When retrieving large loose bodies, an appropriate-sized skin incision should be performed.

9.5 Prognostic Risk Factors

Decreased preoperative forward flexion has been shown to predict poor functional results [33]. Additionally, although debridement can eliminate pain and thus may improve shoulder function, it does not restore rotator cuff force couples or improve the biomechanics of the shoulder [33, 54, 55]. Further, it remains highly unlikely, that functional high-demanding patients are benefiting from this procedure. Therefore, these patients might be better indicated for more advanced surgical approaches such as superior capsular reconstruction [20, 21, 56, 57] or reverse total shoulder arthroplasty [26, 30].

9.6 Outcomes

A few mid-term studies for arthroscopic debridement for irreparable RCT have been published over the years, with limited data being available for revision cases. Pander et al. demonstrated significant improvement in subjective pain (87% of the patients), function (85%), and satisfaction (67%) in patients with irreparable rotator cuff tears along with no differences in pre- and postoperative range of motion [58]. Park and colleagues reported significant improvement in pain and clinical outcomes scores in 16 patients after an average 8.2-year follow-up [59]. When comparing debridement to partial repair, Franceschi et al. found significant improvement in both groups, with debridement patients increasing forward flexion from 104° to 132° [60]. These results are comparable to recently published data from Ho et al., showing good mid-term outcomes for this procedure [33]. Hsu et al. reported on 151 patients who underwent a mini-open procedure for unrepaired and failed irreparable rotator cuff tears, and reported 73% of the patients meeting the ASES threshold (MCID: minimally clinically important difference) [61]. Klinger et al. compared patients with arthroscopic debridement alone and debridement plus tenotomy of the long biceps tendon and found significant clinical improvements after a mean follow-up of 2.5 years with no significant differences between study groups [62].

Historically, Fenlin et al. found satisfactory outcomes in 18 out of 19 patients when performing an open debridement technique, [63] similar to Gartsman et al., who reported improved outcomes in 26 out of 33 patients [64]. Rockwood et al. investigated 53 patients for 6.5 years and found improvement in forward flexion (105° to 140°) with worse outcomes in patients with prior open rotator cuff repairs [31].

For the treatment of the long head of the biceps alone, only limited data is available in the current literature. Boileau et al. examined the use of a simple long head of the biceps tenotomy (or tenodesis) for patients with massive irreparable rotator cuff tears and noted that 78% of the patients were satisfied at a mean follow-up of 3 years [2]. Walch et al. reported a satisfaction rate of 87% in 307 patients with massive rotator cuff tears treated by biceps tenotomy alone. However, the procedure did not stop the progression of rotator cuff tear arthropathy [65].

9.7 Summary

Irreparable rotator cuff tears are a difficult problem to address, especially in revision surgery. In the past decade, several surgical approaches have been described to treat these irreparable rotator cuff tears. However, many of these techniques come along with high costs, morbidity, complication profiles and are technically demanding. Arthroscopic debridement and tenotomy of the long head of the biceps is a technically less-demanding procedure and has been shown to achieve good to excellent outcomes in patients with irreparable rotator cuff tears. Although this procedure remains a feasible surgical approach for a difficult-to-treat patient population, indications have to be chosen carefully.

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Revision Repair for the Failed Rotator Cuff

10

Daniel P. Berthold, Lukas N. Muench, and Andreas B. Imhoff

10.1 Introduction

The surgical management of rotator cuff tears (RCT) has risen consistently with continuous evolvement of open and arthroscopic techniques. Over the past decade, the incidence of arthroscopic RCT repairs has increased by almost 600%, whereas the use of open techniques only increased by 34% [1–3]. However, despite high satisfactory rates being achieved with both procedures, current literature still reports a high rate of re-tears ranging between 13% and 80%, mostly depending on the technique used as well as the initial tear size, muscle atrophy, fatty infiltration, and tendon retraction [4, 5]. Additionally, almost 25% of re-tears are observed within the first 2 years after surgery, [6] however, 50% of these patients are still expected to have satisfactory outcomes [7, 8].

When approaching revision RCT, the exact etiology of failed cuff surgery has to be determined. Patients presenting with functional impairment and persistent pain following rotator cuff repair remain a challenge for physicians, as these symptoms may be caused by extrinsic and/or intrinsic factors. However, structural failure does not always result in clinical failure and many patients with partial healing of the repaired cuff will be much improved after surgery, despite remaining residual defects.

Additionally, prognostic and risk factors associated with successful and unsuccessful outcomes after reconstruction of RCTs are poorly understood. Consequently, efforts have recently been focused on identifying subgroups of patients that may benefit from undergoing revision rotator cuff surgery [9].

10.2 Clinical Examination

A detailed physical examination is critical for a correct assessment of re-injury. As the patient often presents with ongoing shoulder pain, weakness, and functional deficits, the focus should be placed on location, intensity, and quality of pain. Extrinsic and intrinsic factors leading to pain, tingling, numbness, or burning sensations need to be carefully evaluated and may indicate a differential diagnosis such as a stiff shoulder, neuropathy, vasculopathy, or joint infection. Additionally, concomitant intra-articular lesions, which have been left unaddressed during primary surgery, have to be excluded.

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When approaching an RC re-tear, the physician needs to evaluate, whether there was a time after the initial intervention when the patient was pain-free or if a new history of trauma might be responsible for the re-tearing condition. Patient compliance and duration of physical therapy and rehabilitation play an important role during preoperative evaluation.

Following the history of the patient, physicians should focus on a thorough physical examination. It is critical to perform a complete physical examination including examination of the glenohumeral joint, sternoclavicular joint, cervical spine, and ipsilateral upper extremity along with a complete neurovascular exam, in order to rule out concomitant injuries. If the inspection reveals ecchymosis or any cardinal symptoms of an inflammatory reaction, a postoperative infection has to be excluded. A detailed neurovascular examination of the upper extremity can hereby exclude any possible brachial plexus lesions or more rare vasculopathies such as thoracic outlet syndrome. Further, the shoulder girdle should be evaluated for the presence of muscle atrophy. Active and passive range of motion (ROM), as well as scapulothoracic motion, need to be assessed. The presence of any scapular dyskinesia such as scapular winging or scapula alata is of great importance, as it may cause chronic shoulder dysfunction and/or pain.

10.3 Radiographic Examination

In addition to a thorough clinical exam, a detailed radiological evaluation is required. Besides, imaging prior to primary surgery should be further evaluated regarding initial tear size, muscle atrophy, fatty infiltration, tendon retraction, and concomitant intra-articular pathologies. Plain AP, y-view, and axillary radiographs might help in determining the extent of the rotator cuff pathology with the main focus on superior humeral head migration, bony disorders, and anchor misplacement or migration (Fig. 10.1) [10].

MRI scans may be useful for detecting concomitant injuries of the glenohumeral joint as well as determining the extent of the re-tear and quality of the involved tendons [11] although postoperative MRI is difficult to interpret, as only 10% of reconstructed tendons generate a normal MRI signal (Fig. 10.2) [10, 12]. Tissue remodeling and fibrous tissue may produce an intermediate signal within the tendon and can persist for

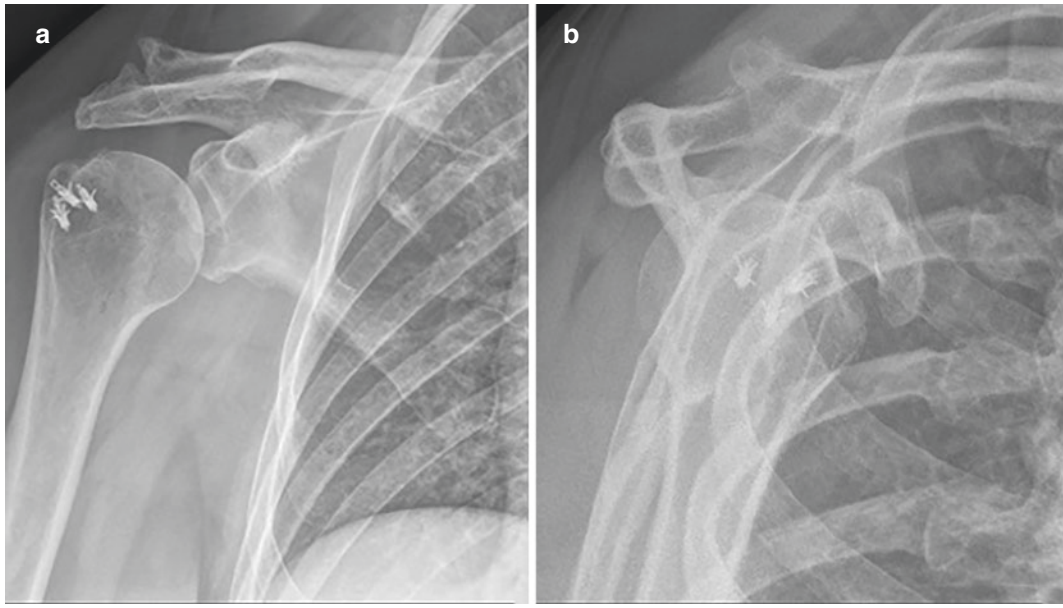

Fig. 10.1 Figure displaying (**a**) a.p. radiographs and y-view (**b**) of a patient with failed primary rotator cuff repair

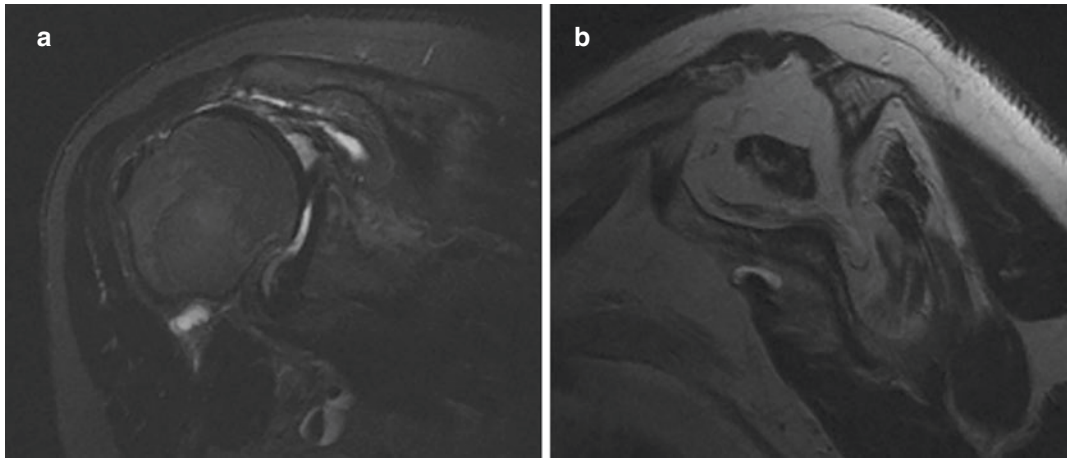

Fig. 10.2 (**a**) MRI showing a retracted torn supraspinatus tendon with (**b**) severe atrophy of the muscle belly

6 months following repair [10, 12, 13]. Additionally, fluid leakage into the subacromial space (after opening the rotator cuff interval) or (metal) artifacts may be observed [10]. Thus, intra-articular contrast might be helpful to evaluate the cuff with increased sensitivity [14].

Currently, there remains controversy if initial tendon and muscle quality is a determinant factor in tendon healing after rotator cuff repair [10, 15, 16]. When repairing the supraspinatus, Park et al. did not find any significant relationship between preoperative tissue quality (fatty infiltration) and postoperative tendon healing [15]. On the contrary, they observed that any fatty infiltration of the infraspinatus or subscapularis had a highly significant relationship affecting postoperative tissue healing [15].

Of great importance in current MRI diagnostic is the preoperative bone quality, especially the bone mineral density of the greater tuberosity. In a systematic review, Lädermann and colleagues found an increase in studies reporting on impaired bone quality within the greater tuberosity in chronic, retracted RCTs [10, 15, 17]. Further, bone quality might also be deficient due to anchor removal, cyst formation, or consequent osteolysis after the use of bioabsorbable anchors [10, 18].

If MRI is contraindicated or diagnostic assessment restricted due to technical restrictions (as mentioned above), ultrasound or CT arthrogram might be helpful, with current literature reporting high sensitivity in the diagnostic of RCT [19–21].

10.4 Indications

The indications for revision rotator cuff surgery are similar to those for primary repair. However, the surgeon should help managing patients' expectations and raise awareness for factors that can and cannot be changed with undergoing revision rotator cuff surgery.

In case of an acute traumatic re-tear in a physiologically young patient, revision surgery should be recommended [22]. In the setting of a chronic re-tear, the patient should be advised to undergo a trial of nonoperative treatment with the focus on restoring range of motion as well as strengthening of the remaining rotator cuff, shoulder girdle, and periscapular musculature. If conservative management has been unsuccessful, surgery can be considered along with patient-related factors (age, comorbidities, functional impairment, size of initial RCT) and the state of the remaining cuff [22].

In contrast, patients with irreparable rotator cuff tears, severe atrophy, or fatty infiltrations should not be considered for revision rotator cuff surgery [22].

10.5 Technical Aspects of Revision Rotator Cuff Reconstruction

Revision rotator cuff reconstruction can be performed using open, mini-open, or all-arthroscopic techniques, depending on the indication and the surgeon's preference. After induction of general anesthesia, the patient is positioned either in beach-chair position or in lateral decubitus position. If surgeons face inappropriately placed arthroscopic portals, care should be taken to replace a new portal in the anatomically necessary positions. The arm is placed in a movable arm holding device or a balanced suspension. Landmarks should be marked.

The surgical procedure starts with a diagnostic arthroscopy of the glenohumeral joint using a standard posterior portal. Concomitant intra-articular pathologies are evaluated and addressed first if necessary. Detailed examination of the long head of the biceps tendon (LHBT), the superior labrum, and the remaining rotator cuff should be performed. If still present, the LHBT should undergo either tenotomy or tenodesis. Acromioplasty should be considered, but care has to be taken to avoid acromial over-resection.

Careful handling of the remaining rotator cuff is of great importance, as retorn rotator cuff tissue is often of poor quality (Fig. 10.3). Further iatrogenic tissue damage has to be avoided. If necessary, any scar tissue or adhesions should be removed carefully. A circumferential debridement might be necessary if the patient presented with a restricted range of motion due to a stiff shoulder pathology before surgery. Retained sutures, misplaced or dislocated anchors should be carefully removed (Fig. 10.4). If metal hardware was used, hardware removal may create large bone defects, therefore, should be considered to be left in place. Large and massive tears often require extensive dissection and mobilization of the rotator cuff margins to allow a tension-free repair to the original footprint (Fig. 10.5). If the rotator cuff is considered irreparable due to retraction, conversion to other techniques might be necessary. If the remaining cuff is deemed reparable, careful preparation of the greater or/and lesser tuberosity is performed (Fig. 10.6). The decision to use single-row or double-row fixation mostly depends on the tissue quality and tension on the repair. However, double-row or transosseous reconstructions should be favored over single-row reconstruction. Primary subscapularis tears can be reconstructed using single-row repairs. When using new anchors in or around previously used anchor tracks, oversized anchors should be considered to improve anchor stability within the bone [23]. If bone defects prevent the use of any anchors, transosseous techniques need to be considered. If anatomic repair is not possible, margin convergence is an alternative option.

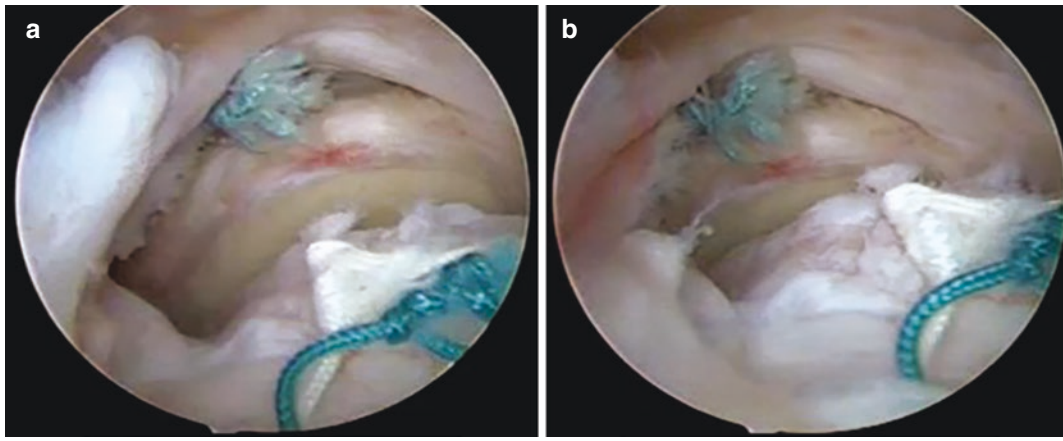

Fig. 10.3 Figure displaying poor tissue quality (**a** and **b**) in a chronic, torn supraspinatus tendon

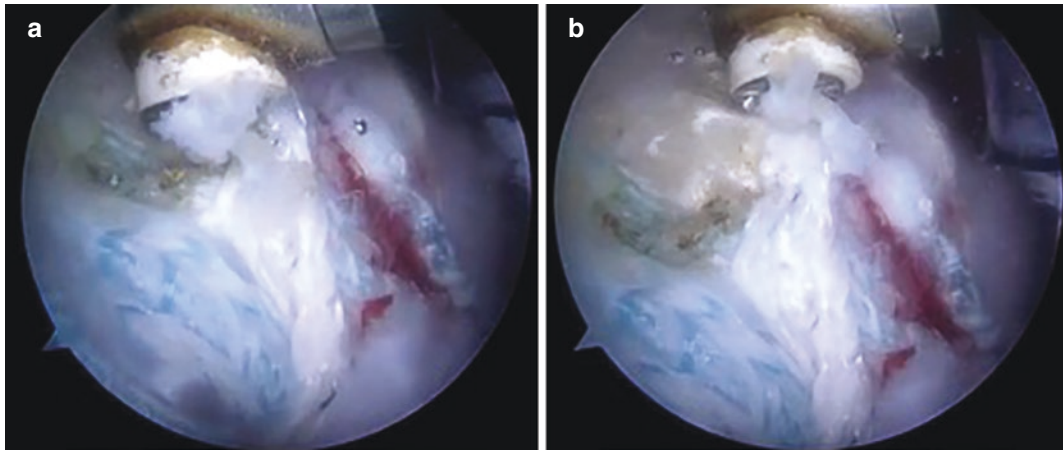

Fig. 10.4 (**a**) Figure displaying retained suture, (**b**) which should be carefully removed

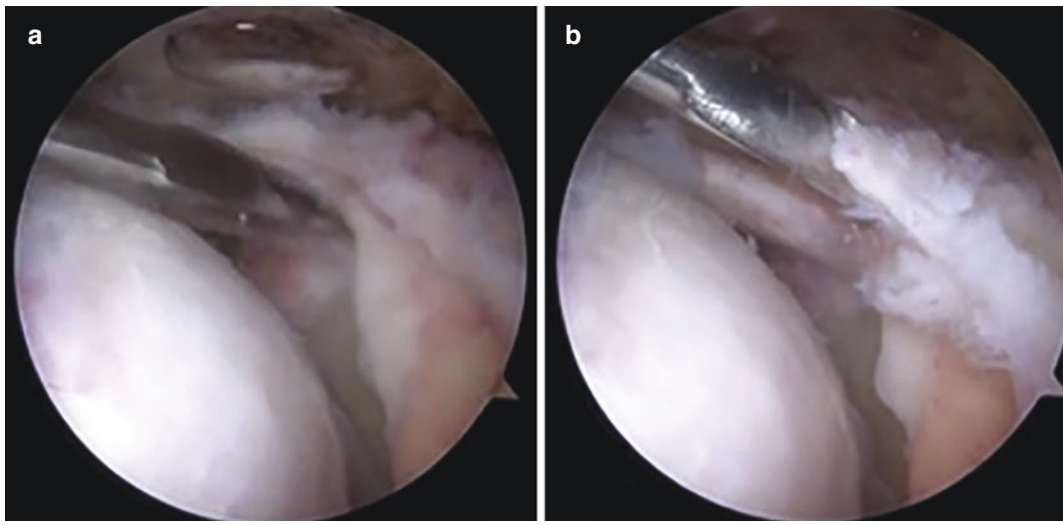

Fig. 10.5 (**a**) Figure showing a far retracted supraspinatus tendon, (**b**) deemed irreparable

10.6 Subscapularis Repair

Four portals are routinely used for subscapularis repair: a standard posterior viewing portal, an anterior portal used for anchor placement and suture passage, an anterolateral portal (just anterior to the biceps tendon) used for subscapularis mobilization and preparation of the lesser tuberosity and a second accessory anterolateral portal placed just posterior to the biceps tendon for the placement of traction sutures.

Arthroscopic repair of the subscapularis should be performed immediately after identification of the tear as shoulder swelling can limit visualization and compromise the ability to perform an effective repair. In the revision situation, chronic subscapularis tears can be retracted medially and scarred to the inner deltoid fascia and MGHL, making identification difficult. In retracted subscapularis tears, the superior glenohumeral ligament and the coracohumeral ligament might be torn off the humerus at the upper border of the lesser tuberosity and remains attached to the superolateral portion of the tendon, forming the "comma sign" just above the superolateral corner the subscapularis [24]. This

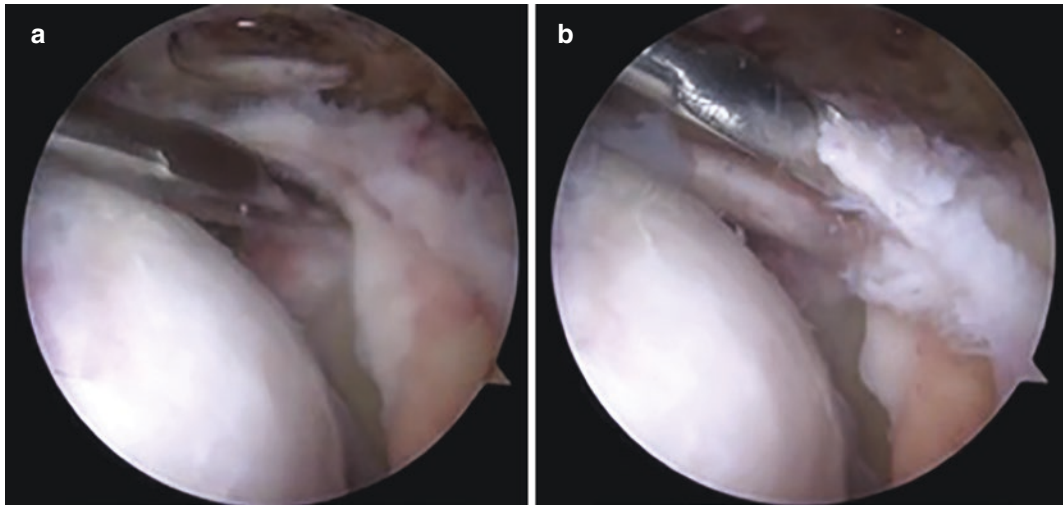

Fig. 10.6 (**a** and **b**) Debridement of the greater tuberosity should be carefully performed

"comma sign" can be used as a marker for the tendon. A tendon grasper can now be used to pull the medially retracted tendon laterally to place traction sutures along the upper lateral border of the subscapularis tendon.

Subsequently, mobilization is performed using electrocautery while traction is maintained through the accessory anterolateral portal. Care has to be taken to avoid dissection along the inferior border of the tendon to minimize the risk of neurologic or vascular injury. By preserving the lateral margin of the rotator interval, the continuity between the subscapularis and the posterosuperior rotator cuff can be preserved, allowing for later margin convergence, if necessary. After adequate mobilization, the subscapularis tendon is repaired using single or double-row fixation.

10.7 Supraspinatus and Infraspinatus Repair

The remaining cuff is now thoroughly evaluated through the lateral portal. As adhesions between the acromion, deltoid, and rotator cuff may occur, a dissection has to be performed using electrocautery or a shaver. In some cases, the anterior and posterior borders of the rotator cuff margins might be scarred to the deltoid fascia, and therefore have to be removed carefully. By placing the arthroscope into the lateral portal, dissection can be started at the medial border of the posterosuperior cuff. Bursectomy and debridement are critical, in order to prevent swelling of the surrounding tissue and optimize visualization. Dissection is continued until all adhesions between deltoid, acromion, and cuff are resected and tension-free mobilization of the cuff is guaranteed. However, care is taken to avoid damage to deltoid fibers or any muscular tissue of the remaining cuff. Using an additional superior-medial (Neviaser portal) or a posterior infraspinous portal may allow to pierce the retracted rotator cuff tendon more medially when compared to using conventional portals [25]. Additionally, a curved suture passer (Bananalasso, Arthrex Inc., Naples, FL, USA) may be used as it can be easily pushed through the skin, thus avoiding a skin incision. Care has to be taken to avoid any damage to the suprascapular nerve, which may be located 1-cm from the supraglenoid tubercle [26].

Depending on the remaining tendon tissue and the type of rotator cuff tear (Crescent shape; U-shaped; L-shaped), repair can be performed using margin convergence (in U-shaped or L-shaped tears) or directly to the bone (in crescent-shaped tears) in a single- or double-row construct. If anatomic repair is not possible, many authors recommend performing a partial repair by repairing as much tendon to tuberosity as possible [27, 28]. One may consider a medial-

ization of the remaining rotator cuff when the tendon's mobility is insufficient to cover the anatomic footprint, [29, 30] although, there remains a lack of data, especially in revision cases. Regardless of the technique used, reestablishing the force couple is of great importance.

10.8 Advantages of Arthroscopic Techniques

Generally, arthroscopic approaches offer several advantages compared to open revision repairs. Arthroscopy allows for a complete evaluation of the glenohumeral joint and subacromial space, which is important for diagnosis and treatment of concomitant pathology. Additionally, arthroscopic techniques minimally disrupt the deltoid. To this, correct classification, evaluation of the re-tear, and complete rotator cuff can be performed by using arthroscopy. Finally, postoperative stiffness can be reduced by using this less invasive approach.

10.9 Outcomes

Efforts to draw revealing conclusions from existing studies are limited by small sample sizes, differences regarding surgical technique, heterogeneity of tear types, and methods of quantifying the outcome [9]. Compared to primary arthroscopic rotator cuff repair, outcomes following revision surgery are generally reported to be less satisfactory [9, 31–33]. The first published series of revision rotator cuff repair surgery dates back to the early 1980s and involved open revision, however, without the use of any validated shoulder score [34, 35]. In 2004, Lo and colleagues published the first study of patients undergoing arthroscopic revision surgery and noted significant improvements in UCLA scores and active motion elevation, with overall good to excellent results in 64% of procedures [24, 36]. Since then, most of the results published are reporting similar, comparable promising results in terms of functional and clinical outcomes [2, 10, 32, 37–40]. However, these results are tempered by high complication (12%) and reoperation rates (5%) [2].

Similar, Willinger et al. investigated on clinical and radiological outcomes after revision RCR [36]. Of interest, they found that over 50% of patients showed a re-tear on postoperative MRI, however, tendon integrity was not correlated with better clinical outcomes after revision RCR at final follow-up. To this, almost equal strength could be restored for external rotation but not for abduction and internal rotation when compared to the intact contralateral side.

When stratifying outcomes by type of surgery, mean postoperative range of motion is greater with arthroscopic repair than open repair (forward flexion: 146° vs. 125°; external rotation: 51° vs. 42°) [2]. However, in 2019 Brochin et al. showed similar improvement from preoperative to postoperative range of motion for both techniques in a systematic review [2]. Mean VAS pain score were better with arthroscopic repair, contrary to the ASES score, with no significant differences between both techniques. Surprisingly, complication rates (16% vs 8%) and reoperation rates (7% vs. 2%) were higher for arthroscopic techniques than open revisions [2].

10.10 Prognostic and Risk Factors

Prognostic and risk factors associated with successful and unsuccessful results after reconstruction of the rotator cuff, especially revision rotator cuff repair, are poorly understood [10]. However, several patient-related risk factors are known to have a negative association with worse outcomes: Female sex, [37–39] surgery on the dominant arm [39], poor preoperative range of motion, [10, 38, 39, 41] high preoperative decreased clinical outcomes scores, [2] acromiohumeral distance (<7 mm) [32], and any presence of osteoarthritis [32]. Additionally, poor tendon quality has been shown to result in worse postoperative clinical outcomes [24, 35]. Patients with pseudoparalysis and glenohumeral arthritis often do poor after revision surgery and may better be treated with arthroplasty.

The influence of age on revision rotator cuff surgery continues to be controversial [40]. Lädermann et al. failed to demonstrate a significant correlation between age and functional outcomes, [38] contrary to Keener et al. who showed

age-related differences in repair integrity, with worse outcomes in patients aged 59 years (compared to patients aged 51 years) [33]. Chuang et al. also found worse outcomes in patients older than 70 years of age [39]. However, with a mean increase in Constant Score of 23.9 for patients over the age of 65 years and 24.5 for patients younger than 65 years, this could still imply that patients over 65 years can be considered for revision rotator cuff surgery [9, 39].

From a biomechanical point of view, non-restoration of a balanced force couple or suspension bridge system might be one of the main reasons along with the initial tear size and tissue quality for clinical failure [10, 42–44].

10.11 Summary

As the rate of primary RCR increases, the number of failures and subsequent revisions is likely to increase. Arthroscopic revision rotator cuff repair can be technically demanding, and the complication including failure rates are high. Compared to primary arthroscopic rotator cuff repair, outcomes following revision surgery are generally reported to be less satisfactory but remain high. Several patient-related risk factors are known to have a negative association with worse outcomes; however, prognostic and risk factors associated with unsuccessful results after reconstruction of the rotator cuff are poorly understood. The aim of shoulder surgeons should be to avoid unsatisfactory results and help in managing patients' expectations.

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Repair and Augmentation: Overview

11

Garrett H. Williams, Stephen G. Thon, and Felix H. Savoie III

11.1 Introduction

Failure of rotator cuff repair (RCR) procedures remains a significant issue. An effort to augment the repair with various types of patches and/or implants has made its way into practice in an attempt to increase positive outcomes and decrease the incidence of re-tears and consequent revisions. Augmenting repairs is meant to increase the durability and strength of the repaired tendon by improving the host's ability to heal or strengthening the repair. Incorporating patches or implants as augmentation has shown promise in the repair of RC tears that would previously have been unrepairable. This includes tears that offer no way to anatomically connect the torn tendon to bone without causing tension. A systematic review found that the use of patches to bridge the gap from torn tendon to the anatomic position led to restoration of the normal anatomy of the RC, significant decline in the rate of re-tears, limited complications from the procedure or implant itself, and significant improvement in comparison of preoperative and postoperative assessments [1].

The re-tear rates after primary RCRs has been reported in the range of 16%–57% [2–5]. It is documented that many of the re-tears occur at the tendon-bone interface likely due to the complexity in healing between two vastly different tissue types [6]. Shea et al. demonstrated an increased load to failure and a decreased gap of the tendon to bone interface in a biomechanical cadaveric study using an extracellular matrix graft onto the repair [7]. These findings suggested that augmentation of RCR could decrease the incidence of re-tears and revisions by decreasing the tendon to bone gap. Based on histology of the tear, large and massive sized tears have a diminished healing potential when compared to small and medium tears [8]. Because of this many believe that augmentation would have the greatest effect on large and massive tears that have consistently been shown to have higher rates of re-tearing and revision [2].

Given the high rates of failure of RCR, there is an obvious need to improve outcomes. Augmentation of the repair is a promising technique with potential to improve results of RCR. There are many types of augmentation patches including xenograft patches, allograft patches, synthetic patches, and bovine collagen implants. Each of these materials has different properties that change the dynamics by which they interact with the tendon and bone in the RCR. This chapter will explore different options in augmentation of RCR with a brief overview of the types of patches seen in the literature and the results associated with each.

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11.2 Autograft Augmentation

Local tissue (biceps) and other tissue from the host (hamstring and fascia lata) have been utilized to both supplement the repair and the superior capsule. Each of these 15 autograft tissues have reasonable success in improving the postoperative function and will be covered in-depth in later chapters.

11.3 Xenograft Augmentation

One option to assist in RCR is the use of a xenograft patch to support the newly repaired tendon. Attempts have been made at using porcine small intestine submucosa (SIS) and porcine dermal collagen. It is thought that the use of these tissue types will recruit the patient's cells to improve rate and quality of healing.

SIS has been shown to be effective as a vascular graft and showed favorable results in the repair of infraspinatus tear in canine models [9–11]. In theory, SIS would serve as a type of biological scaffold which would attract host cells to the site of repair and improve the biological environment to promote tendon healing. The structural integrity of SIS makes it unlikely to serve as a stable mechanical augmentation, but by promoting faster and more stable healing, the patch would increase durability of the repair [9]. These grafts have been used in the repair of both large and massive RCTs. There are no absolute contraindications to use of SIS in RCR, but other options should be considered if the patient has a history of reaction to any porcine products. The technique for implementation of the patch with the repaired rotator cuff varied slightly between trials, but all involved rehydrating the patch with saline and proceeding to attach the patch to cover the tendon-bone interface as well as to the intact tendon posteriorly and anteriorly covering the extent of the tear. Care should be taken to decrease the gap between the patch and the underlying tissue [9, 12, 13]. The results of these early attempts at using SIS to augment the RCR were ultimately disappointing. There are several documented trials showing less favorable outcomes when compared to RCR without augmentation [9, 12–14]. On follow-up MRI to assess structural integrity of the repair with augmentation, there was no significant difference when compared to standard repair alone. There were also well-documented cases of inflammatory reactions to the implant itself [9, 12]. Given the complications of SIS and lack of improved outcomes, it is not recommended for use as augmentation of RCR [9, 12–14].

Another option for the augmentation of RCR is the use of a porcine dermal tissue matrix patch. This patch is normally a single layer of porcine dermis that has been acellularized and cross-linked to form a single sheet of collagen. The chemical cross-linking rids the patch of immunogenic elements that result in an inflammatory response form the host [15]. This a method is used to further decrease the risk of adverse events some of which were seen in the SIS augmentations. The dermal ECM patch is also used as a support for the biologic environment with hopes of increasing the healing rate of the repaired tendon. This type of xenograft has been used in the setting two tendon or massive RC tears [1, 16]. This graft has more structural stability than the SIS and serves as a better mechanical support to help stabilize the repair while it heals. The porcine dermal ECM graft has been used successfully to bridge the gap when the tendon being repaired was unable to be attached anatomically and restore correct anatomical position [1]. There are no absolute contraindications to use of this patch as augmentation of RCR; however, care should be taken if the patient has a history of an autoimmune disease against collagen. The implantation technique depended on the function of the patch. If the patch was needed to bridge a tendon that could not be placed anatomically, the graft was cut to the appropriate size. The graft was then used to create a template of locations for the sutures to be inserted. Sutures are then placed in the native rotator cuff tendon and used to zip-line the graft into place. The sutures connecting the graft and the native tendon were tied, and the graft was anchored to the greater tuberosity. This technique allowed the graft to remain flat upon closure and avoid any unnecessary

tension [16]. If the graft was being placed directly over an anatomically repaired tendon, the procedure is the same as described previously for the SIS patch. This type of repair with augmentation showed significantly improved outcomes both structurally and clinically when compared with historical controls of repair without augmentation [1, 12, 17]. There were no adverse complications noted in the literature which is a marked improvement over the SIS xenograft [1, 12, 16, 17]. With no significant complications and much greater outcomes both clinically and radiographically, porcine dermal ECM augmentation is a favorable alternative over the SIS augmentation.

11.4 Allograft Augmentation

Another option to consider when repairing RC is the use of human allograft to augment the repair. Currently, the most commonly used allograft patch is composed of an acellular human dermal matrix. The goal of this augmentation is to provide structural support to the repaired tendon as well as increasing the healing rate of the repair. Allografts are indicted in the treatment of small, medium, large, and massive RC tears. There is also promising data that allografts can be used to successfully restore anatomic positioning in RC tears that were unable to be restored without placing tension on the tendon [18]. There are few absolute contraindications to the use of dermal allograft patches, but some of the manufacturer's recommendations include avoiding use in patients with autoimmune connective tissue disorders or active infections at the transplant site. The technique used to implement these patches again varies depending on surgeon preference, but most follow the same basic technique as the xenograft patches. Initially, the rotator cuff is repaired to a normal anatomic position if possible. The allograft patch is rehydrated and trimmed to match the rotator cuff footprint. Sutures are attached to the native tendon and used as guidewires to lower the patch into place where it is secured by further suturing and tying it to the tendon. The patch is pulled with enough tension to remove any defects in shape and anchored to the humerus tightly enough to decrease any gap between the patch and the underlying tissue layers [19, 20]. If the RCT is deemed irrepairable, the same procedure is followed using the graft as an interposition implant to connect the native tendon to the bone [20].

Studies have shown promising results in the use of human dermal allograft as augmentation for RCR. In a cadaveric study using matched shoulder pairs, Barber et al. showed a significant increase in the initial strength of an RCR when comparing standard repairs and those augmented with an allograft patch. This study led to more investigations into the use of allografts as a way to strengthen RCRs and improve outcomes. Many studies have analyzed using allografts in large and massive tears and have shown improvement in structural integrity via imaging as well as clinical outcome based on pre- and postoperative scoring systems [18–20]. In the use of allografts to repair previously irreparable tears, Gupta et al. demonstrated an improvement in pain ratings, range of motion, and strength of augmented repairs. Upon follow-up after 3 years, almost 75% of the repaired tendons remained intact and the other 25% only had partial tears [19]. In another trial of previously irreparable defects, augmentation showed improvement in strength and ROM as well as intact grafts in the majority of participants [18]. Overall, results from several studies indicate that the use of human dermal allograft as augmentation of RCR is a viable option to assist in the repair of large and massive RCTs [18–21]. Along with promising results, it is notable that there were no adverse reactions attributable to the implant in these studies. This is a marked improvement over the reactions seen specifically in the SIS portion of xenograft augmentation.

11.5 Synthetic Patches

Along with the tissue types mentioned earlier, some orthopedic surgeons have attempted augmentation of repaired tendons with a synthetic graft. There are many different synthetic material options for tendon augmentation including

polylactide, polyglycol, polypropylene, and many more, but they all function similarly by increasing the mechanical durability of the repair and providing an improved healing environment for the native tendon by decreasing tension on the tendon. Based on the biomechanical characteristics of these grafts, they serve as better mechanical support of the repaired tendon compared to the xenograft and allograft implants [22]. On the other hand, these synthetic materials do not have the same biologic properties as the other grafts which decrease their ability to promote host healing. This is seen with early studies of the synthetic grafts in canine models that showed an increase in tensile strength, load to failure, and biomechanical function [23, 24].

The synthetic patches are indicated in the use for any RCR as seen appropriate by the orthopedic surgeon. They are theorized to have the most potential in large and massive tears where the biomechanical integrity of the patch can help ease the stress burden on the repaired tendon. The only contraindications to use of a synthetic patch are a previous inflammatory reaction to a component of said patch or an active infection at the implant site. For the surgical technique, the many surgeons opted for open repair of the rotator cuff. The tendon was reattached anatomically, and the patch was overlaid and secured using sutures running through the implant into the native tendon [25, 26]. In repairs where the graft was used as a bridge between the tendon and the bone, the graft was trimmed to the necessary dimensions to connect the viable tissue to the bone and secured to the native tendon with sutures. The remaining portion of the tendon located on the greater tuberosity was removed, and the graft was attached via transosseous fixation [27].

When compared to the allograft patches, synthetic grafts have been shown to have lower re-tear rates, most likely due to their superior mechanical stability [21, 28]. They have been shown to improve clinical outcomes in terms of function, strength, and re-tear rates compared to biologic patches [25]. The disadvantage of using a synthetic versus a biologic allograft remains its ability to support host self-healing. Studies have shown the synthetic patches have worse tissue induction qualities and poor host integration in comparison to biologically derived augments [21, 22]. Based on many trials of synthetic implants, there were no adverse reactions directly attributable to the implantation of the graft [21, 25, 29].

11.6 Bio-Inductive Implants

Bio-inductive implants derived from bovine Achilles tendon are a more recently developed type of augmentation that shows promising results in initial studies. These implants are formed by taking bovine Achilles tendons and processing them to only leave a scaffold of type I collagen that has nearly all of the foreign DNA removed [30]. The removal of DNA elements is an important step in improving the rates of adverse reactions that were traditionally seen in several types of the xenograft. The bovine collagen implant works to increase healing at the site of a repair. The implant is non-structural and non-mechanical; it allows for the in-growth of new tendon tissue at the site of the implant. This is important to note because in the early stages of healing it provides no extra support to the repaired tendon and requires time to allow the implant to incorporate to the host tissue. In sheep models, the implant showed growth of fibroblasts as early as 6 weeks. At 12 weeks, there was a layer of connective tissue and clear incorporation of new tissue into the bone. At 1 year, the new tissue resembled native collagen [30]. Second look studies in human subjects have shown fibroblasts beginning to proliferate in as few as 5 weeks and by 6 months the tissue had the appearance of tendon without any trace of the original collagen implant [31].

Bio-inductive implants are indicated in the augmentation of RCR of tears ranging from partial to large or massive. They function to improve the host's healing ability which is useful in the repair of any rotator cuff tear. There are no absolute contraindications to the use of this implant, but caution should be used when a patient has a history of allergy to bovine products or underly-

ing autoimmune disease against collagen. The benefits to the use of this implant are that the surgeon's desired surgical technique for repair of the rotator cuff is not altered in any way. The RCR is performed to the surgeon's preference, and the implant is then placed on the bursal surface of the repaired tendon and secured to the tendon and bone with staples designed for each tissue type [31–34].

This implant has been used in patients undergoing RCR with successful results. Schlegel et al. demonstrated improved patient outcomes as well as improved structural integrity in RCR of partial tears when augmented with a bovine collagen patch [33]. In the repair of large and massive RC tears, Thon et al. demonstrated a 96% healing rate and only 9% clinical failure rate. They showed extensive tendon formation on postoperative MRI and US and improved clinical outcomes [34]. To date, there has not been any evidence of an inflammatory reaction attributable to the implant [31, 33–35].

11.7 Author's Preferred Technique and Pearls

At the current time, the authors preferred technique is for the use of the bio-inductive collagen implant if augmentation is indicated. The RCR is performed as in our previously published series [34]. The bio-inductive implant is then placed into the subacromial space through either the posterior or lateral portal using the proprietary guide that is provided with the implant. For larger tears, the senior authors have found great success inserting the implant from a posterior portal while viewing from a lateral portal. If inserted in this direction, the rectangular shape of the implant provides more coverage of the repaired tendon from anterior to posterior. The implant is then secured in the same fashion as if it were inserted from the lateral portal with the included PLLA tissue staples and PEEK bone staples as needed. We tend to avoid the PEEK bone staples whenever possible due to their rigidity and attempt to secure the implant with only the included PLLA staples.

In our series of large and massive rotator cuff tears, we found a 96% healing rate on postoperative MRI at 2 years of follow-up [34]. Additionally, 16 of the 23 patients were undergoing revision RCR for a previously failed surgery which did not affect outcomes. In our experience, the use of this implant does not improve muscle atrophy postoperatively. We have a strict contraindication for its use in patients with Goutallier Grade 3 or higher muscle atrophy. Likewise, patients with large and chronic tears prior to surgery will require extensive rehabilitation periods longer than that found in small- to medium-sized tears.

11.8 Conclusion

Revisions of previous RCRs are difficult and technically demanding procedures with relatively low success rates compared to primary repairs. Augmentation with a wide variety of materials and tissue types has been suggested in an attempt to find the right balance between mechanical support and the ability to increase the host's ability to heal these difficult tears. Among these implants, xenografts are the least successful and are not commonly used in practice today. Human allografts, synthetic grafts, and bio-inductive implants have all shown promising results during augmentation of RCRs. Long-term follow-up studies are needed to assess their durability and comparative studies are needed for direct comparisons of each graft.

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12 Debridement and Releases to Set up for Revision Success

Stephen G. Thon, Garrett H. Williams, and Felix H. Savoie III

12.1 Introduction

A previously failed or revision rotator cuff presents with unique challenges when compared to a primary rotator cuff repair (RCR). In general, there are issues regarding tissue scarring, foreign material, tissue identification, tissue quality, and tissue mobility that surgeons encounter during these situations [1]. Being prepared for these variances can be the difference between a successful outcome and a non-successful one.

Tissue scarring becomes of great importance after a chronically torn rotator cuff tear (RCT) as well as a previously failed RCR. Rotator cuff tissue can scar to the overlying bursa, the bony structures above (scapular spine, acromion, etc.), the ligaments in the subacromial space, and to the deltoid fascia. Once a surgeon has entered into the subacromial space it is imperative to recognize the difference between the native rotator cuff tissue and the scar tissue around it. Surgeons can make the mistake of debriding too aggressively and removing healthy rotator cuff tendon. Removing this scar tissue is important in being able to identify healthy tissue from non-healthy tissue, as well as being able to adequately assess the current status and quality of the remaining rotator cuff tissue.

Assessing the remaining tissue quality is especially important in the revision RCR setting. Tissue that has been previously operated on is at higher risk of failure, particularly the more operations that have been undertaken [2, 3]. Tissue quality can be so poor that a repair cannot be completed and separate or additional procedures such as superior capsular reconstruction or tendon transfers must be performed instead [4]. However, surgeons should be prepared for this possibility in advance and should use pre-operative imaging to help determine the tissue quality, including muscle atrophy, prior to any operation.

Lastly, once the tissue has been fully identified and has been deemed of high quality to proceed with an RCR, the surgeon must assess the mobility of the rotator cuff tendon tissue to reduce back to the greater tuberosity. If additional mobility of the tendon is needed, then specific tissue releases are then undertaken to help improve the excursion of the rotator cuff tendon laterally to allow for a repair without tension.

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12.2 Intra-articular Preparation, Capsular and Ligamentous Releases

Successful treatment of a failed or revision RCR starts with a thorough pre-operative exam. A full physical exam and radiographic exam consisting of both X-rays and magnetic resonance imaging (MRI) should be performed. Specific to the topic of this chapter, special attention should be paid to evaluate the patients' passive internal rotation while in the abducted position. Limitations of IR of the affected side compared to the non-affected side in this position often signal a posterior-inferior or inferior capsular contracture, which in our practice is an indication for inferior capsular release [1, 5]. Similarly, any superior migration of the humeral head on anterior-posterior X-rays may also be a sign of inferior capsular contracture. MRI exam is also crucial to assess for the extent of the RCT, any muscle atrophy as determined by the Goutallier classification [6], and degree of medial retraction of the tendon. Retraction of the tendon medial to the glenoid edge is an indication to consider suprascapular nerve release at the suprascapular notch [7].

After the decision to proceed with surgery has been determined, preparation to repair the failed or revision RCT begins intra-articular. As mentioned before, in these complex cases, arthroscopic release of the capsular tissue is often indicated [1, 5, 8]. Release of the capsular tissue allows for two things: (1) allows any superior migration of the humeral head to fall inferior and re-center on the glenoid face and (2) allows for separation of the scarred and/or retracted rotator cuff tendons to be separated from the labrum and glenoid. We generally perform this with an electrocautery device. After a standard posterior portal is established, the camera is inserted posteriorly with the electrocautery device inserted from an anterior portal. The capsular release is then taken from the level of the portal distally, just outside the labrum and extended toward the 6 o'clock position inferiorly as indicated pre-operatively (Fig. 12.1: anterior inferior release). The view is then turned more superiorly and the anterior release goes from the coracoid,

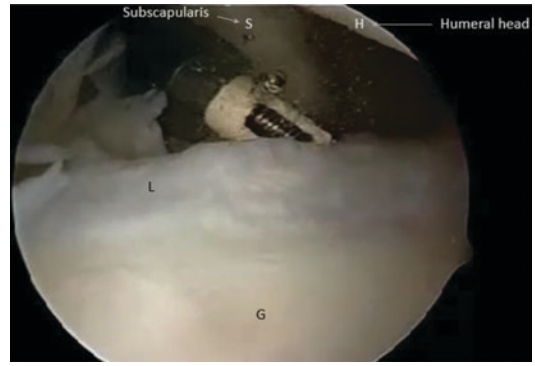

Fig. 12.1 The arthroscope is in the posterior portal and a release of the anterior inferior capsule and anterior band of the inferior glenohumeral ligament is performed. *G* glenoid, *L* labrum

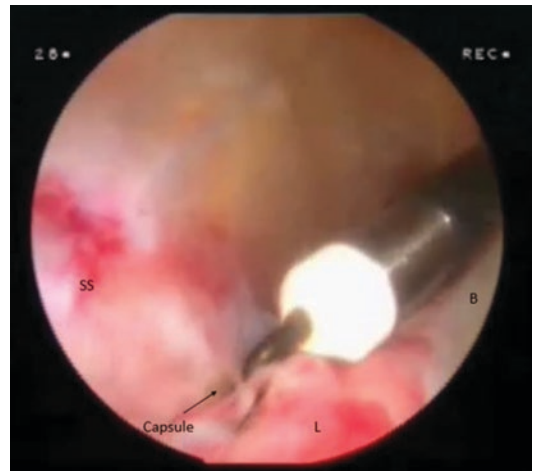

Fig. 12.2 The superior capsule is released, along with any adhesions between the bone of the supraspinatus fossa and the overlying supraspinatus muscle. *SS* supraspinatus, *B* biceps, *L* labrum

over the biceps and releases any attachments between the supraspinatus muscle and tendon and the labrum and superior glenoid (Fig. 12.2). We usually try to preserve the biceps attachment to use it as a graft if it is present.

Once this is complete, the camera and electrocautery are swapped, with the camera anterior and the electrocautery posterior. The release is then taken from posterior superior, connecting the previous superior release to the posterior capsule, moving toward the inferior 6 o'clock position. The two releases are connected at this point

at the 6 o'clock position (Fig. 12.3). Often in these revision situations there is quite a bit of scarring superiorly, posteriorly, and inferiorly. Although the authors like the precision of a needle tip hooked cautery, a stouter side effect type device may be needed in some cases due to the thickness of the adhesions.

Inferior capsular release is slow and methodical to protect the axillary nerve. Great care is taken at the 5–7 o'clock positions not to go too deep and damage the axillary nerve which is on average 1–2 cm from the glenoid margin [9, 10]. Inferior capsular contracture can also bring the nerve closer to the electrocautery so a judicious approach is indicated. In all rotator cuff repair cases, we routinely release the coracohumeral ligament (CHL) off the posterior-lateral aspect of the coracoid [1, 5] (Fig. 12.4a, b). The CHL has two bands that originate off the coracoid and extend to the supraspinatus and subscapularis. These bands should be released from the subacromial-subcoracoid bursa. In order to visualize and release this ligament, the anterior bursa is debrided while visualizing from the lateral portal. To do this, the motorized shaver or electrocautery is placed through the anterior portal between the subscapularis and coracoid. Following the coracoacromial ligament to the coracoid is an excellent method to find this interval. The tip of the shaver is then used to identify the posterior-lateral aspect of the coracoid and the attached conjoined tendons of the short head of the biceps and coracobrachialis (Fig. 12.4a). Viewing slightly more medially, the CHL can be identified. Once identified, the surgeon can use either the cautery (preferred) or shaver to debride and release the CHL. Care is taken not to bring the instrument off the bone, either superior into the coracoacromial ligament (CAL) as it may cause bleeding or inferior to the conjoint tendon, due to proximity of the axillary nerve.

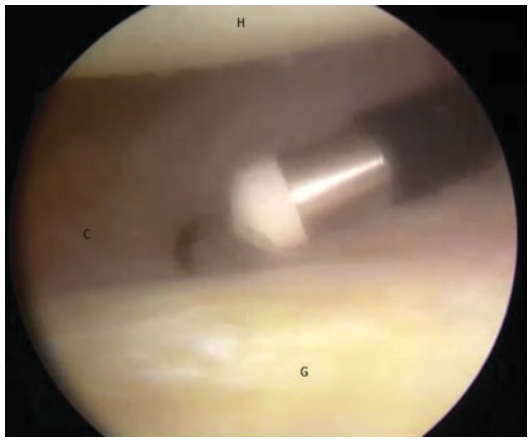

Fig. 12.3 The inferior capsule is completely released to allow the humeral head to drop down and ease tension on the repaired rotator cuff muscle and tendon. *H* humerus, *G* glenoid, *C* inferior capsule

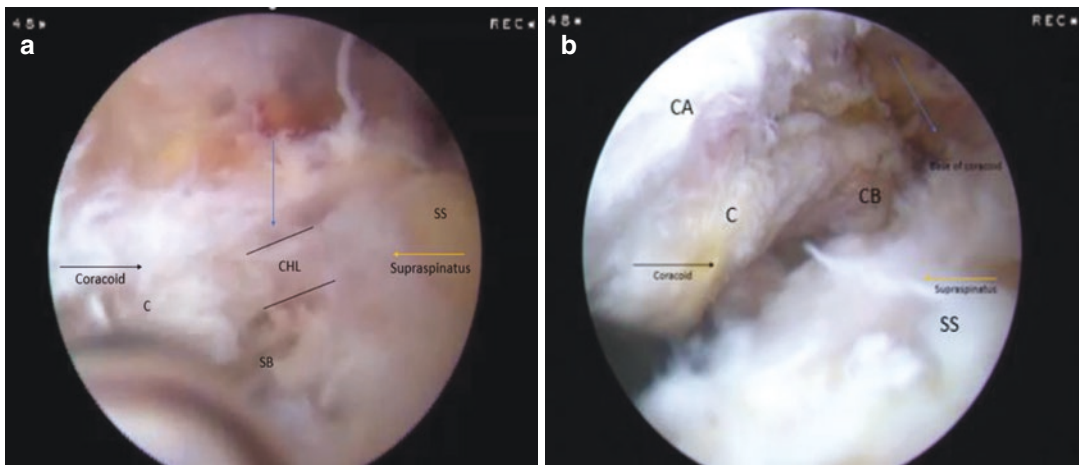

Fig. 12.4 (**a**) View of the coracohumeral ligament from the lateral portal shows in connection to both the supraspinatus and subscapularis. *SS* supraspinatus, *SB* subcoracoid bursa, *C* coracoid. (**b**) The CHL has been released, exposing the lateral aspect of the coracoid base. *CA* coracoacromial ligament, *C* coracoid, *SS* supraspinatus

Once the CHL has been completely released, one can move medially to complete an anterior interval slide, staying posterior to the CC ligaments and anterior to the muscle belly of the supraspinatus. A Nevaiser portal is established and a blunt trocar of switching stick introduced to retract the supraspinatus muscle posteriorly and widen the safe area. A second, more medial Nevaiser portal can be established and a second switching stick used to protect the suprascapular nerve and artery. An arthroscopic scissor or punch can then be used to release the suprascapular ligament and decompress the suprascapular nerve. (Fig. 12.5)

In general, the number and degree of capsular and ligamentous releases directly correlates with the size of the tear pre-operatively. These releases allow for proper mobilization of the rotator cuff tendon and make the tear easier to reduce down to the greater tuberosity. Small tears necessitate an isolated CHL release whereas massive tears necessitate a CHL release with a 360-degree capsular release. In addition, a suprascapular nerve release may be necessary in massive tears as well. A suprascapular nerve release is indicated in our practice with a known positive EMG/NCV,

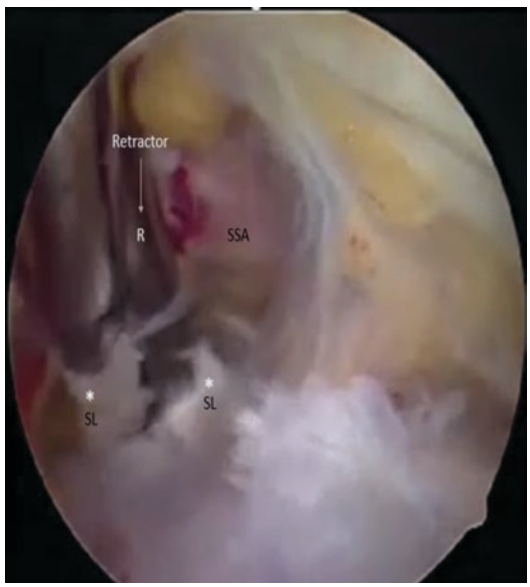

Fig. 12.5 The suprascapular ligament has been released to finish the anterior interval slide. *SSA* suprascapula artery, *SL* suprascapular ligament

Table 12.1 Releases indicated based on tear size in our practice

Tear size	Releases indicated
Small (0–1 cm)	CHL release
Medium (1–3 cm)	CHL Posterior-inferior capsule
Large (3–5 cm)	CHL Entire inferior capsule (9–3 o'clock)
Massive (5 cm or greater)	CHL 360-degree capsular release +/− suprascapular nerve release

CHL coracohumeral ligament

Grade 4 or higher atrophy [6], a torn rotator cuff tendon that is retracted medial to the glenoid and in most revision situations with grade 2 or higher atrophy of the supraspinatus and infraspinatus [7, 11]. Table 12.1 summarizes the releases traditionally performed in our practice.

At this point attention can be turned to the greater tuberosity with the scope placed back into the posterior portal. The greater tuberosity is debrided using a motorized shaver or the electrocautery device. Any dead tissue is removed from the bone including any remaining stump of rotator cuff that may still be attached. If this is a revision setting, remove or impact any old anchors. A small trough should be created along the articular margin for the entire planned insertion of the RC tendon using the motorized shaver [1, 5]. Microfracture or drill trephination holes spaced ~5–10 mm apart along this trough to allow for bleeding and stem cell penetration of the repaired tissue [[12, 13]-Milano, Taniguchi]. If necessary or desired, these steps may also be performed after entering the subacromial space.

12.3 Debridement

An important first step of any RCR is identifying the healthy tissue that will be repaired back to the greater tuberosity. In the setting of a previously failed or revision RCR, this can be especially difficult due to chronicity, scarring, and tendon retraction. Bursal tissue can become heavily scarred requiring significant time for removal and debridement. A systematic approach is necessary

to improve the efficiency and maximize the available time to complete the rotator cuff repair prior to shoulder swelling. It is vitally important that any residual tendon be preserved.

In general, we start the debridement in the lateral gutter, move anterior, and then progress over the top of the remaining rotator cuff tissue posterior. The camera is placed in the posterior portal, and a lateral portal is established with outside-in technique with an 18-gauge spinal needle. The motorized shaver is then inserted in the lateral gutter with the shaver head facing toward the humerus and away from the deltoid fascia to protect the axillary nerve. The camera and shaver are then brought anterior resecting bursal tissue as it is moved from lateral to anterior. The anterior bursal tissue is removed until the posterior aspect of the coracoacromial ligament, subscapularis tendon, and the posterior aspect of the coracoid are fully visible. The shaver is then brought superior to the undersurface of the acromion moving from anterior to posterior.

The lateral edge of the acromion is identified, and any scar or bursal tissue is removed from the lateral edge. This proceeds until the entire lateral edge of the acromion is visualized from the anterolateral corner to the posterolateral corner the scapular spine. At this point, the tissue planes between the bony structures (acromion, scapular spine) and soft tissue can generally be visible and identified. The surgeon can continue to use the motorized shaver or alternatively may switch to electrocautery. While remaining directly adjacent to the bone and keeping the tool of choice pointed away from the soft tissue (this limits the risk of iatrogenic injury to normal tendon), the tissue can then be fully released from the undersurface of the acromion and scapular spine. We try to be superior to and preserve any bursal tissue, leaving it on the muscle and tendon. The entirety of the bony structures should be visible from anterior to posterior once this is complete but should not progress medial to preserve the blood supply to the rotator cuff and bursa (See Chap. 1—Anatomy of the Rotator Cuff). The goal at this point is not to debride or remove soft tissue but simply to separate it from the overlying bone for adequate visualization. After release from the bony structures, remove any remaining scar or bursal tissue posteriorly between the posterior deltoid fascia and the infraspinatus and teres minor tendons and connect back to the lateral gutter.

Attention may now be turned to the rotator cuff tendon tissue itself. The camera should be moved to the lateral portal to properly view the available tissue in its entirety from anterior to posterior [1, 5]. The motorized shaver or electrocautery is inserted either posteriorly or anteriorly to debride any remaining bursal tissue overlying the rotator cuff [1]. Great care is taken at this stage to only debride known scar or bursal tissue and to preserve all available tendon tissue. The tendon edge should now be freely mobile. An arthroscopic tendon grasper can be inserted to assess the mobility of the tendon [1]. Ideally, the tendon now has enough lateral excursion to reduce to the articular margin of the greater tuberosity with the tendon grasper. If it does not, then additional releases and/or further debridement is necessary. At this point, an acromioplasty and/or distal clavicle excision can be performed if indicated. (Fig. 12.6a. initial view of massive rotator cuff, b view after release, c repair d patch)

12.4 Interval Slides

The interval slide is a technique used to increase mobility in severely retracted torn tendons seen in large and massive rotator cuff tears. This process was initially introduced by Bigliani et al. in 1992 as an open surgical technique [14]. Tauro introduced the arthroscopic anterior interval slide by freeing the retracted supraspinatus tendon from the rotator interval [15]. Eventually, two different interval slides emerged, the anterior and the posterior interval slides [16]. Both techniques involve mobilizing the rotator cuff tendons by releasing them from their attachments and the adjacent tendons. This allows for increased movement laterally and the ability to reattach the tendon to the anatomic footprint [17].

The anterior interval slide (AIS) is defined as the release of the supraspinatus tendon from the rotator interval [16]. AIS is indicated in the treat-

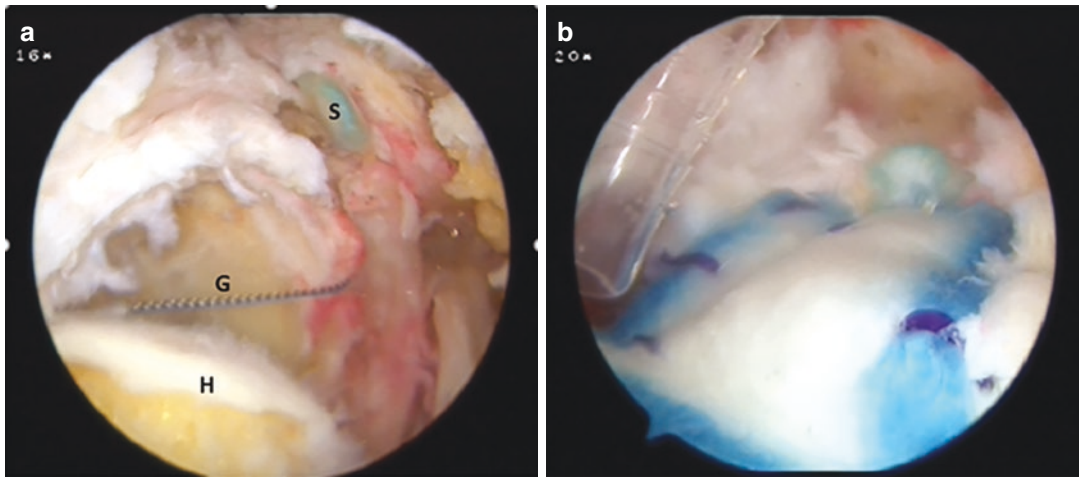

Fig. 12.6 (**a**) Initial lateral view of massive, failed rotator cuff. *H* humerus, *G* glenoid, *S* old suture from prior surgery. (**b**) Rotator cuff repaired with vascular patch added to the repair to help with vascular ingrowth

ment of large to massive rotator cuff tears with severe constriction of the tendon preventing attachment to the humeral tuberosity [18]. By releasing the tendon from any adhesions at the rotator interval, the tendon has increased mobility allowing it to be attached anatomically without excessive tension. By creating additional mobility of the tendon, tear patterns previously seen as unrepairable were now able to be repaired [17]. This technique involves releasing any adhesions on the bursal and articular sides of the supraspinatus all the way to the coracoid process base. The lateral tissue that links the supraspinatus to the infraspinatus tendon is left intact. The extent of release is confirmed by exposure of the coracoid base [19]. The procedure for AIS was previously described by Lo et al [16]. Briefly, standard posterior and lateral portals are established. After a capsular release, the lack of tendon mobility is confirmed. Traction sutures are placed in the supraspinatus and infraspinatus tendons to assist in visualization and alignment. Using the base of the coracoid as a guide, an accessory lateral portal is established, and scissors are used to shear the tissue connecting the supraspinatus tendon and the rotator interval [16, 20, 21].

AIS has been shown to increase clinical outcomes in patients where anatomical attachment was impossible before the interval slide [21]. Lo et al. demonstrated a significant improvement in pain scores, forward elevation, strength, and UCLA scores in a small group of patients with massive immobile rotator cuff tears [16]. Although clinical outcomes are improved in patients who underwent AIS, concerns exist in the rates of re-tearing and the vascularity of the remaining tendon [21, 22]. Although Berdusco et al. found improved clinical outcomes, they found a re-tear rate of 55% with the remaining 45% having some evidence of tissue spanning the defect [21].

If the AIS does not increase the mobility of the tendon enough for anatomic repair, a posterior interval slide (PIS) is indicated. The PIS is the process of releasing the supraspinatus tendon from its attachment to the infraspinatus tendon [16, 20]. Briefly, the scapular spine is used as an anatomical landmark for the plane between the supraspinatus and infraspinatus. Traction sutures are placed on both tendons and used to hold traction as well as prevent injury to the suprascapular nerve. The interval is then released using scissors or electrocautery. Confirmation of acceptable mobility is confirmed, and repair of the rotator cuff tear is completed [22]. Cadaveric studies have found PIS to be effective in assisting the mobilization of a retracted supraspinatus tendon [23].

In circumstances where both the supraspinatus and the subscapularis are involved in the tear,

a standard interval slide will result in two separate flaps. Although the flaps can usually be repaired, the complication can be avoided by performing a technique described by Lo and Burkhart as interval slide in continuity [24]. This technique involves the release of the coracohumeral ligament and a portion of the rotator interval while still maintaining the integrity of the lateral margin. This increases the mobility of the subscapularis and supraspinatus without creating two separate flaps [24].

Results following PIS with rotator cuff repair have been inconsistent. Berdusco et al. concluded using interval slide techniques can result in improved clinical outcomes of patients with massive rotator cuff tears; however, they also found a significant re-tear rate [21]. Lo et al. found improvements in pain, strength, and shoulder function in patients that underwent a double interval slide [16]. Although some studies demonstrated clinical improvement, Kim et al. found a re-tear rate of 91% on follow-up MRI imaging at 6 months using a posterior interval slide technique. In addition, the clinical measurement showed no significant improvement when compared to patients that underwent partial repair with margin convergence only [22].

There were no significant reactions attributable to the interval slide procedure reported in the literature. As mentioned earlier, there are concerns with the devitalization of vasculature on the remaining tendon as well as concerns with further impairment of an already damaged muscle tendon unit [1, 22, 25].

12.5 Author's Preferred Technique and Pearls

Our specific RCR techniques have been previously published [1, 5, 7, 26, 27]. The authors preferred technique is to perform RCR in the lateral decubitus position. While all of the above steps can be performed in either the lateral decubitus or beach chair positions, the lateral decubitus position specifically provides easier access to the inferior capsule and improves distention of the glenohumeral joint allowing for an easier and more efficient inferior capsular release. The humerus can also be easily rotated into internal and external rotation, as necessary, to provide sufficient access to the entire insertion of the tendon on the greater tuberosity. The lateral position also allows the surgeon to visually assess any superior migration of the humeral head and the adequacy of the capsular release when complete as the humeral head will drop inferior and center on the glenoid.

For our capsular release, we prefer to use a hook cautery as it allows for accurate and controlled cuts in the capsule. Hook cautery are also generally low profile and allow the surgeon to have easier access to the inferior capsule. A complete capsular release, thorough debridement, and RC tissue release from the undersurface of the acromion allows for improved mobilization of the rotator cuff tendons along with easier reduction to the tuberosity. The sum of each of the parts significantly contributes to the ultimate success of the repair. Trephination holes placed via microfracture awl or drill should be placed along the entire articular margin to maximize blood flow and stem cell penetration at the site of the repair [12, 13]. At the current time, we do not perform any interval slides for fear of devitalizing the vasculature of the remaining rotator cuff tendon tissue [22, 25]. Instead, we prefer margin convergence techniques to reduce tension on the repair and allow for easier reduction to the greater tuberosity [1, 5, 8, 28–30].

12.6 Conclusion

A thorough release and debridement of the rotator cuff tissues is often important in the failed or revision RCR setting. These concepts and techniques can also be applied to difficult or large primary RCRs as well. Adequate planning and preparation is vital to improve efficiency in the operating room and to maximize the available time to complete the repair. The concepts and techniques presented above set the groundwork for a surgeon to safely and efficiently perform an RCR after a previously failed surgery.

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Repair with Biologic Augment

13

Grace C. Plassche, Stephanie C. Petterson, and Kevin D. Plancher

13.1 Introduction

Recurrent tears following rotator cuff repair are common. While reports vary in the literature (range 5%–94% [1, 2]), approximately 20% of cases experience poor tendon healing and 31%–47% of cases experience failure of the repair construct [3, 4]. Risk factors for retear and poor tendon healing can be categorized as patient demographic factors, intraoperative factors, and postoperative factors. Older age, larger tear size, tendon retraction, poor tendon quality, fatty infiltration, and compromised healing potential (i.e., immunosuppression, diabetes, smoking status) have been shown to increase the risk for retear [5]. The intraoperative factors associated with a tendon defect are concurrent biceps tenotomy or tenodesis and acromioclavicular (AC) joint coplaning [6]. Single-row vs. double-row fixation, number of anchors and anchor placement are examples of intraoperative factors that do not affect tendon healing. Although there is a variety in postoperative protocols such as early vs. late motion or the use of an abduction pillow, there are no specific postoperative factors associated with risk of retear [7, 8].

Primary and revision repair place a significant burden on the health economy of the United States. The average total cost of rotator cuff repair is estimated to be $7000, while the average total cost of revision rotator cuff repair is estimated to be $58,000 [9, 10]. Therefore, it is vital that precautions are taken in order to minimize the number of secondary and tertiary revision procedures performed. Revision rotator cuff repairs are twice as likely to result in structural failure and experience worse functional outcomes compared to primary rotator cuff repair [11]. This may be related to retained hardware or concomitant bony defects.

Treatment strategies for revision rotator cuff repairs must consider the cause of structural failure and address associated risk factors that may have contributed to the retear. In patients with poor tendon-to-bone healing quality, patient-specific factors, such as diabetes, hemochromatosis, immunosuppression, smokers, steroid users, or laborers and athletes who place high stress on their rotator cuff must be considered when examining subsequent interventions. Utilization of

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biologic augmentation in these patients may aid in tissue healing. A bioinductive patch or graft can provide mechanical strength and/or deliver growth factors or stem cells to the repair site and may help create the ideal environment for tissue regeneration given the avascularity of the enthesis [12]. Stem cells create an ideal environment for tissue regeneration by releasing immunomodulatory and angiogenic cytokines such as TGF-Beta, VEGF, and PGE2 which may aid the biologically-augmented patch by providing an environment that is conducive for cell and vessel migration [13].

Several graft options have been tested in animal studies and human studies and range from naturally derived to synthetically manufactured (Table 13.1). Allografts, autografts, and xenografts are the essential options for naturally-derived patches and are beneficial for their ability to integrate into host tissue. Alternatively, synthetic grafts have been developed to provide an option with optimal mechanical stability [13, 14]. Studies have also investigated the tissue healing effects of incorporating specific growth factors or amniotic cells into structural as well as non-structural grafts [15]. As several of these patch options are in the earlier phases of testing, there is no universal consensus on which extracellular matrix conveys the greatest clinical and functional benefit, given the limited number of randomized clinical trials and clinical research studies. This chapter will detail evaluation of failed rotator cuff repair and explore the various options that exist for biologic augment for revision rotator cuff repair.

13.2 Rotator Cuff Repair Failure Evaluation

Rotator cuff repair failure can be defined in a multitude of ways. First, failure can be defined as persistent pain and weakness of the rotator cuff and functional deficits [16]. Failure can also be defined as failure of tendon healing following repair as well as retear of the repair construct [17]. When rotator cuff repairs fail to heal as a result of a poor healing environment, there is often advanced muscle atrophy and fatty degeneration [17]. Rotator cuff repairs may fail gradually or acutely and depend upon modifiable and nonmodifiable risk factors. The predominant mode of rotator cuff failure is the tendon pulling through sutures, and there are three locations where a retear may occur (1) bone-tendon failure inside the tunnel, (2) at the interface between the tendon and tunnel, and (3) tendon-suture junction [16, 17]. Additionally, suture anchors can pull of the bone and produce loose bodies which damage the articular surface [17]. Therefore, it is important to first correctly diagnose the retear and identify the causes of the rotator cuff repair failure. A thorough patient history and physical examination must be undertaken to determine if there was inciting incident for retear.

Reasonable suspicion of a failed rotator cuff repair may be raised by a variety of symptoms consisting of night pain, persistent pain, weakness, stiffness, and rehabilitation regression. With the potential for a retear established, a physical examination should evaluate both shoulders for muscle atrophy and scapular dyskinesia. Furthermore, passive and active range of motion (ROM) and strength of the rotator cuff should be examined. A painful arc of motion may be experienced as the arm is raised from 70° to 120° of abduction when the rotator cuff repair has failed [17]. Additionally, a lidocaine injection test can also be performed to assist in the diagnosis of rotator cuff retear with pain relieved after injection and persistent weakness observed.

If reasonable suspicion is determined by symptoms and physical examination, imaging studies should be conducted to confirm the presence of a retear. Routine radiographs are often the first imaging modality undertaken. Plain radiographs may reveal glenohumeral osteoarthritis and cuff tear arthropathy as well as a decreased acromiohumeral distance (<2 mm), subacromial osteophytes, or humeral head migration. However, radiographs are not sufficient in diagnosing failure and advanced imaging is required to visualize retear of the rotator cuff as well as determine the nature of the retear.

Magnetic resonance imaging (MRI) and ultrasound have been used in the diagnosis of rotator

Table 13.1 Graft options for rotator cuff repair revision

Product	Company	Source
Human-derived tendon augmentation grafts		
Clarix® Cord 1 K	Amniox Medical, Inc. (GA, USA)	Human amniotic membrane and umbilical cord
AmnioClear™	AFCell (IN, USA)	Human amniotic tissue
AmnioFix®	MiMedx (GA, USA)	Human amniotic membrane
AlphaGEMS	Riordan-McKenna Institute (TX, USA)	Human placental amnion
GraftJacket®	Wright Medical Group, Inc. (TN, USA)	Human cadaver dermis
Arthroflex®	Arthrex (FL, USA)	Human cadaver dermis
XWrap™	Applied Biologics (AZ, USA)	Human amniotic membrane
Synthetic tendon augmentation grafts		
Artelon®	Artimplant AB, (Sweden)	Polyurethane urea polymer
Sportmesh™	Biomet Sports Medicine (IN, USA)	Polyurethane urea polymer
Gore-Tex® Patch WL	Gore and Associates, Flagstaff (AZ, USA)	Expanded polytetrafluoroethylene
LARS™ Ligament	Corin USA (Tampa, FL)	Terephthalic polyethylene polyester
Leeds-Keio®	Xiros PLC, Neoligaments (Leeds, UK);	Polyester ethylene
Poly-tape®	Yufu Itonaga Co., Ltd. (CA, USA)	Terephthalate
X-Repair®	Synthasome (CA, USA)	Poly-L Lactide
Biomerix® RCR Patch	Biomerix (NY, USA)	Polycarbonate polyurethane urea
Animal-derived tendon augmentation grafts		
Bio-Blanket®	Kensey Nash Corporation (PA, USA)	Bovine dermis
CuffPatch®	Arthrotek (IN, USA)	Porcine small intestine submucosa
OrthADAPT®	Pegasus Biologic Inc. (CA, USA)	Equine pericardium
Zimmer® Collagen Repair Patch (Previously Permacol™)	Zimmer (IN, USA)	Porcine dermis
Restore™	DePuy Orthopedics (IN, USA)	Porcine small intestine submucosa
Shelhigh No-React® Encuff Patch	Shelhigh Inc. (NJ, USA)	Bovine or porcine pericardium
TissueMend®	Stryker Orthopedics (NJ, USA)	Fetal bovine dermis
Conexa®	Wright Medical Group, Inc. (TN, USA) (Formerly Tornier)	Porcine dermis
Regeneten Bioinductive Implant	Smith & Nephew (MN, USA) (Formerly Rotation Medical)	Bovine tendon

cuff tears and retears. MRI is often considered the gold standard for diagnosing primary tears but may not provide the same sensitivity in failure of the rotator cuff repair. This is a result of the confounding effects of retained sutures and anchors as well as altered signals from postsurgical changes. MRI can provide vital information about tendons, muscles, and cartilage, specifically with intra-articular contrast with 70%–90% accuracy [18]. Ultrasound can act as an alternative imaging modality that avoids the issues related to postsurgical changes. Ultrasonography has high sensitivity and specificity (90% and 79%) for detecting rotator cuff repair failure if operated correctly. Sonography can be utilized to monitor healing postoperatively, specifically in patients who may have increased risk of failure [19]. Depending on the technical expertise of the technician, ultrasound can be an extremely accessible and effective imaging modality for the diagnosis of rotator cuff repair failure.

13.3 Patient Selection

Given the increased concern for healing capacity in revision rotator cuff repair, it is important to evaluate and select the patients who will benefit

from biologic augmentation. Candidates for this type of reoperation include individuals with compromised healing and suboptimal tissue quality due to factors such as diabetes, immunosuppression, or smoking. Patients who put high stress on the rotator cuff such as laborers or overhead athletes may also benefit from a biologically-augmented revision. Given the limited evidence in revision rotator cuff repair, we must look at successes and indications in primary repair to guide surgical decision-making in the revision setting. Biologic augmentation in primary repair is indicated specifically in patients with retracted tears, healthy muscle tissue, and poor tendon quality all of which are often present in patients requiring revision rotator cuff repair [20].

13.4 Outcomes of Revisions with Biologic Augmentation

Patch augmentation has shown promising results with low rates of structural failure in primary and revision rotator cuff repairs [13, 21, 22]. The increased contact between the tendon and bone provided by a patch limits the formation of weaker, fibrovascular scar tissue and promotes the formation of normal tissue [13]. Native tissue regeneration results in increased biological healing, strength of rotator cuff repair, and function, which is further enhanced if the patch simultaneously provides stem cells or growth factors [22]. In a recent systematic review of 22 revision rotator cuff repair studies, 12% of revision rotator cuff repairs utilized biologic patch augmentation [16]. This illustrates the relatively limited application and evidence for biologic augmentation in revision rotator cuff repair and highlights the need for more clinical trials to assess potential, efficacy, and indications. However, patch and graft utilization have been shown to be a safe and effective treatment for a wide variety of primary tears including partial-thickness and large or massive full-thickness rotator cuff tears [21–25].

Human dermal matrix allografts have previously been proven to result in significantly higher healing rates in primary rotator cuff repair and were indicated for patients with full-thickness recurrent tearing of the supraspinatus and/or infraspinatus tendons [20, 21]. Hohn et al. in 2018 evaluated the clinical outcomes of arthroscopic application of a structural acellular human dermal matrix allograft in arthroscopic revision rotator cuff repair [21]. Twenty-three patients, 19 men and 14 women, with a mean age of 60.1 ± 9.3 years, were included. Three (13%) patients reported tobacco use and three (13%) patients had a history of diabetes. Average retear size was 3.7 ± 0.7 cm. The rotator cuff was repaired using an arthroscopic single-row repair with triple-loaded suture anchors placed on the medial footprint. The allograft was then placed over the top of the rotator cuff and secured circumferentially. Postoperative patient-reported outcomes showed promising results at minimum 2-year follow-up with a postoperative ASES score of 77 and SANE score of 69. Ultimately, 17% of the patients had imaging-confirmed symptomatic retears at an average of 22 months (range, 3–72 months) postoperatively, with 13% of patients undergoing surgery [21]. The authors found a significant correlation between a shorter duration of time from primary to revision repair and worse outcomes and higher retear rate. Although the direct reason for the correlation is unknown, it is possible that tissue quality was compromised and could not withstand the strain of the repair or poor patient postoperative compliance led to both the primary and secondary failures [21]. This study is limited by a small cohort size, but the results exhibit the potential effectiveness of allografts in revision rotator cuff repair.

Augmentation grafts and patches were initially tested in arthroscopic rotator cuff repair, but they have recently been implemented in open revision of massive rotator cuff retears. A study by Petri et al. assessed the effectiveness of a structural human acellular dermal extracellular matrix patch impregnated with growth factors, glycosaminoglycans, and proteoglycans (Arthroflex, Arthrex, Naples, FL) in 13 shoulders undergoing open revision rotator cuff repair [22]. All patients (10 men and 2 women, average age 57 years) underwent revision rotator cuff repair using a deltoid-splitting, anterolateral approach

with an extended linked double-row technique with suture tapes. The biologic patch was trimmed and draped over the repair and tensioned [22]. No postoperative complications or adverse events were reported, and no patients required further surgery. At minimum 2-year follow-up, the ASES function score significantly improved compared to preoperative values and average patient satisfaction was 9/10 [22]. These patients had massive rotator cuff retears in the presence of otherwise healthy rotator cuff muscles indicating a potential benefit to a specific subset of patients. The positive clinical and functional outcomes once again indicate the potential benefit of augmentation in the setting of rotator cuff repair failure.

The bovine Achilles tendon derived bioinductive implant (REGENETEN, Smith & Nephew, Andover, Massachusetts, USA), which is not used as a structural graft at this time, is one such option that has shown positive results in revision rotator cuff repairs [26]. The aim of this biological patch is to enhance the body's healing potential by remodeling tissue which results in increased strength. This is achieved through a highly porous design which facilitates fibrovascular tissue ingrowth, collagenous tissue formation, and eventual scaffold resorption as demonstrated in a pre-clinical sheep model [27]. Clinical results indicate that native tendon thickness increases with no inflammatory reactions in partial-thickness, full-thickness, and revision rotator cuff tears [26, 27]. Additionally, significant improvements have been reported in patient-reported outcomes (e.g., patient satisfaction and the American Shoulder and Elbow Surgeons (ASES) pain score) following rotator cuff repair and revision repair with the bovine bioinductive patch [26].

The outcomes of primary rotator cuff repair with the reconstituted bovine Achilles tendon bioinductive implant (REGENETEN, Smith and Nephew, Andover, MA, USA) have been tested and confirmed in several clinical trials [26, 28–30]. One study included revision rotator cuff repairs [26]. Twenty-three patients with large (11 tears of 3–5 cm) or massive (12 tears of >5 cm) rotator cuff tears were included (average age 57.9 years, range 32–71 years) and 16/23 (70%) of these patients were revision repairs [26]. Safety was evaluated by implant-related adverse event reporting, postoperative tendon healing and thickness were monitored with MRI and ultrasound, and ASES scores were collected to assess clinical outcomes. At 2-year follow-up, mean ASES score was 82.9 and mean tendon thickness had increased from 6.29 mm at 3 months to 7.28 mm at 2 years. Ultrasound and MRI confirmed a 96% (22/23) healing rate, and there were no adverse events related to the implant. There was one failure due to progression of glenohumeral arthritis; however, this was not related to tendon healing capacity and the rotator cuff repair was intact [26]. Despite these promising results, further investigation into the outcomes of revision repair in larger cohorts are necessary with mid- to long-term outcomes to confirm the efficacy of the bovine collagen patch in the revision setting.

13.5 Other Augmentation Alternatives

In addition to the allografts and bovine collagen patch mentioned previously, there are various other graft options which have not been tested in the revision rotator cuff repair setting but have shown promising results in primary repairs. Synthetic patches are one such option. Synthetic patches can be manufactured from a multitude of materials such as polypropylene, polyurethane, poly-L-lactide, and polyethylene polymers [15]. Patches made of aligned nanofibers have exhibited increased strength and elastic modulus and can attract fibroblasts, an important factor in tissue regeneration [23]. Recent clinical studies have illustrated the safety of these patches as well as the potential for increased healing rates, biocompatibility, tendon regeneration, ROM recovery, and decreased retear rates [15, 24, 25]. Despite the biomechanical strength and decreased risk of host rejection, there are concerns over the degradation products of synthetic patches [15]. The various polymers utilized in these grafts can produce high levels of lactic and glycolic acid which can inhibit

mineralization of the matrix and decrease cellular proliferation [23]. The inconsistency and potential issues associated with synthetic grafts was illustrated in a study of poly-L-lactide patch augmentation in 16 consecutive patients with massive or recurrent rotator cuff tears. Despite relatively high postoperative Penn Shoulder and ASES pain and function scores, 62% of patients had full-thickness retears [31].

Xenografts are animal-derived extracellular matrices that have been decellularized and can thus be utilized as scaffolds with useful growth factors [15]. The major concern with xenografts, especially when compared to their allograft counterparts, is the potential inflammatory response they may elicit. The two most commonly utilized xenograft sources are porcine small intestinal submucosa and porcine dermis, both structural grafts [23]. The submucosa graft provides type 1 collagen and several growth factors (e.g., TGF-b, FGF-2, VEGF) that aid in tissue regeneration. Despite the exciting prospects of these constituents, the clinical outcomes were less than promising as healing rate and outcome scores did not improve [23]. In addition to the inherent mechanical weakness, surgeons have moved away from this option as it is thought that failure is secondary to the host rejection of the submucosa graft [23]. The dermal xenograft has exhibited more positive results as the inflammatory response is minimal and studies have noted significant improvements in motion, strength, and ASES score [15, 23]. In a cohort of 22 patients treated porcine dermal xenograft, 73% of patients had an intact repair at 2-year follow-up [32]. However, the literature remains mixed regarding the efficacy of porcine dermal xenografts, especially compared it to other graft types. A systematic review comparing allografts, synthetic grafts, and xenografts noted lower forward extension, abduction, and external rotation with the porcine dermal patch as well as decreased functional scores and an average retear rate of 44%, versus failure rates of 23% and 15% in allografts and synthetic grafts, respectively [25].

Beyond patch and graft augmentation which combine mechanical and chemical factors, there are certain procedures which focus solely on the biochemical aspects. Beneficial molecules can be delivered to the site of repair in the hopes of creating a more conducive and natural healing environment [23]. Such therapies include platelet-rich plasma (PRP) and mesenchymal stem cells (MSC), and cytokines. Despite the increase in use of these biologic products across orthopaedics, specific studies of each augmentation in revision rotator cuff repair are lacking and any conclusions must be drawn from their application in primary repair.

PRP has experienced a dramatic rise in popularity, attributable to its ease of use as an injection and its high concentration of growth factors involved in the healing process (TGF-B, FGF, PDGF) [15]. However, a meta-analysis found that PRP has not been shown to improve healing rate or functional outcomes when compared to control groups in rotator cuff repair [33]. It is proposed that the benefit from PRP as an adjuvant may be limited to small to medium tears in the hopes of preventing retear, in which case revision rotator cuff repairs will likely derive little benefit from PRP [15].

MSCs, which can be derived from bone marrow, placenta, or adipose tissue, have been shown to aid healing rates of primary rotator cuff repairs [15, 23]. Stem cells have been found to be metabolically active in the repair site which results in fibrocartilage formation, thus regenerating tissue that is more natural and provides the necessary strength [23]. Functional outcomes have not been shown to derive the same benefit from MSCs; however, further studies are needed to truly understand the impact of MSCs [34]. In a study of 75 patients (35 men and 40 women, average age, 63.12 ± 7.26 years) comparing conventional rotator cuff repair and augmentation with MSCs and a patch, the augmented repairs exhibited a lower retear rate, 19% versus 46%, confirmed by imaging at average 20-month follow-up [15, 34]. This may be indicative of the direction of future

studies as the various augmentation modalities can be combined to provide the optimal biomechanical and biochemical support necessary for revision rotator cuff tears.

13.6 Author's Preferred Technique

Revision rotator cuff repair requires care and attention in order to prevent a retear. In the case of a revision rotator cuff repair, patch augmentation is indicated in patients with healthy rotator cuff muscles and potentially compromised healing potential. The results of our first 16 patients with partial-thickness and full-thickness tears who underwent rotator cuff repair augmented with the bovine Achilles tendon-derived bioinductive implant (REGENETEN, Smith & Nephew, Andover, Massachusetts, USA) are promising. The implant was not utilized as a structural graft. At most recent follow-up within 2 years (average 14 months), these patients exhibited significant improvements in postoperative range of motion and strength including flexion, external rotation at 90 degrees abduction, and internal rotation. Patients also reported minimal disabilities (Disabilities of the Arm, Shoulder, and Hand score), low pain (Visual Analog Scale score), and SF-12 Physical and Mental scores that are near the national average.

One patient in our series experienced a retear of a previous repair and underwent revision rotator cuff repair with patch augmentation. The patient was a 75-year-old male with a history of hypercholesterolemia, hypothyroidism, and hyperinsulinemia. Fourteen weeks after his primary rotator cuff repair, the patient reported extreme pain in his left shoulder. Inspection of the painful shoulder revealed relatively normal passive range of motion with 170° of forward flexion though the patient expressed that there was immense pain with active flexion range of motion to 160°, with 90° of abduction and 90° of external rotation. It was noted that his internal rotation was

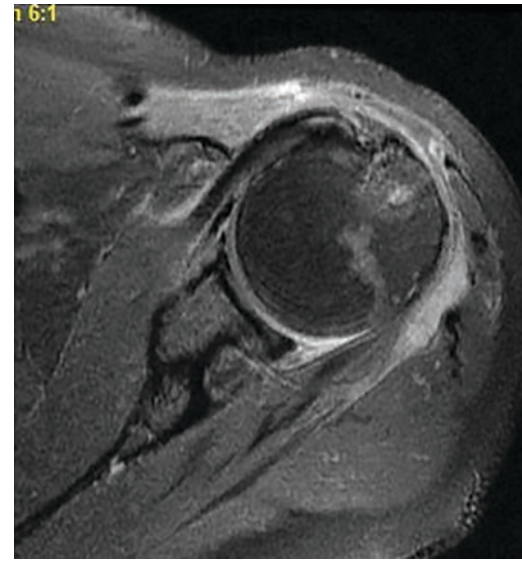

Fig. 13.1 MRI of supraspinatus tear in 75-year-old patient. © Kevin D. Plancher

to T11, which was equivalent to the contralateral side. The patient exhibited 4/5 strength when testing the supraspinatus against resistance. Given the physical findings there was a high index of suspicion that the patient had a retear of the rotator cuff and an MRI was pursued. MRI revealed a full-thickness tear of the supraspinatus (Fig. 13.1).

Musculature was confirmed as normal and the cervical spine had also been previously imaged allowing for the elimination of potentially confounding diagnoses. It was recommended that this patient was a good candidate for revision rotator cuff repair with bovine bioinductive patch augmentation (REGENETEN, Smith and Nephew, Andover, MA, USA) (Fig. 13.2a–c).

At 1-year follow-up, the patient was pain-free at rest and with all activities. The patient is able to play tennis multiple times a week and expresses his satisfaction with the repair. There have been no further complications, and he exhibits full shoulder ROM and 5/5 muscle strength. In the case of this repair, biologic augmentation was effective though more patients and longer term follow-up is required.

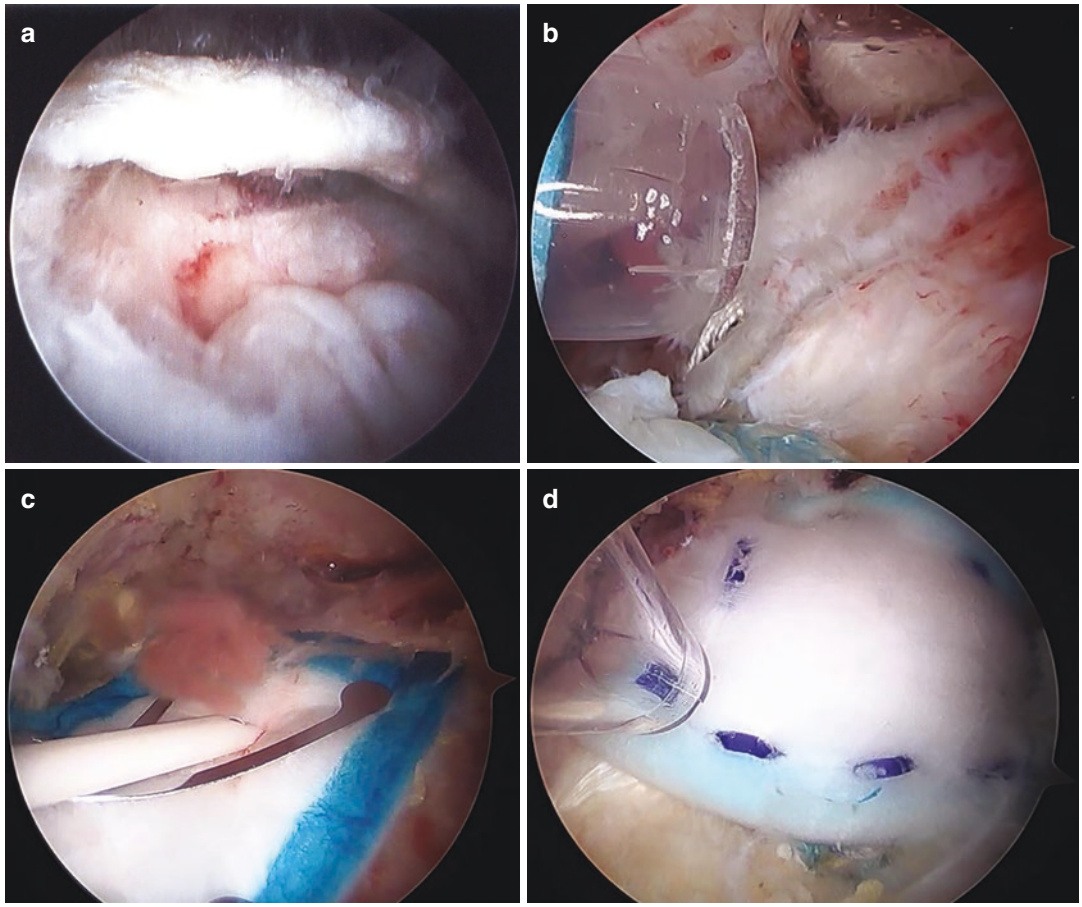

Fig. 13.2 Arthroscopic views of the placement of the bovine bioinductive patch over the completed rotator cuff repair. (**a**) Arthroscopic view of rotator cuff tear in 75-year-old patient. (**b**) Rotator cuff repair completed with insertion of the canula for the bovine bioinductive patch. (**c**) Placement of the bovine bioinductive patch over the rotator cuff repair. (**d**) Final placement of the bovine bioinductive patch secured with multiple tendon anchors over the complete rotator cuff repair. © Kevin D. Plancher

13.7 Conclusions

Failure of rotator cuff repair can reach rates as high as 94%, indicating the necessity for effective revision strategies. There are numerous reasons for failure; however, insufficient biological healing and inadequate strength of the initial repair construct are the most common factors. Biological augmentation patches have the potential to provide biomechanical and biochemical support for revision rotator cuff repairs as evidenced in the limited literature. Further, larger scale studies are needed to confirm the efficacy of augmentation methods and elucidate the modality best suited for these repairs.

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14 Repair with Interposition Graft for a Failed Rotator Cuff Repair

Moayd Abdullah H. Awad and Ivan Wong

14.1 Introduction

Rotator cuff tears is a common shoulder pathology with an estimated 270,000 primary repairs performed annually in the United States [1]. The incidence of primary rotator cuff repairs (RCR) has been increasing recently given the successful clinical and functional outcomes [2]. The main goals of rotator cuff repair are pain relief, restoration of function, and the creation of an intact cuff with avoidance of complications. The evaluation of a successful repair has evolved from traditional physician measurements to more patient-centered assessments, which include the ability to perform daily and exertional activities and quality of life [3]. Rotator cuff healing can be further evaluated with advanced imaging studies including ultrasound (US), magnetic resonance imaging (MRI), and computerized tomography (CT) scans with contrast [4]. Healing rates range from 31% to 93% depending on the tear size and the method of fixation [5]. Despite structural failure, many patients reported satisfactory clinical outcomes [6]. Patients experiencing continuous pain and weakness following surgery are considered to have a failed RCR and usually need a revision surgery [7].

In this chapter, we aim to address a failed rotator cuff repair using graft interposition, also known as bridging, as an option for failed rotator cuff repairs. We will explain the basic concepts behind bridging and the surgical technique with a video demonstration of the procedure (Video 14.1). Finally, we will go over the current literature regarding this procedure and the possible complications.

14.2 Graft Utilization in Rotator Cuff Repairs

The utilization of grafts in addition to RCR was first described by Neviaser in 1978 [8]. In 2008, Snyder described the arthroscopic technique of utilizing acellular human dermal matrix (GraftJacket) for repairing massive rotator cuff tears [9]. Although this technique was described for reconstructing massive rotator cuff tears, it can still be used for reconstructing failed primary RCR. Different grafts options were introduced [10] including allografts which are discussed in this chapter, while other options are reviewed in other chapters of this book.

Supplementary Information The online version of this chapter (https://doi.org/10.1007/978-3-030-79481-1_14) contains supplementary material, which is available to authorized users.

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Acellular human dermal matrix when harvested is prepared to preserve the vascular channels, collagen, elastin, and proteoglycan constituents while eliminating all cellular components. Extensive biomechanical and biochemical evaluations were done to test its applicability as a graft material [11]. In a histologic evaluation, Snyder found an intact graft with early evidence of host tissue integration in a biopsy obtained 3 months after repair [12].

14.3 Preoperative Evaluation

When deciding a revision surgery for failed RCR, numerous patient factors should be considered. Patient age, current symptoms, and range of motion (ROM) should be evaluated in the same concept of making the decision for primary repair that is described in the next paragraph. Other factors taken into account in the decision-making for revision surgery include the presence of superficial or deep infection (contraindication), tear size, and the presence of glenohumeral arthritis or cuff arthropathy. Additionally, higher rates of failure have been reported in patients above the age of 65, massive tears (>5 cm), the presence of >50% fatty infiltration, active smokers, and diabetic patients [13].

The decision-making process usually starts with a good history and physical exam, with the most common complaints being pain and weakness. Current patient activity level and physical demands either for work, sports, or recreation are also important factors to consider. It is also important to distinguish the patients experiencing persistent pain/weakness since surgery from those who had a period of improvement then started to get worse, as these patients usually experience a decrease in function related to trauma [14].

A physical exam of the shoulder should always start with examining the C-spine. Patients with C-spine pathologies can exhibit shoulder pain and limited ROM. On inspection of the shoulder, the physician should look for signs of atrophy of the supraspinatus and infraspinatus as they may indicate a massive re-tear. Palpation of the glenohumeral and acromioclavicular (AC) joints, rotator cuff insertions, and biceps groove is performed to locate the area of maximum tenderness. Both active and passive ROM should be assessed with focused strength exams of each rotator cuff muscle. Diagnostic injections can be helpful to differentiate between extrinsic (e.g., C-spine radiculopathy) and subacromial impingement, or AC injections can be used to diagnose AC arthritis [13].

Preoperative imaging usually starts with standard shoulder X-rays, followed by MRI or US. Postoperative MRI has a high specificity (91%) but low sensitivity (25%) to diagnose recurrent rotator cuff tears [15].

14.4 Surgical Technique

Bridging used for a failed rotator cuff repair can be done either open or arthroscopically depending on the surgeon preference. Due to the higher complication rates of the open technique [16], arthroscopic bridging reconstruction is more often used. This book chapter describes arthroscopic bridging reconstruction in the lateral decubitus position as described by Bond et al. [9] (Fig. 14.1).

Once the patient is positioned and general anesthesia is induced, the arm is suspended in 50° of abduction and 20° of forward flexion for intra-articular examination. A posterior portal is created and all procedures begin with a standardized 15-point diagnostic evaluation as described by Snyder [17]. The arm is then placed in the subacromial position (10° of abduction/10° of forward flexion) and the bursal tissue is debrided. The subacromial space is then accessed and decompression is done, if needed as determined by fraying on the CA ligament. Then, the previous repair is visualized from both the anterior and the posterior portals and the tear size and retraction is evaluated. The tear is appropriately released and mobilized in order to assess if a

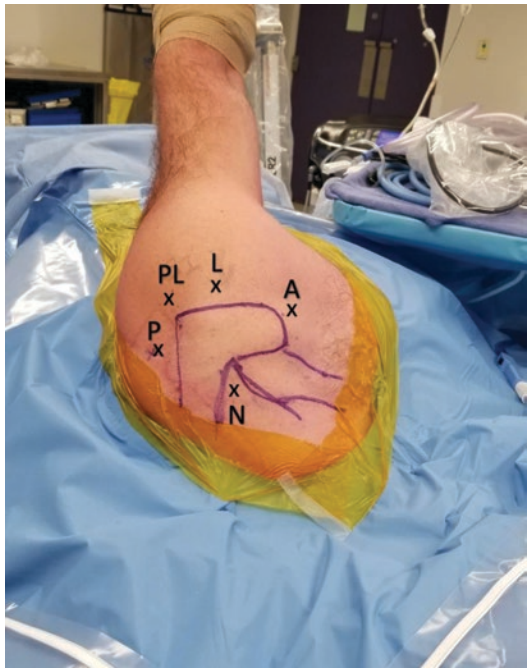

Fig. 14.1 Picture showing a patient positioned in the lateral decubitus position with their left shoulder prepped for surgery, with markings of the acromion and distal clavicle. *P* posterior portal, *PL* posterolateral portal, *L* lateral portal, *A* anterior portal, *N* neviaser portal

revision of the primary repair is applicable or not. If the tear size is massive or the retracted tendon is unable to reach the footprint at the humeral site, an acellular human dermal matrix is prepared on the back table. Four measurements are usually taken: (1) anterior to posterior, just medial to the residual cuff tissue; (2) anterior to posterior at the medial edge of the greater tuberosity along the articular cartilage; (3) medial to lateral and the posterior edge of residual tissue; and (4) medial to lateral at the anterior stump or biceps tendon. Based on these measurements, the graft is prepared to the same dimensions with 11 STIK knots and four alternating suture colors which are marked and templated (Fig. 14.2a, b). Once the measurements are taken, the remnants of the retracted tendon are debrided until healthy tissue is exposed. The lateral edge of the tendon is properly freed and the greater tuberosity is decorticated until cancellous bone is exposed (Fig. 14.3).

Both the anterior (with biceps tendon if intact) and posterior edges of the cuff are anchored to bone using suture anchors (named goal post anchors). Beginning anteriorly, the cuff remnants and biceps tendon (if intact) are pierced using a medium crescent suture passer. Ideally, three sutures are passed anteriorly through anterior portal, three sutures medially through the Neviaser portal, and three sutures posteriorly through the posterior portal, using sequential suture colors for easier suture management. A map of these colored sutures is created to help with suture management in subsequent steps of this procedure. Once all of the sutures are passed, the graft is inserted from the lateral portal through a passport cannula. After that, the graft sutures are tensioned to make the graft lie flat then subsequently tied (Fig. 14.4). A third medial anchor is placed between the two goal post anchors to secure the middle of the lateral graft. Two suture anchors are then used to create a double row fixation to compress the lateral aspect of the graft over the greater tuberosity.

14.5 Postoperative Protocol

All patients are discharged with an abduction shoulder brace (Slingshot 3.0; Breg Inc., Carlsbad, CA, USA). Ice compression is recommended for the first 48–72 h. The standardized physiotherapy protocol consisted of 8 weeks of passive mobilization followed by active mobilization. After achieving full ROM, special attention is given to strengthening of the surrounding muscles and to scapular control.

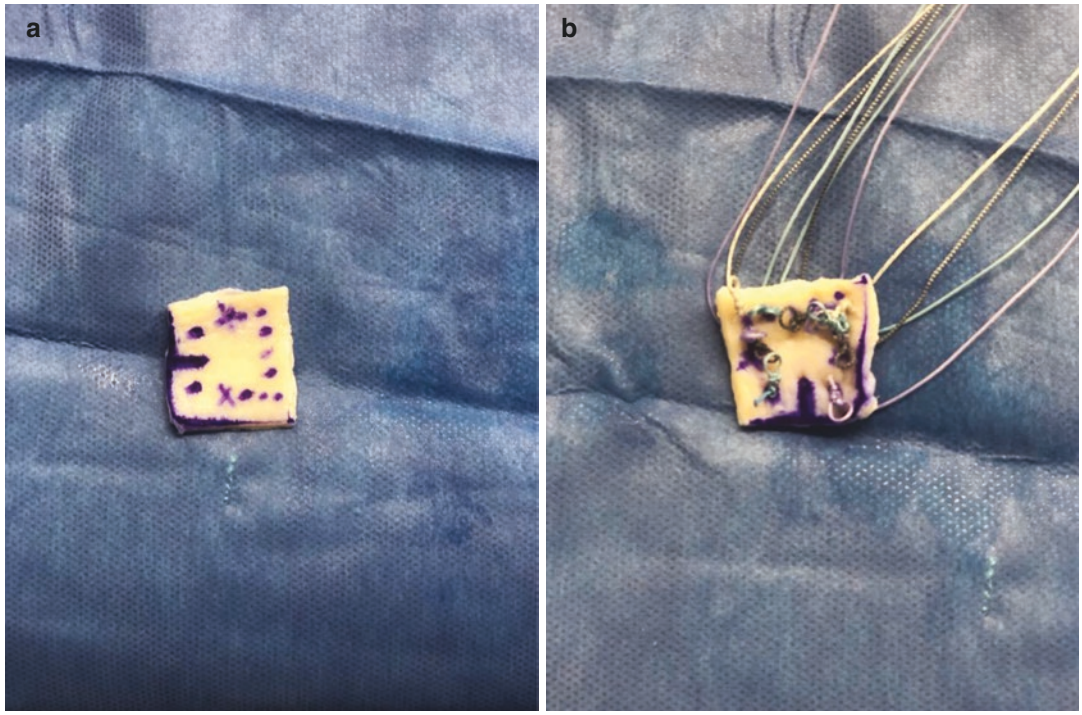

Fig. 14.2 Pictures of graft preparation. (**a**) Graft is cut to match the tear size; then orientation and suture holes are marked on the graft. (**b**) Graft after placement of 11 STIK knots with four sequential suture colors

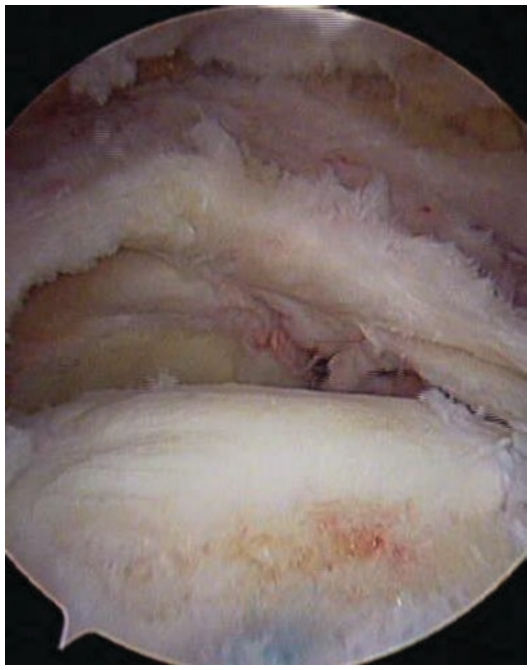

Fig. 14.3 Arthroscopic picture showing the medial tendon retracted to the glenoid level

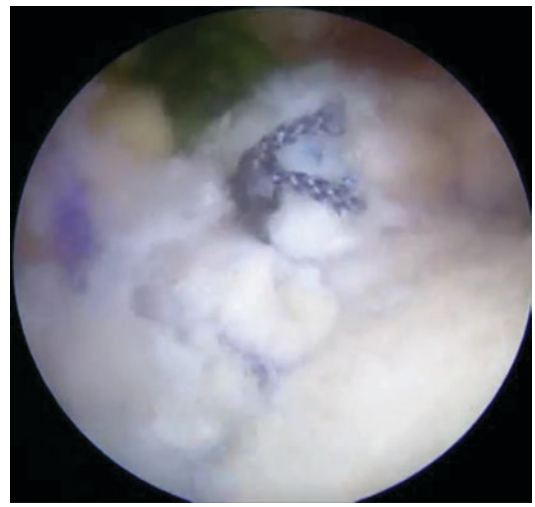

Fig. 14.4 The final view of the graft, viewing from the posterolateral portal

14.6 Discussion

Using bridging for failed RCR is a relatively new technique and its clinical outcome studies are not abundant. Any RCR revision surgery should start with good visualization of the re-tear site, proper stepwise mobilization, and soft tissue releases of the tendon. When a tension-free repair is achievable, the tendon should be repaired to the anatomic footprint. In the cases of large or massive irreparable cuff re-tears, surgeons should be thinking of other options including bridging for a large defect.

The advantages of the bridging include the following: it is an anatomic procedure that provides a tension-free construct and at the same time it avoids the morbidity associated with other options like tendon transfer or arthroplasty without burning any bridges for future surgeries. Previous published data showed a significant improvement in the University of California, Los Angeles (UCLA) and American Shoulder and Elbow Surgeons (ASES) scores at mean follow-up of 26 and 36 months [9, 18]. Healing rates varied between 74% and 90% intact graft on postoperative MRI [19]. As for active, young patients with no signs of arthritis, joint-preserving surgeries should be considered.

Debridement and partial repair was the traditional treatment when tears are irreparable. Although patients may experience an initial clinical improvement, they usually have a significant progression of their glenohumeral joint arthritis and a decrease in their acromio-humeral distance especially with the high failure rate (up to 40%) reported with this method [16, 20].

Superior capsular reconstruction (SCR) is a non-anatomic joint-preserving surgery that is becoming used more frequent recently with limited clinical and radiological results. Lin et al. [21] compared SCR with bridging in a recent systematic review and showed comparable healing and complication rates in two groups, but better active external rotation and patient-reported outcome scores in the bridging group, including Constant-Murley score, ASES, and visual analog score for pain. This study also showed that bridging is safe technique with an overall infection rate of 0.76% (i.e., 4 out of 593 patients, with three superficial infections and one deep infection) and all complications occurred in patients who had open procedures. At the moment, there are no randomized clinical trials to compare the two techniques; future randomized clinical studies with long follow-up period are needed to compare those techniques.

Reverse shoulder arthroplasty (RSA) is showing promising results in older patients and in patients with severe cuff tear arthropathy [22]. In non-arthritic shoulders, it demonstrated good clinical outcomes but was associated with a major complication rate of 12% [22]. Another study looked at the results of RSA in patients aged 60 and younger and found a complication rate of 39% (including early and late instability, persistence pain and stiffness, and infection) and 9% failure rate [23]. In addition, options are limited in terms of salvage procedures for a failed RSA. Black et al. looked at 16 patients who had a failed RSA and they reported a 56% major complication rate and 38% of the patients required further surgeries [24].

14.7 Conclusion

Failed rotator cuff repair is a common problem with different surgical treatment options available. Having a good understanding of the patient's overall clinical and radiological assessment is a key for proper surgical decision-making. Bridging may be an ideal surgical procedure for active patients with large or massive failed rotator cuff repairs, avoiding the morbidity associated with tendon transfers or arthroplasty, and not burning any bridges for future surgery.

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15 Superior Capsule Reconstruction with Biceps Tendon

Giuseppe Milano, Giuseppe Bertoni, and Niccolò Vaisitti

15.1 Introduction

Rotator cuff tears are common cause of upper extremity pain and disability. Age is the major risk factor and incidence ranges between 6.5% and 22.4% [1, 2]. Clinical manifestations of these tears are quite variable, depending on the size and location of the tear, ranging from no symptoms with good mobility to intense pain and pseudoparalysis of the shoulder.

The rate of primary rotator cuff repair has continued to rise in recent years with successful clinical results [3]. However, treatment of massive and irreparable rotator cuff tears (MIRCTs) remains a challenge. Over the years, many surgical techniques have been proposed to deal with MRCTs like tendon transfers [4], debridement, interposition grafts [5], and reverse total shoulder arthroplasty (RTSA) [6].

Massive and irreparable rotator cuffs tears are associated to a defect of the superior capsule [7]. The superior capsule is formed by a continuous sheet of collagen fibrils, which extends from the superior aspect of the glenoid medially to the greater tuberosity laterally. Its insertion on the greater tuberosity is even broader than the supraspinatus footprint [8]. It is thought that the superior capsule has a fundamental role in the static and dynamic stability of the shoulder and that injury to this anatomical structure can cause superior translation of the humeral head and changes in the joint kinematics, thus leading to cuff tear arthropathy (CTA) [7, 9–11].

In 2012, Mihata et al. [7] first described the superior capsule reconstruction (SCR) technique in a cadaveric study and showed that SCR with a fascia lata graft prevents superior humeral translation. One year later, preliminary clinical results were published [10]. The authors showed that, in the setting of irreparable rotator cuff tears, the arthroscopic SCR can restore superior glenohumeral stability and shoulder function. Since then, several variations of the original technique have been proposed, introducing different grafts source, thickness, and fixation configurations, with good clinical outcomes [12–19]. In this chapter, we described a technique of SCR with the autologous long head of biceps tendon (LHBT) as graft. The authors described the surgical technique, suggesting some advantages, such as costs, graft availability, limited donor-site morbidity, and ease of use and reliability.

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15.2 Indications and Contraindications to Superior Capsule Reconstruction

Accurate diagnosis is always made through patient history, physical examination, and imaging. Imaging requires standard radiographic evaluation for the assessment of arthritic changes and magnetic resonance imaging (MRI) that provides information about tear characteristics, fatty infiltration, and muscle atrophy. Ideal candidate for an arthroscopic SCR is a patient with:

- Massive contracted tears of the superior cuff (supraspinatus and upper part of infraspinatus tendon) with grade III–IV of fatty infiltration according to Goutallier classification [20].
- Upper migration of the humeral head.
- Intact or at least repairable subscapularis tendon.
- Delaminated tears: retraction and poor mobility of the articular layer.
- Intact teres minor.
- No severe cuff tear arthropathy (stage 1–3 according to Hamada classification) [21].

However, definitive indication to SCR is always confirmed at the time of surgery when actual tear reparability can be tested.

Recent studies showed that SCR is also a viable option in the setting of revision of failed rotator cuff repair as well as in pseudoparalytic shoulders [17, 22, 23]. Moreover, combination of SCR and partial cuff repair as well as over-the-top incorporation of the native rotator cuff have also been reported [16, 24]. Suturing the cuff over the SCR probably widens the indication of SCR also to repairable cuff tears.

Contraindications to SCR are:

- Severe glenohumeral osteoarthritis.
- Shoulder stiffness.
- Neurological diseases with involvement of the axillary nerve.

Recently, following the same principles of SCR, an anterior capsular reconstruction (ACR) has also been described for irreparable subscapularis tendon tears [25]. If a combination of both ACR and SCR could be a viable option in case of massive irreparable cuff tears involving subscapularis, supraspinatus, and infraspinatus tendon have not been defined yet.

15.3 Superior Capsule Reconstruction with Biceps Tendon Autograft

However, at least three major downsides could be claimed regarding the standard SCR technique:

- Steep learning curve: although fascinating, the technique requires a learning curve even for expert and skilled shoulder surgeons.
- Intraoperative time: it surely requires a longer intraoperative time than a standard or functional cuff repair, making the procedure even more difficult due to soft tissue imbibition.
- Costs: four to seven anchors as well as additional sutures and tapes, based on the technique, could be needed; nevertheless, the cost of the graft, if an autograft is not used.

For these reasons, alternative surgical techniques for SCR have been recently proposed.

The use of the LHBT as autograft was proposed by some authors with different techniques [26–30] and takes its rationale from peculiar features of this tendon. First, its anatomic insertion at the superior glenoid pole is an ideal position because it is demonstrated that medial fixation of a patch graft to the glenoid significantly reduces superior humeral translation in comparison to medial fixation to the torn rotator cuff tendon [31]. Second, medial attachment of LHBT is anatomical and does not require other fixation, thus sparing time and devices. Third, maintaining the native insertion of LHBT ensures an additional blood supply that could help tissue healing [5]. Moreover, thickness of the superior capsule ranges from 4.4 to 9.1 mm, which is similar to the thickness of the LHBT [32]. Finally, the technique does not imply either additional costs or morbidity related to graft harvesting.

Recent biomechanical studies showed that SCR with LHBT restores shoulder stability in irreparable rotator cuff tears by re-centering the humeral head on the glenoid and that is biomechanically equivalent and potentially even stronger than fascia lata autograft in the prevention of superior humeral migration [33–35].

The following surgical technique consists of the SCR by using the proximal part of (LHBT). The technique can be isolated or associated to a partial repair of the residual posterior part of the rotator cuff.

15.4 Surgical Technique

15.4.1 Patient Positioning

The procedure is performed under general anesthesia with the patient positioned in the beach chair position (procedure can be performed either way in lateral decubitus according to surgeon's preference). The shoulder is prepared and draped in a sterile fashion.

15.4.2 Portal Placement

Arthroscopy is performed through the following viewing portals:

- Posterior portal, used as a viewing portal or as working portal for suture management when the scope is in the lateral portal.
- Antero-superior portal, used for suture management.
- Lateral portal, used as a viewing portal or as working portal for suture management when the scope is in the posterior portal.
- One or two superolateral portals for anchors placement.

Additional anterior mid-glenoid portal can be established if combined subscapularis repair is necessary.

15.4.3 Step-by-Step Procedure

The arthroscopic procedures always start with an intra-articular diagnostic evaluation on air through the posterior portal in order to confirm rotator cuff tear and assess LHBT status as well as ruling out advanced articular degenerative changes and eventual subscapularis tendon tear. Two plastic cannulas with different calibers are always used: one 8.0 mm operative cannula and one 5.5 mm outflow cannula. An antero-superior portal is established through the rotator cuff tear in order to palpate the intra-articular structures and to create an outflow before starting the inflow. If a reparable subscapularis tendon tear is present, it must be repaired as first step.

Once the intra-articular phase has been completed, the scope is passed into the subacromial space through the posterior portal and the lateral portal is now created. By using an electrocautery device, the bursectomy is performed. The scope is then switched through the lateral portal, so the bursectomy can be completed through the posterior or the anterior-superior portal and tear characteristics can be then early assessed: size, location, shape, delamination, and tear retraction are evaluated, thus confirming the indication to an SCR (Fig. 15.1).

The scope is now switched again into the posterior portal. Biceps tendon is evaluated by inspection and palpation. Mobility and integrity of the LHBT is checked with a tendon grasper. Indication to SCR with LHBT is confirmed based on good tissue quality of the LHBT and especially from its proximal attachment to the superior labrum to a distance of 4 cm. By using an electrocautery device and a shaver blade, residual soft tissues on the greater tuberosity and around the LHBT are removed to favor LHBT re-routing posterolaterally.

By using a direct suture passer (FastPass Scorpion; Arthrex, Naples, FL, USA), two high-strength permanent braided sutures (#2 FiberWire, Arthrex) are passed through the LHBT with a "lasso-loop" configuration

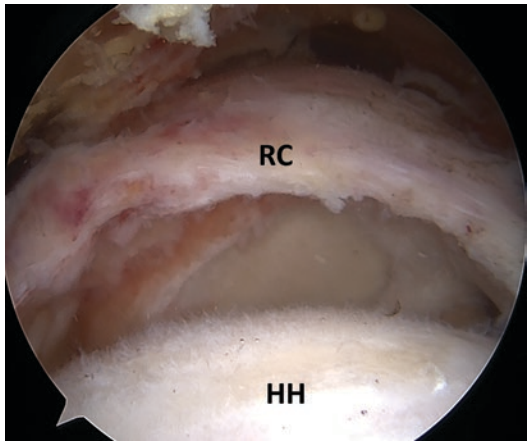

Fig. 15.1 Arthroscopic view of a right shoulder in beach chair position from the lateral portal. Tear characteristics can be assessed: size, location, shape, delamination, and retraction. *RC* rotator cuff, *HH* humeral head

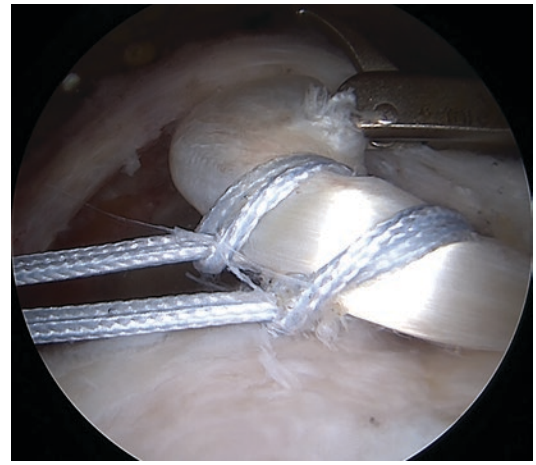

Fig. 15.2 Arthroscopic view of a right shoulder in beach chair position from the lateral portal. Two high-strength permanent braided sutures (#2 FiberWire, Arthrex) were passed through the LHBT with a "lasso-loop" configuration

(Fig. 15.2). Sutures are placed at the intra-articular exit of the tendon on the top of the intertubercular groove without taking down the transverse ligament. The LHBT is then tenotomized distally to the sutures (Fig. 15.3), so that the proximal stump of the tendon can be re-routed posteriorly and transferred onto the supraspinatus tendon footprint with the aid of a tissue grasper. A knotless PEEK anchor (4.75-mm Swivelock, Arthrex), positioned through the superolateral portal, is used to fix the LHBT into the supraspinatus footprint (Fig. 15.4). Care is taken to position the arm at 30° of abduction during tendon fixation. In this way, the LHBT, which is natively attached on the glenoid, acts as the autograft for the SCR. When possible, both anterior and posterior side-to-side repair are performed to the tendon graft, so that LHBT autograft also acts as an interpositional graft besides restoring capsular continuity in the transverse plane (Fig. 15.5). Functional repair by margin convergence of the residual rotator cuff can be performed over the biceps. Alternatively, additional anchor on the posterolateral aspect of the greater tuberosity can be inserted and used for functional repair of the infraspinatus tendon, based on tear pattern and retraction (Fig. 15.6). Small bone vents of the greater tuberosity are always performed.

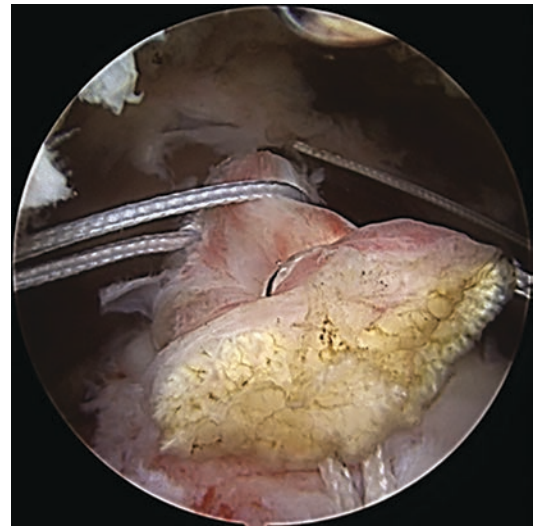

Fig. 15.3 Arthroscopic view of a right shoulder in beach chair position from the lateral portal. The LHBT is tenotomized distally to the sutures, and the proximal stump of the tendon is re-routed posteriorly and transferred onto the supraspinatus tendon footprint

15.4.4 Postoperative Care

Postoperatively, the arm is immobilized in an abduction sling with neutral rotation for 6 weeks.

Rehabilitation protocol starts 4 weeks after surgery according to the following phases:

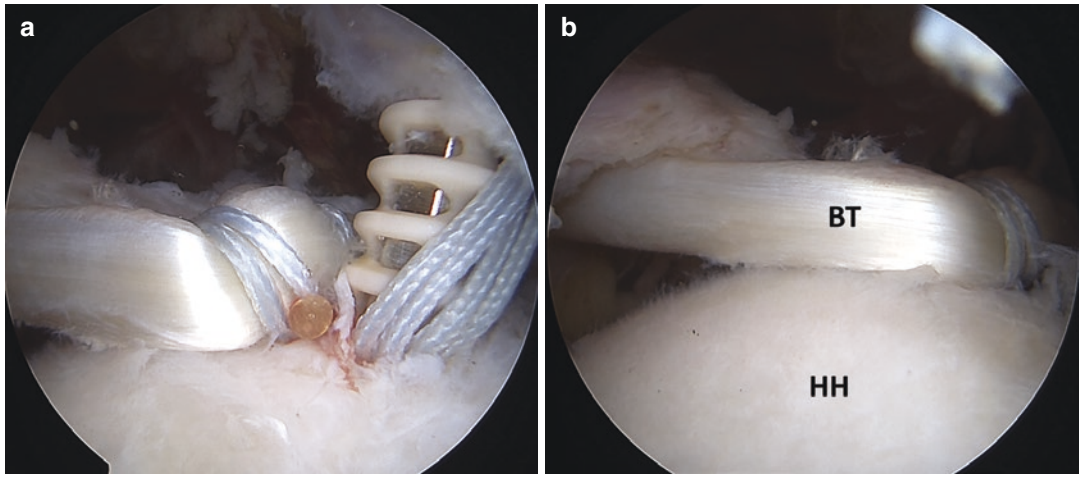

Fig. 15.4 Arthroscopic view of a right shoulder in beach chair position from the posterior portal. (**a**) A knotless PEEK anchor (4.75-mm Swivelock, Arthrex), positioned through the superolateral portal, is used to fix the LHBT into the supraspinatus footprint. (**b**) The biceps graft is fixed in tension. *BT* biceps tendon, *HH* humeral head

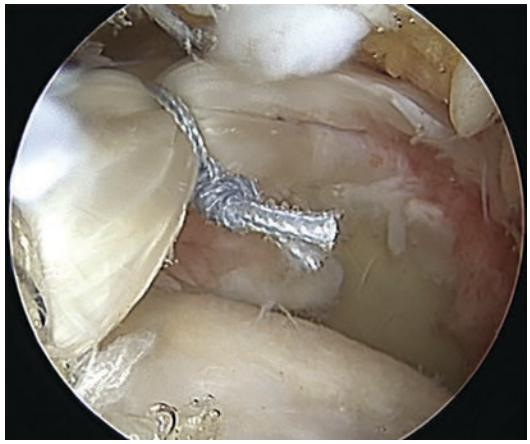

Fig. 15.5 Arthroscopic view of a right shoulder in beach chair position from the lateral portal. Posterior side-to-side repair was performed to the tendon graft, so that LHBT autograft also acts as an interposition graft

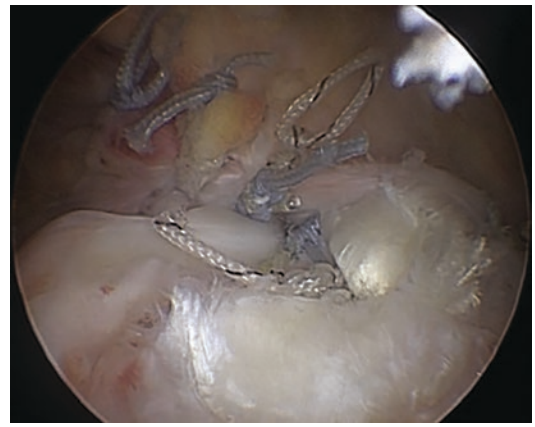

Fig. 15.6 Arthroscopic view of a right shoulder in beach chair position from the lateral portal. Functional repair by margin convergence of the residual rotator cuff can be performed over the biceps autograft

- Phase 1 (4–8 weeks after surgery): massotherapy and physical modalities for the management of pain, inflammation, and muscle contractures, and passive ROM exercises.
- Phase 2 (9–12 weeks after surgery): active-assisted ROM exercises and closed kinetic chain exercises to strengthen the residual rotator cuff, subscapularis, biceps, deltoid, pectoralis major, and scapular stabilizers.
- Phase 3 (13–16 weeks after surgery): active ROM exercises and open kinetic chain exercises, proprioceptive and plyometric exercises, and postural rehabilitation of the kinetic chain (lumbo-pelvic, thoracolumbar, and scapula-thoracic muscles).

Return to heavy manual work or sports activities is allowed 9 months after surgery. The

authors use to perform an MRI at 12-month follow-up.

15.5 Conclusions

Arthroscopic SCR by using the proximal portion of the LHBT combines several advantages:

- The biomechanical rationale of SCR remains unchanged.
- The technique does not require a long learning curve.
- Intraoperative time and costs are surely reduced because neither additional graft, nor anchors for medial fixation are required. Moreover, donor-site morbidity as well as additional time for graft harvesting, in case of fascia lata use, are completely avoided.
- Vitality: this pediculated graft might provide additional blood supply to the repaired rotator cuff tendons.

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Superior Capsular Reconstruction with Dermal Allograft

16

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16.1 Introduction

Injuries to the rotator cuff are common problems affecting patients of all ages [1–3]. These tears can vary in severity and chronicity, ranging from acute, small, full-thickness tears to chronic, massive retracted tears. Management of these tears depends on several factors including symptoms, tear size, chronicity, patient activity level, patient dysfunction, and others [4, 5]. While some tears are amenable to repair in a variety of configurations, others simply cannot be brought back to their original anatomic position and are therefore termed "irreparable." Tears can be deemed irreparable for a variety of reasons, one of which occurs following a failed prior double-row rotator cuff repair in which the repair fails at the medial row near the muscle tendon junction and leaves remnant rotator cuff attached to the humeral head [6]. Cho et al. described this as a Type II failure, as opposed to a Type I failure that happens at the tendon to bone interface [6].

Irreparable rotator cuff tears, specifically in younger patients without significant glenohumeral arthritis, present a challenging problem for orthopedic surgeons.

There are several options for treatment including non-operative management with physical therapy and injections, arthroscopic debridement, and subacromial decompressions with or without a biceps tenodesis, partial repair, tendon transfer, superior capsular reconstruction (SCR), and reverse total shoulder arthroplasty (RTSA) [7–10]. SCR has emerged as an excellent treatment option for physiologically young patients with irreparable rotator cuff tears and no significant glenohumeral arthritis. SCR was first described by Mihata et al. as an alternative to arthroscopic debridement and RTSA in patients with irreparable rotator cuff tears [11]. The authors described the use of a fascia lata autograft that was doubled or tripled to create a graft thickness of 6-8 mm. This technique was then modified such that dermal allograft was substituted for fascia lata autograft [12]. This chapter will discuss the biomechanics surrounding SCR as well as clinical evaluation of a patient with an irreparable rotator cuff repair, operative techniques, rehabilitation, and outcomes following SCR.

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16.2 Pertinent Anatomy and Biomechanics

16.2.1 Anatomy

The glenohumeral joint is the most mobile joint in the body. In addition to this mobility, the joint is relatively shallow, which leads to inherent instability. As such, the glenohumeral joint is the most frequently dislocated joint in the body. The glenohumeral joint relies on static and dynamic stabilizers to prevent dislocation. The dynamic stabilizers provide stability in the middle ranges of motion and consist of the surrounding musculature and their respective tendons. Examples include the deltoid, biceps, and rotator cuff muscles [13, 14]. The static stabilizers provide stability to the joint at the extremes of motion. These consist of the glenoid labrum, the glenohumeral ligaments, and the capsule, which includes the superior shoulder capsule [15].

The glenohumeral joint capsule has several thickenings giving rise to various ligaments including the superior glenohumeral ligament, middle glenohumeral ligament, and inferior glenohumeral ligament (IGHL). The IGHL consists of an anterior and posterior bundle with an interposed axillary pouch between them, which provides support to the humeral head during arm elevation. The superior capsule is formed by a thin continuous sheet of collagen fibrils, spanning from the glenoid labrum medially to the humerus laterally [16]. It attaches to 30%–61% of the greater tuberosity; therefore, it may occupy as much as, if not more of the greater tuberosity footprint than the supraspinatus [12]. At this attachment, the capsule is 4.4–9.1 mm thick [17]. The superior capsule may act as a hammock overlying the joint, preventing the humeral head from making contact with the acromion. Additionally, Adams et al. proposed that a defect in the superior capsule may be the "essential lesion" in patients with superior cuff tears, as opposed to the tear in the cuff itself, and the repairs that do not involve restoring the normal superior capsule anatomy may result in suboptimal outcomes [18].

16.2.2 Biomechanics

There are several biomechanical studies examining the influence of SCR on the superior stability of the shoulder joint [19–29]. In a cadaveric study involving eight shoulders, Mihata et al. compared the superior translation of the humerus in five conditions: (1) intact rotator cuff, (2) cut supraspinatus tendon, (3) patch graft to reconstruct supraspinatus tendon, (4) patch graft to reconstruct superior capsule, and (5) patch graft to reconstruct both the supraspinatus tendon and the superior capsule. They demonstrated that excision of the supraspinatus tendon significantly increased superior translation of the humerus [19]. Supraspinatus reconstruction with the graft resulted in partial restoration of superior translation, while superior capsule graft fully restored superior translation of the humerus. Mihata et al. also performed a study evaluating the biomechanical effect of thickness and tension of a fascia lata graft on glenohumeral stability for SCR in irreparable supraspinatus tears. They concluded that an 8 mm thick fascia lata graft resulted in greater superior stability compared to a 4 mm thick graft [30]. Additionally, the 8 mm thick graft had a significant decrease in superior translation, while 4 mm thick graft did not.

The use of dermal allograft has become an interesting choice for SCR. Mihata et al. compared SCR using fascia lata allograft to that using human dermal allograft for irreparable rotator cuff tears. In this study, SCR using fascia lata allograft fully restored superior translation, subacromial contact pressure, and superior glenohumeral joint force; whereas, SCR using human dermal allograft only partially restored superior glenohumeral stability [31]. It was also discovered that the human dermal allograft had elongated by 15% during testing, while the fascia lata allograft remained the same size. A more recent study by Scheiderer et al. tested the biomechanical effect of SCR using 3 mm and 6 mm thick dermal allograft [20]. They concluded that SCR with a 6 mm thick dermal allograft better restored normal glenohumeral joint position and forces compared with a 3 mm thick graft for the treat-

ment of irreparable rotator cuff tears. Different grafts have also been studied and include the long head of the biceps as well as patella tendon allograft [21, 22]. Han et al. performed a study looking at SCR using the long head of the biceps; they concluded that the long head of the biceps with appropriate distal insertion on the greater tuberosity restores shoulder stability in irreparable rotator cuff tears by re-centering the humeral head on the glenoid [21]. Croom et al. performed a study examining patellar tendon allograft as an alternative graft material for SCR [22]. They concluded that it was able to reduce superior translation of the humeral head and peak subacromial contact pressure, without restricting range of motion.

SCR graft fixation has become an important area of study. Mihata et al. examined the biomechanical role of capsular continuity in SCR [23]. They analyzed SCR without side-to-side suturing, SCR with posterior side-to-side suturing, and SCR with both anterior and posterior side-to-side suturing. They discovered that SCR with side-to-side suturing completely restored superior stability to the shoulder joint though establishing posterior continuity between the graft, residual infraspinatus tendon, and underlying capsule. Pauzenberger et al. performed a study evaluating how anatomic reconstruction of the superior capsule and rotator cuff improves biomechanical properties in repair of delaminated rotator cuff tears [24]. They measured contact area and pressure, displacement under cyclical loading, and load to failure of three double-row repair configurations: double-row suture repair with medial knots, knotless double-row repair using suture tapes, and knotless double-row double layer-specific repair. They concluded that anatomic restoration of the superior capsular and tendon insertion in delaminated rotator cuff tears with a double layer-specific repair configuration demonstrated the greatest footprint restoration with increasing abduction.

A similar study by Leschinger et al. compared SCR techniques and an interpositional graft [25]. They looked at SCR with glenoidal 3-point patch grafting, SCR with glenoidal 2-point patch grafting, and affixing a graft below the acromion. They determined that with additional medial anchoring at the base of the coracoid, the depressing and centering effect of the superior capsule could be regained in a more physiologic way compared to SCR with 2-point fixation or with an interpositional graft below the acromion. Additionally, a study by Adams et al. examined the effect of glenohumeral fixation angle on deltoid function during SCR [26]. SCRs were performed at possible fixation angles of 0°, 15°, 30°, 45°, and 60° of glenohumeral abduction and analyzed under the following five conditions: (1) native shoulder, (2) complete supraspinatus and superior capsule tear, (3) SCR alone, (4) SCR with posterior margin sutured, and (5) SCR with anterior and posterior margin sutured. The authors concluded that SCR with anterior and posterior margin convergence at 15° of glenohumeral abduction showed similar deltoid abduction force compared with the intact state. Graft fixation in 60° significantly reduced deltoid force in all SCR conditions.

Mihata et al. performed a study examining the effects of acromioplasty on SCR for irreparable supraspinatus tendon tears [27]. They demonstrated that adding acromioplasty to SCR with fascia lata significantly decreased the subacromial peak contact area compared to SCR without acromioplasty, without altering the humeral head position, superior translation, or subacromial peak contact pressure. The authors suggest that when performing SCR, acromioplasty may help to decrease the postoperative risk of abrasion and tearing to the graft. In a similar study, Curtis et al. investigated SCR with a subacromial allograft spacer. They concluded that SCR with subacromial resurfacing using human dermal allograft resulted in decreased superior translation relative to SCR with human dermal allograft alone, while it increased subacromial contact pressure [28].

An interesting study by Omid et al. analyzed the effects of latissimus dorsi tendon transfer with and without SCR using dermal allograft [29]. Eight cadaveric shoulders were tested under five conditions: (1) intact rotator cuff, (2) irreparable rotator cuff tear, (3) SCR with dermal

allograft, (4) SCR plus latissimus dorsi tendon transfer, and (5) latissimus dorsi tendon transfer alone. The authors found that adding SCR to latissimus dorsi tendon transfer adds static stabilization to a dynamic stabilizer, which is important because this may provide additional stability at the low to middle ranges of abduction.

16.3 Clinical Evaluation

16.3.1 History

Obtaining a detailed history is one of the most important parts of determining if a patient is a good candidate for an SCR with dermal allograft. The most important piece of the history is the patient's chief complaint as this can help dictate treatment. Some patients will complain of pain as their chief complaint while others will complain of an inability to lift their arm. One should ask about the length of symptoms, character of the symptoms, previous treatments (including recent injections, prior surgeries, etc.), handedness, any activities the patient participates in (sports, gardening, etc.) and their expectations following treatment. Understanding the character of the pain is important as a dull ache that persists in the shoulder during the day and wakes the patient up at night may be the result of arthritic changes within the shoulder and not stemming from the rotator cuff tear. It is also important to understand the patent's perceived disability from the shoulder (what they can and cannot do) and what is important for them to be able to do. Finally, it is important to ask about any radicular symptoms or neck issues the patient may be having to understand if there is a cervical component to their pathology.

16.3.2 Physical Exam

To begin, both shoulders are exposed, maintaining modesty in females. The surgeon should take note of any previous surgical incisions and evaluate for any side-to-side differences in muscle bulk/evidence of muscle wasting as this can impact the decision to perform an SCR. Visible atrophy often indicates a chronic tear. A neck exam as well as a neurovascular exam should be performed to rule out other causes of upper extremity pathology. The patient is taken through active and passive range of motion (ROM) to ensure there is not a significant decrease in passive ROM. While active ROM may be significantly decreased, specifically in abduction and forward flexion, there should not be any significant limitation in passive ROM as this can indicate a separate issue of adhesive capsulitis, significant glenohumeral arthritis, etc. We generally classify patients as having pseudoparesis if their active forward elevation is less than 90° while we reserve the term pseudoparalysis for patients with essentially no active forward elevation/abduction. This is an important distinction as patients with true pseudoparalysis often do not do well following SCR while those with pseudoparesis can do quite well after SCR [32, 33].

The strength of each rotator cuff muscle is then individually tested and compared to the contralateral shoulder. Many patients will have significant weakness in testing of the supraspinatus (empty can or Champagne toast test) and infraspinatus (resisted external rotation at the side [34]. However, it is extremely important to evaluate the function of the teres minor by testing for a Hornblower's sign and the subscapularis by performing a belly press, lift off and bear hug test. Understanding which tendons are involved and the patient's functional status are extremely important as these play a significant role in treatment decision-making. Patients who have involvement of the subscapularis will not do well with an SCR if the subscapularis is irreparable. Conversely, if the subscapularis is preserved and strong, patients fare much better following SCR. Finally, the acromioclavicular joint and biceps tendon are examined for pathology to determine if any concomitant procedure such as a distal clavicle excision or biceps tenodesis are needed at the time of SCR.

16.3.3 Imaging

All patients who present with shoulder pain undergo a standard series of X-rays in the office

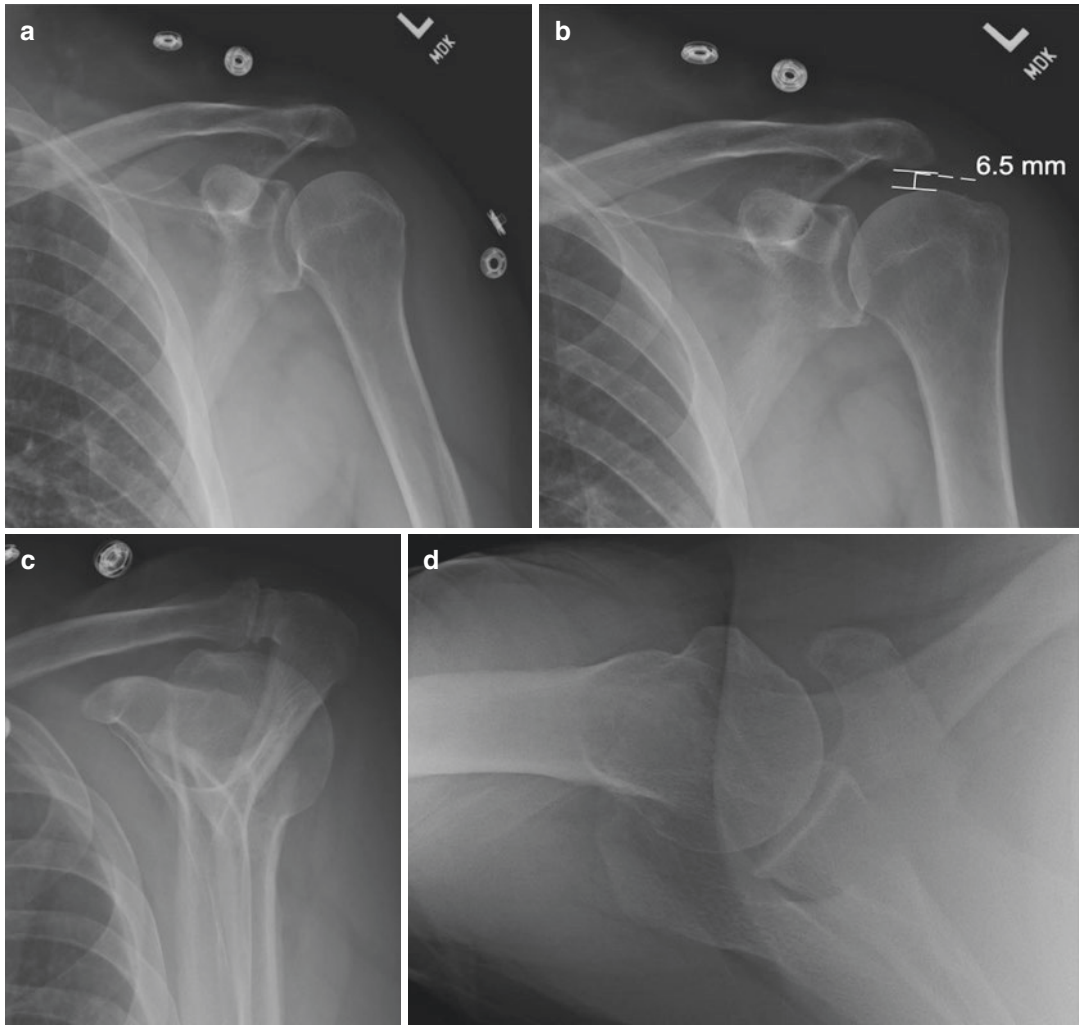

Fig. 16.1 (**a**–**d**) Anteroposterior (AP), Grashey, scapular Y and axillary lateral radiographs of the shoulder in a patient with a small amount of superior migration of the humeral head but an acromioclavicular humeral interval of 6.5 mm. There is no significant evidence of glenohumeral arthritis

including an anteroposterior (AP), Grashey, scapular Y and axillary lateral view (Fig. 16.1a–d). It is important to evaluate for glenohumeral arthritis and rotator cuff tear arthropathy. The authors use the Hamada classification to determine the extent of rotator cuff tear arthropathy (Table 16.1) [35]. Having a reliable classification system is important as this can help dictate treatment. We typically reserve SCR for patients with Hamada 1 and 2 while we recommend other options such as reverse total shoulder arthroplasty (RTSA) for patients with Hamada stage III or higher (Fig. 16.2).

Table 16.1 Hamada classification of rotator cuff tear arthropathy [35, 46]

Grade	Radiographic findings
Grade I	AHI[a] ≥ 6 mm
Grade II	AHI < 6 mm
Grade III	AHI < 6 mm + acetabularization
Grade IVa	Glenohumeral joint narrowing
Grade IVb	Glenohumeral joint narrowing + acetabularization
Grade V	Humeral head collapse

[a]Acromiohumeral interval

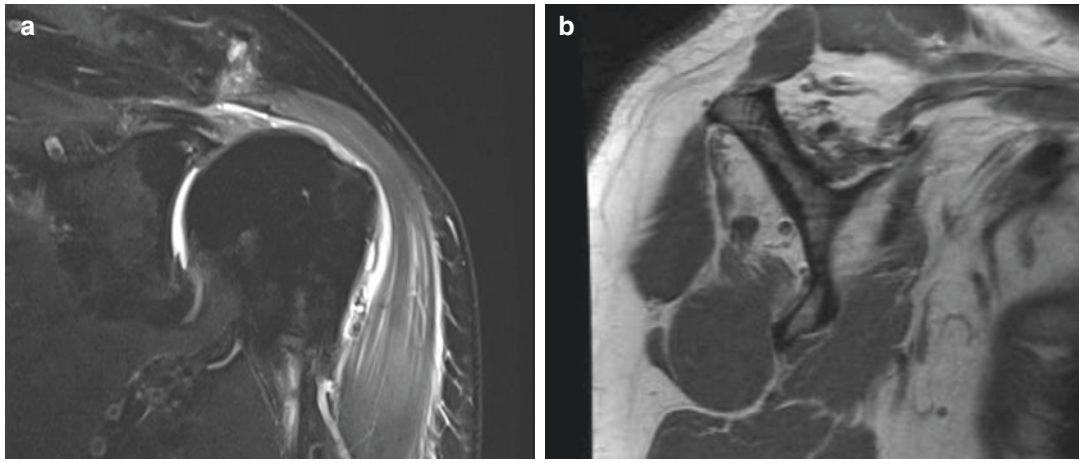

Fig. 16.2 (**a**) Coronal magnetic resonance image of a patient with a tear of the supraspinatus retracted to the level of the glenoid. (**b**) Sagittal magnetic resonance image of a patient with Goutallier Stage IV fatty muscle atrophy of the supraspinatus and infraspinatus

While X-rays are extremely useful in this patient population, magnetic resonance imaging (MRI) is often the next step to help dictate treatment. MRI will provide information regarding the tear such as tear size, pattern, amount of tendon retraction, and muscle atrophy. Furthermore, the MRI will allow for a better understanding of arthritic changes within the shoulder as those patients with significant arthritic changes in addition to irreparable rotator cuff tears are often better served with revers shoulder arthroplasty. The authors commonly use the Goutallier classification system adopted for MRI when evaluating fatty atrophy, as this is, in the author's opinion, one of the most critical data points to determining the proper treatment (Table 16.2) [36, 37]. While the final decision to proceed with an SCR is made intraoperatively, imaging findings suggestive of irreparable rotator cuff tears include Goutallier grade 3 or 4 fatty infiltration, narrowing of the acromiohumeral distance below 5 mm and tear retraction to the glenoid. The authors do no routinely obtain a computed tomography (CT) scan or ultrasound on these patients unless there is a reason the patients cannot obtain an MRI.

Table 16.2 Goutallier classification of fatty infiltration within the rotator cuff musculature

Stage	MRI findings
Stage 0	Normal muscle, no fat
Stage 1	Some fatty streaks; less than 10% fatty muscle atrophy
Stage 2	More muscle than fat; less than 50% fatty muscle atrophy
Stage 3	Muscle equal to fat; 50% fatty muscle atrophy
Stage 4	Less muscle than fat; greater than 50% fatty muscle atrophy

MRI Modification [36]

16.4 Operative Treatment

The decision to proceed with an SCR must take several of the aforementioned factors into play. Patients with minimal glenohumeral arthritis, pseudoparesis, Hamada Grade I or II, and a well-functioning or repairable subscapularis are some of the best candidates for SCR. Those patients with Hamada Grade III or higher, an irreparable subscapularis tear, and those with true pseudoparalysis are often better served with a reverse shoulder arthroplasty (Table 16.3).

Table 16.3 Indications, contraindications, and the in between for performing a superior capsular reconstruction

Indications	Contraindications	In between
Intact subscapularis	Irreparable subscapularis tear	High grade but repairable subscapularis tear
Minimal degenerative joint disease	Advanced degenerative joint disease	Moderate degenerative joint disease
Hamada I or II	Hamada IV or V	Hamada III
Better than 90° of abduction	True Pseudoparalysis	Pseudoparesis
Willing to go through intensive rehabilitation	Will not comply with restrictions/ rehabilitation protocols	
Minimal comorbidities	Uncontrolled diabetes, smoker	Patients with well-controlled diabetes
No prior shoulder procedures	Failed prior SCR	Minimal prior shoulder surgeries

Once a patient has been properly indicated for an SCR, it is imperative to have a very candid discussion with the patient so they understand the lengthy rehabilitation process as well as the potential risks and benefits of the SCR. The goal of the SCR is to improve function and decrease pain, but the rehabilitation process following SCR is often slower than following a rotator cuff repair, and patient expectations must be adjusted accordingly. A discussion is then had about graft options including dermal allograft, Achilles allograft, hamstring autograft, fascia lata allograft, and fascia lata autograft [11, 12, 38–40]. The authors prefer dermal allograft as the results in short- to mid-term follow-up have been encouraging, and there is no donor site morbidity [41]. While results following fascia lata graft for SCR have been excellent, there can be a significant morbidity that accompanies harvesting a large portion of the fascia lata that the authors feel is unnecessary [11, 30].

16.4.1 Procedure

SCR with a dermal allograft can be performed in the beach chair or lateral decubitus position. The authors perform SCR in the beach chair position with the use of an arm holding device (Trimano, Arthrex Inc., Naples, FL, USA). All bony prominences are well padded and patients typically have regional anesthesia accompanied by sedation or general anesthesia. Once the patient is positioned, an exam under anesthesia (EUA) is performed to ensure there is no significant loss of passive range of motion that needs to be addressed. The patient is then prepped and draped in the usual sterile fashion and after administration of preoperative antibiotics and following the timeout, a skin incision is made and the arthroscope is introduced into the glenohumeral joint. A diagnostic arthroscopy is performed. The glenoid and humeral head cartilage surfaces are assessed. The biceps tendon is then assessed. If patients have preoperative biceps symptoms, which is very common in this patient population, we perform a subpectoral biceps tenodesis. As such, we release the biceps at this point in the case with either an arthroscopic basket, arthroscopic scissor, or electrocautery device.

Following this, the rotator cuff is evaluated. The subscapularis is assessed first to determine if there is any evidence of a tear. This is done via the posterior lever push and internal rotation of the arm [42]. If there is a subscapularis tear, two accessory portals, one anterior and one anterolateral, are created with the use of spinal needle localization and cannulas are placed to aid in suture passage. The subscapularis is repaired before moving on to the SCR. If there is an isolated upper border subscapularis tear, we commonly will place two FiberLink (Arthrex Inc., Naples, FL, USA) sutures through the torn subscapularis and secure these into one, unloaded 4.75 mm SwiveLock (Arthrex Inc., Naples, FL, USA) anchor at the anatomic insertion of the

subscapularis after the bone bed has been prepared with a motorized shaver. Care is taken not to over tension the repair. If there is a more significant tear, a double-row repair is commonly performed. When this repair is complete, the arthroscope is placed into the subacromial space.

Once in the subacromial space a thorough bursectomy and subacromial decompression with acromioplasty is performed. Great care is taken to reestablish the gutters to improve visualization. The rotator cuff tear is then evaluated from the subacromial space. Releases are performed and once the gutters have been cleaned and the rotator cuff mobilized as much as possible, tear size, retraction, mobility, etc. are evaluated. If the tear is deemed to be irreparable, the decision is made to proceed with the SCR (Fig. 16.3). However, if there is a portion of the posterosuperior rotator cuff that is repairable, this can be repaired before proceeding with SCR. This is typically done in a double row, transosseous equivalent fashion with the use of loaded and unloaded 4.75 mm SwiveLock (Arthrex, Naples, FL) anchors.

Once the decision is made to proceed with SCR, preparation begins on the glenoid side. First, an anterolateral portal and lateral portal are established under direct visualization. Passport cannulas (Arthrex, Naples, FL) are placed in each of the three working portals. We use a 12 mm cannula in the lateral portal to allow for graft passage and 8 mm cannulas in the anterolateral and posterior portals. The arthroscope is transferred to the lateral portal. For glenoid preparation, the superior labrum is commonly left in place, but the surface of the superior glenoid as well as the glenoid extending anteriorly and posteriorly is cleaned of all soft tissue (Fig. 16.4a, b). A shaver or burr is

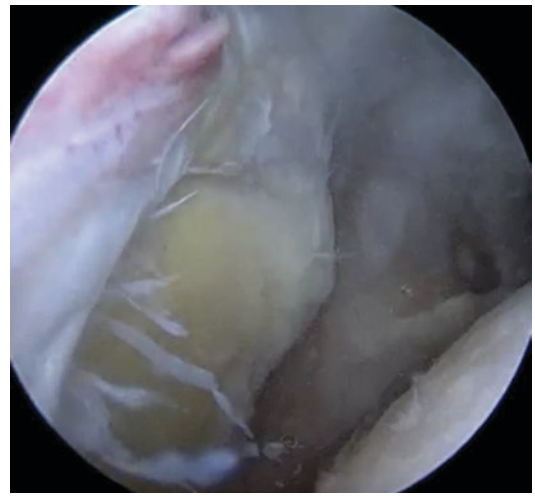

Fig. 16.3 Arthroscopic image demonstrating an irreparable rotator cuff tear

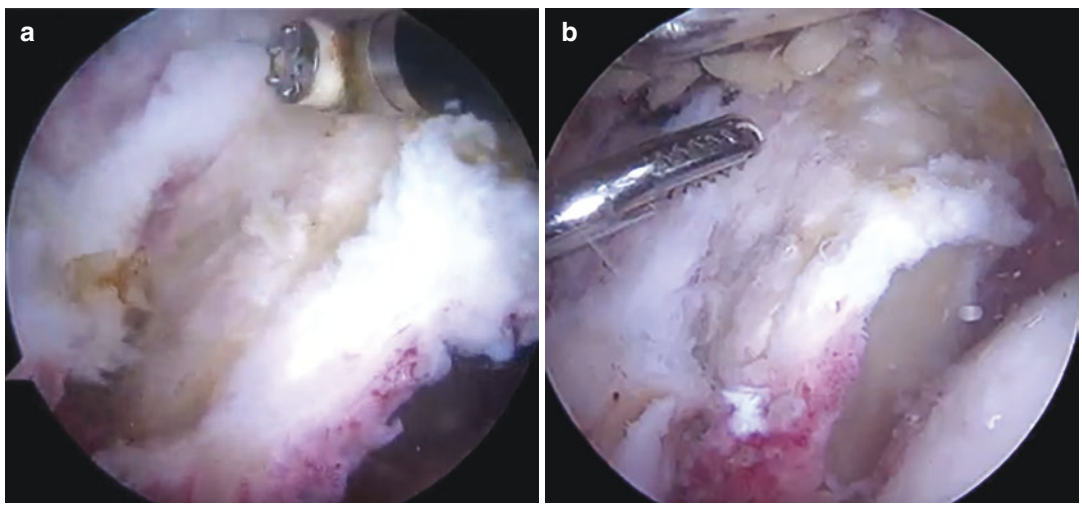

Fig. 16.4 (**a** and **b**) Arthroscopic image demonstrating removal of all soft tissue from the glenoid where the three anchors will be placed with preservation of the superior labrum

then used to expose a surface of bleeding bone to help with graft integration. If there is remnant rotator cuff tissue in the way, this can be retracted using a Wissinger rod or traction suture. We then use three separate spinal needles to obtain the proper trajectory for anchor placement. These anchors can be placed with anterosuperolateral, Neviaser, and/or accessory percutaneous anterior or posterior portals. The important point here is to achieve a perfect trajectory with each spinal needle to avoid skiving off the glenoid and to avoid perforation of the glenoid articular surface when drilling for the anchors. We use the knotless 3.0 mm SutureTak (Arthrex Inc., Naples, FL, USA) anchors on the glenoid side and place these in using a percutaneous kit. The pilot hole is drilled with a 2.6 mm drill and the anchor is malleted into place. Once the anchors are placed percutaneously, the sutures are left alone so they stay nicely separated until it is time to use them. Knotted anchors can also be used if the surgeon prefers. The glenoid is now prepared (Fig. 16.5a–c).

Attention is then turned to the humerus. A combination of electrocautery and motorized shaver are used to debride any tissue from the humeral head surface and to remove the calcified cartilage layer of bone to allow for improved bone healing. We then place two 4.75 mm SwiveLock (Arthrex Inc., Naples, FL, USA)

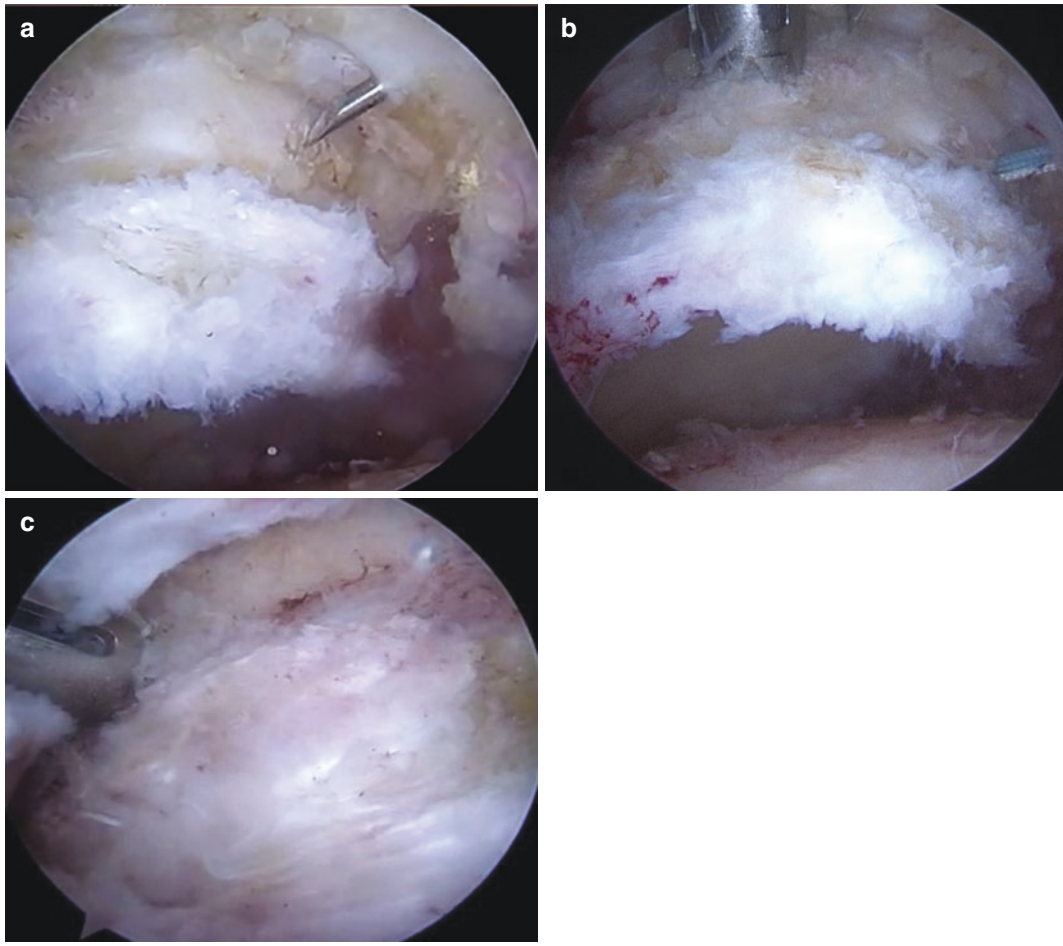

Fig. 16.5 (**a**–**c**) Arthroscopic images demonstrating spinal needle localization and subsequent anchor placement into the glenoid

anchors loaded with FiberTape (Arthrex Inc., Naples, FL, USA) just lateral to the articular surface. These anchors are commonly placed through small stab incision to allow optimal placement at dead man's angle (Fig. 16.6). The arthroscope is then transferred to the posterior portal, and the sutures from these humeral anchors are then retrieved out the lateral portal and a measuring device is used to measure the distance between the five anchors so the graft and be properly sized (Fig. 16.7). It is very important to take accurate measurements and to remember which measurements are between which anchors so the graft size is correct. Once the measurements are taken, attention is turned to the ArthroFLEX decellularized dermal allograft patch (Arthrex Inc., Naples, FL, USA). This is a 3 mm thick dermal allograft and will function as the superior capsule. The shiny side of the graft is placed up during preparation. Mark an "A" on the anterior portion of the graft to minimize confusion with graft orientation. We add 10 mm to the lateral portion of the graft and 5–7 mm anteriorly, posteriorly, and medially. The graft is cut to the previously recorded measurements with the additions as just stated. Once the graft is cut to size, the locations of all the anchors are marked on the graft. The empty anchor inserter is used to punch a hole in the graft for the passage of the tape sutures laterally (not for the glenoid sutures).

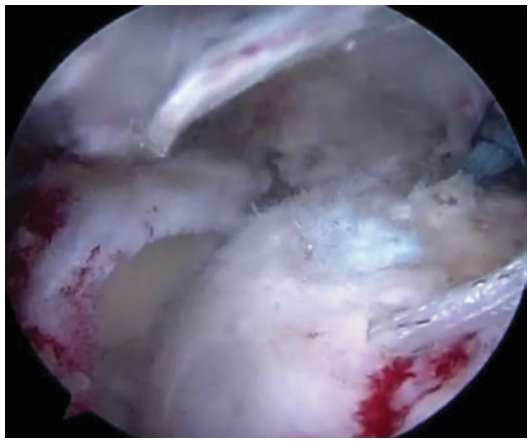

Fig. 16.6 Arthroscopic image following glenoid and humeral head anchor placement

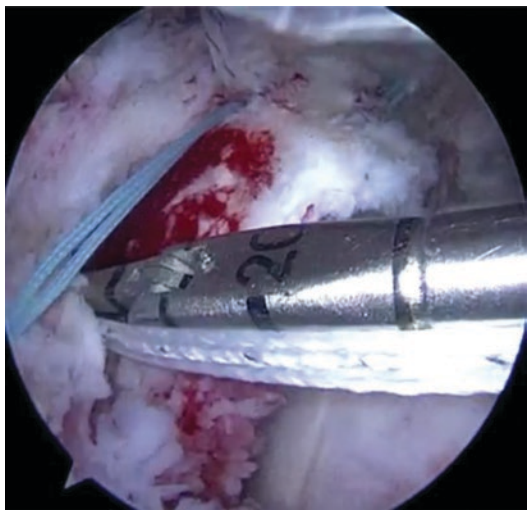

Fig. 16.7 Arthroscopic image of the measuring tool used to measure the distance between all anchors so the dermal allograft can be properly sized

The graft is then brought up to the field and placed on a clean blue towel that is draped over the arm to minimize the risk of C. acnes infection. The tape sutures are then passed through their corresponding holes in the graft and an assistant holds tension on these sutures in their proper orientation to avoid tangling of the sutures. A suture retriever is then used to retrieve the passing stitch and shuttle loop strand from the most anterior glenoid anchor. A suture passing device is used to pass the passing stitch from bottom to top and then from top to bottom in the graft at the marked location of this anchor. The passing stitch is then loaded into the looped suture and the free end of the suture that is coming out of the percutaneous incision is pulled to load the anchor. The slack is removed from the system without advancing the graft into the shoulder. This is then repeated with the sutures from the middle and posterior glenoid anchors. The graft is now ready to be passed into the shoulder. The graft is rolled like a cigar and an atraumatic device is used to push the graft into the shoulder while the slack is taken out of the glenoid anchors simultaneously. Once the graft is in the shoulder it is allowed to unroll (Fig. 16.8). The graft is then securely fixed on the glenoid side by pulling the sutures from the

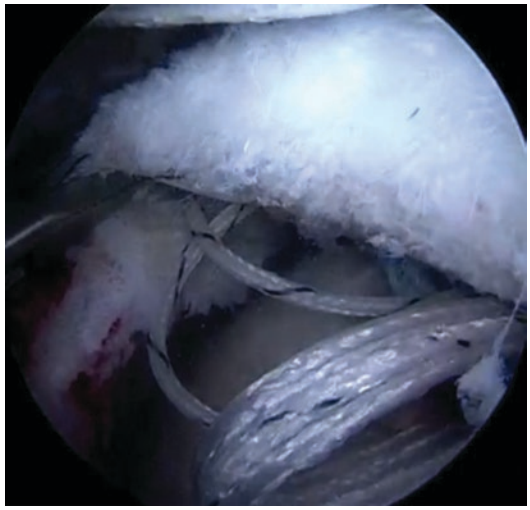

Fig. 16.8 Graft passage into the shoulder

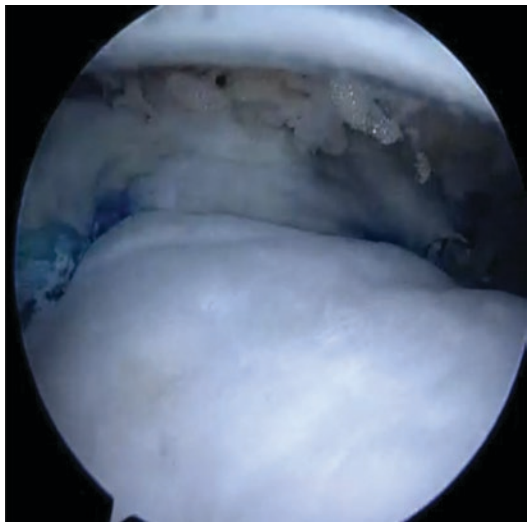

Fig. 16.9 Arthroscopic image of the graft fixed on the glenoid side

glenoid anchors tight, and these sutures are then cut flush with the graft (Fig. 16.9). The lateral aspect of the dermal allograft is then fixed in standard SpeedBridge configuration with the FiberTape (Arthrex Inc., Naples, FL, USA) sutures placed into two unloaded SwiveLock anchors (Arthrex Inc., Naples, FL, USA) (Fig. 16.10). If there is residual supraspinatus tendon remaining, the FiberTape (Arthrex Inc., Naples, FL, USA) sutures from the medial row

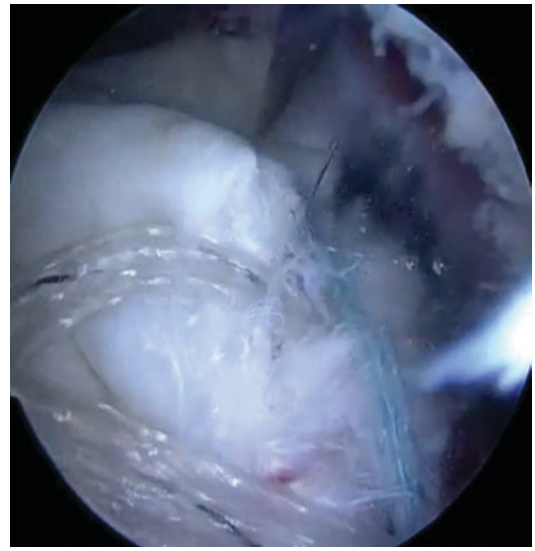

Fig. 16.10 Arthroscopic image of graft fixation on the humeral side in a SpeedBridge configuration

anchors should be passed through this tissue before they are secured laterally to incorporate the native tissue into the repair. When fixing the lateral row anchors, it is imperative to place the shoulder in approximately 40° of abduction to create proper tension on the dermal allograft. The anterior limb from both medial row anchors are placed into the more anterior of the lateral row anchors while the posterior limbs of the medial row anchors are placed into the more posterior of the lateral row anchors. The graft is now securely fixed. Of note, cinch or luggage tag sutures can be placed through the graft before lateral row fixation if there is any concern for a dog ear.

Once the graft is completely secured on the glenoid and humeral sides, side-to-side sutures are then placed to secure the graft to the posterior rotator cuff (Fig. 16.11). We typically use No. 2 FiberWire (Arthrex Inc., Naples, FL, USA) sutures. The graft can be secured anteriorly to the comma tissue using side-to-side sutures but should not be secured to the subscapularis to avoid overconstraining the shoulder (Fig. 16.12). The final repair construct is inspected. The subpectoral biceps tenodesis is then performed in standard fashion.

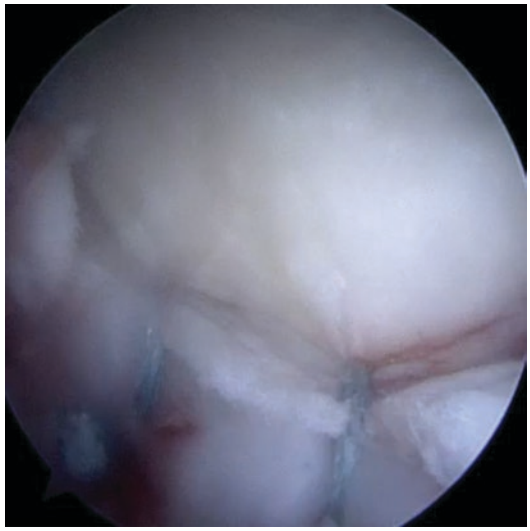

Fig. 16.11 Arthroscopic image of the side-to-side repair of the dermal allograft to the posterior rotator cuff

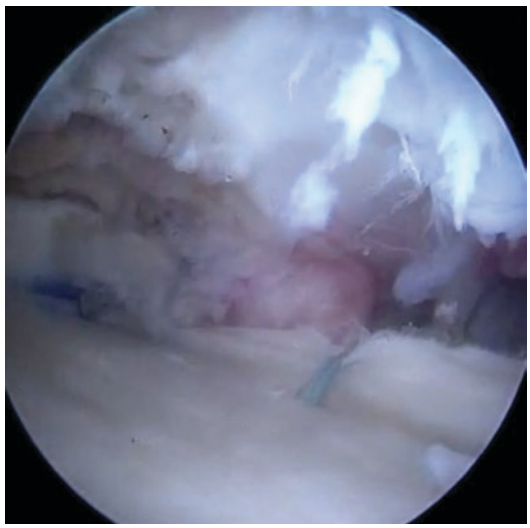

Fig. 16.12 Arthroscopic image demonstrating side-to-side repair of the anterior aspect of the dermal allograft to the comma tissue

16.5 Rehabilitation

Rehabilitation following SCR with dermal allograft is slower than following a standard rotator cuff repair. For the first 6 weeks after surgery, the patient remains in the sling and performs a simple home exercise program including elbow ROM, wrist ROM, and grip strengthening several times per day. Pendulums are usually introduced around 2–4 weeks. At the 6 week mark the patient begins physical therapy (PT) where the therapist concentrates on true passive range of motion (PROM) with ROM goals of 140° of forward flexion (FF), 40° of external rotation (ER) at the side, a maximum of 60–80° of abduction without rotation. They also perform grip strengthening.

At the 8 week mark, they begin active assisted motion and progress to active motion as tolerated and are allowed to increase the ROM as tolerated. They also begin light passive stretching at end ROM as well as scapular exercises and isometrics with the arm at the side. For months 3–12, they are allowed to advance to full ROM as tolerated with passive stretching at end ranges. Once patients have regained their ROM they can progress their strengthening with isometrics, band work, and light weights (usually 1–5lbs for 8–12 reps for 2–3 sets per rotator cuff, deltoid, and scapular stabilizers). To avoid rotator cuff tendonitis patients should only strengthen three times per week. At 4 months, patients can incorporate in eccentrically resisted motions, plyometrics, and proprioception exercises. Patients must understand that, while they typically feel better after a few months, full recovery takes a year or more following SCR.

16.6 Clinical Outcomes

As use of dermal allograft is more recent than fascia lata autograft, many studies to date have evaluated outcomes following SCR with fascia lata autograft [43]. However, there have been several recent publications regarding SCR with dermal allograft. Burkhart et al. reported 2 year results following SCR with dermal allograft in 41 patients at mean follow-up of 34 months [32]. The authors found American Shoulder and Elbow Surgeons (ASES) score improved from 52 to 90 following surgery ($p < 0.0001$). Furthermore, 85% of grafts were fully healed. The authors reported 81% had an overall satisfactory outcome. Makki et al. reported the 2-year clinical and radiographic outcomes of 25 patients following SCR with dermal allograft [41]. There was a

significant improvement in mean Oxford Shoulder Score as well as ROM at final follow-up. MRI showed graft failure in 4 patients, and 3 patients had a revision to RTSA. Overall, 20 patients had successful outcomes at 1 year (80%) and 18 patients had successful outcomes at 2 years (72%).

de Campos Azevedo et al. performed a systematic review of 7 studies with 344 shoulders to compare outcomes following SCR with dermal allograft vs. autograft [44]. The authors found statistically significant and clinically important mean improvements in ROM and clinical outcome scores in both groups. They also reported the graft tear rate for fascia lata autograft ranged from 5% to 32%, compared to 20% to 75% for dermal allograft (Fig. 16.13). Kim et al. performed a similar systematic review of 10 studies with 374 shoulders to compare the outcomes following SCR with autograft vs. all allografts and found no difference in retear rate [45]. However, the number of other complications was 12 (7.5%) in the autograft group compared to 6 (3.9%) in the allograft group but the number of reoperations was 5 (3.1%) in the autograft group compared to 14 (8.2%) in the allograft group. From this review it seems autografts may offer a lower reoperation rate but a higher complication rate compared to allografts.

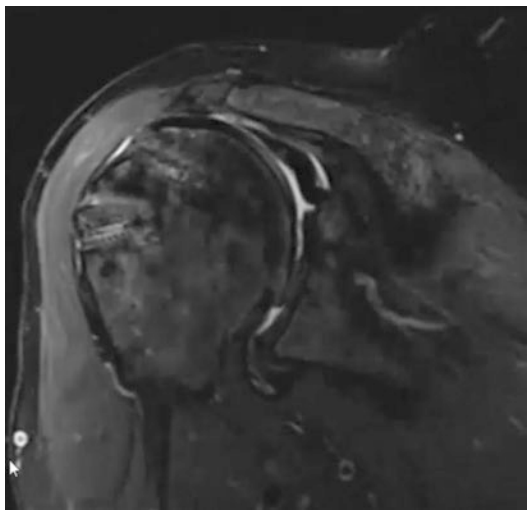

Fig. 16.13 Coronal MRI demonstrating failure of the dermal allograft on the humeral side. Note the graft is securely fixed to the glenoid

16.7 Summary

Superior capsular reconstruction is designed to improve function and minimize pain in physiologically young, active patients suffering from an irreparable rotator cuff tear without significant glenohumeral arthritis. Dermal allograft has become a common graft choice for SCR in the United States with very promising short- and mid-term outcomes. Biomechanical and clinical evidence have shown the dermal allograft is a viable option for SCR. Further work is needed to better understand the long-term outcomes following SCR, as well as the outcomes following conversion of SCR to reverse shoulder arthroplasty.

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Superior Capsule Reconstruction with the Mid-Thigh Fascia Lata

17

Clara de Campos Azevedo
and Ana Catarina Ângelo

17.1 Introduction

In recent years, studies on the pathoanatomy of rotator cuff tears (RCTs) have focused on the role of the superior capsule of the glenohumeral joint in RCTs. Anatomical studies have shown that degenerative RCTs most commonly involve a region 13–17 mm posterior to the biceps tendon, [1] which is near to the thinnest point of the articular capsule [2]. Both the thinnest point of the capsule attachment and supraspinatus insertion are the most fragile areas, which may be related to the initiation of degenerative RCTs. A wide attachment of the superior capsule on the humerus, ranging from 3.5 to 9.1-mm, [2] complements the insertion of the rotator cuff. The functional significance of the superior capsule was mostly overlooked until Mihata et al. [3, 4] reported the biomechanical significance and good clinical results of superior capsule reconstruction (SCR) in irreparable RCTs. The rationale behind SCR for the treatment of irreparable RCTs is that the tenodesis effect of the superior capsular graft provides a fulcrum to the deltoid pulling vector, maintaining static glenohumeral stability, which allows for the remaining shoulder muscles to restore painless active elevation in patients with irreparable RCTs. Modifications to SCR, including the use of other types of fascia lata autograft (FLA) constructs, [5–7] a human dermal allograft (HDA), [8–10] or a long head of the biceps tendon (LHBT) autograft, [11–13] to reconstruct the superior capsule have been proposed by other authors. Several biomechanical and clinical studies were conducted which support the choice of each type of graft [3, 14–17].

In this chapter, a detailed description of arthroscopic SCR using a minimally invasively harvested mid-thigh FLA, the decision-making algorithm, and postoperative treatment protocol used by the authors are presented.

17.2 Decision-Making Algorithm for SCR

SCR is indicated either for primary irreparable RCTs or failed RCT repairs. The following characteristics are considered clinical and

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imaging predictors of RCT irreparability: older age at surgery; longer duration of symptoms; longer duration of overhead sports or work activities; lower preoperative forward flexion of the shoulder; [18] a distance lower than 7 mm between the top of the humeral head and the undersurface of the acromion in the true glenohumeral joint anteroposterior view (acromiohumeral interval, AHI of <7 mm); [19] stage 3 or 4 fatty infiltration, [19–21] according to the 5-stage grading system that focuses on the amount of fatty deposition within the muscle, as developed by Goutallier et al. for computed tomography (CT) scan, [22] and validated by Fuchs et al. for MRI; [23] retraction of the supraspinatus tendon to the level of the glenoid (severe medial retraction) on the proton density fat-saturated coronal MRI; and severe supraspinatus muscle atrophy, as determined by the tangent sign, [20, 21] which is regarded as positive (severe muscle atrophy) when the superior border of the supraspinatus muscle is inferior in relation to the line tangential to the coracoid and scapular spine on the sagittal T1-weighted MRI [24].

The tendon's poor quality as evaluated intraoperatively is the ultimate criterion of irreparability. Every attempt should be made to successfully repair the RCT before deciding to proceed to SCR; the grasper test is usually enough to determine poor tendon quality.

The decision-making algorithm of arthroscopic SCR for irreparable RCTs also takes into consideration the status of the articular cartilage of the glenohumeral joint, loss of passive range of motion, and management of patient expectations with regard to joint preservation and ROM recovery.

17.2.1 Indications for SCR

Active patients with an intractable dysfunctional painful shoulder, with complete passive range of motion, with an irreparable supraspinatus and/or infraspinatus tendon tear, are candidates for arthroscopic SCR.

17.2.2 Contraindications for SCR

Infection, lesion of the braquial plexus, or deltoid dysfunction of any cause, are absolute contraindications for SCR.

Patients with an irreparable subscapularis tendon tear have a poorer prognosis after SCR; thus, an irreparable subscapularis tendon tear is a relative contraindication for SCR.

Patients with articular cartilage radiographic changes Hamada grade 3 or 4 may also have a poorer prognosis after SCR, and these may be considered relative contraindications for SCR; [8] Hamada grade 1 is defined as an AHI ≥6 mm, grade 2 as ≤5 mm, grade 3 as acetabulization (concave deformity of the acromion undersurface) plus an AHI ≤5 mm, grade 4 as narrowing of the glenohumeral joint plus conditions required for grade 3, and grade 5 as humeral head collapse [25].

17.3 Arthroscopic Surgical Technique of SCR

The original technique of arthroscopic SCR, which was first described in the study by Mihata et al. [4] is performed with the patient in lateral decubitus, typically uses three arthroscopic portals and an openly harvested proximal FLA, which, after folding and suturing, is fixed to the superior glenoid rim and humeral head with the shoulder in 30–45 degrees of abduction. Alternative arthroscopic SCR techniques have been described by other authors, using different patient positionings and a range of 3–5 arthroscopic portals, using other types of grafts (autografts and allografts) fixed with the shoulder in other angles of abduction, and using different fixation techniques [7, 11, 12, 17, 26–30]. Arthroscopic SCR using a minimally invasively harvested mid-thigh FLA, which was first described by de Campos Azevedo et al., [7] is described in detail below.

17.4 Patient Positioning

Patients undergo surgery under general anesthesia and in the beach-chair position. The shoulder and ipsilateral thigh are surgically draped for

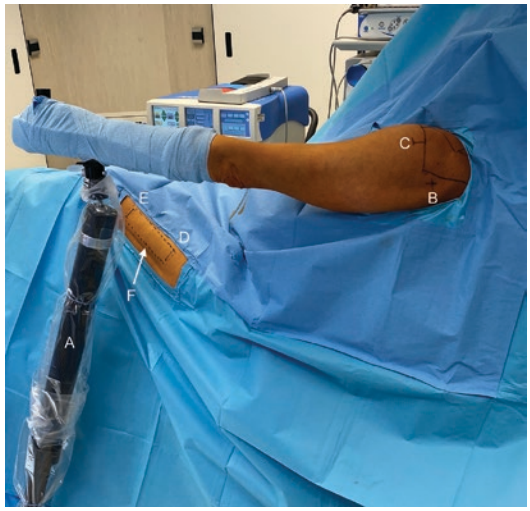

Fig. 17.1 Patient in the beach-chair position draped for arthroscopic SCR of the left shoulder using the mid-thigh fascia lata autograft harvested from the ipsilateral thigh. (A) The forearm is placed in a mechanical arm positioner in traction at 70 degrees of forward flexion and 10 degrees of abduction and in neutral shoulder rotation. The planned skin incisions are marked with a dermographic pen on the thigh; (B) posterior portal; (C) lateral portal; (D) proximal; and (E) distal horizontal 2 cm-long skin incisions; (F) the planned site of fascia lata autograft harvesting is framed by the dashed lined rectangle

shoulder arthroscopic surgery and for minimally invasively harvesting of the mid-thigh FLA. Shoulder passive ROM is confirmed. The forearm is placed in 3-kg forward traction at 70 degrees of forward flexion and 10 degrees of abduction and in neutral shoulder rotation. Alternatively, a mechanical arm positioner may be used to achieve equivalent shoulder position and traction during the procedure (Fig. 17.1).

17.5 Portals

Arthroscopic SCR is performed through a 3-portal technique: a posterior (first) shoulder portal is established 2 cm medial to the posterolateral corner of the acromion, immediately under it, aiming the 4-mm and 30 degrees arthroscope at the coracoid process; an anterior (second) portal is established in the rotator interval under direct glenohumeral arthroscopic vision, and a working cannula (ideally a

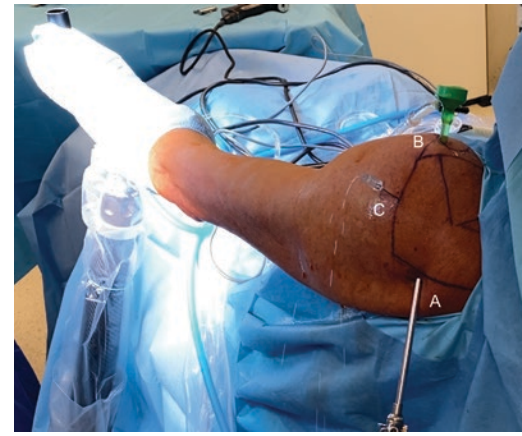

Fig. 17.2 Arthroscopic portals for SCR on a left shoulder. (A) Arthroscope through the posterior portal; (B) Outflow cannula through the anterior portal; (C) Needle marking the site for the lateral working portal

5 × 85-mm cannula) with an outflow connection (attached to a closed-system arthroscopic pump) is placed through it; a lateral (third) portal is established directly under the lateral acromion, and a needle is used to ensure the portal is placed with a good attack angle to the superior glenoid rim (Fig. 17.2) Usually, the lateral portal is 1 cm long and digitally tested to ensure an adequate dimension with no obstacles to graft shuttling).

17.6 Diagnostic Arthroscopy

A gauged probe and an arthroscopic grasper are used to confirm the poor quality of the supraspinatus and/or infraspinatus tendons and the inability to reach the native footprint without undue tension. In recurrent RCTs, all previous sutures should be removed. The RCT is considered irreparable if the torn tendons are frail and do not pass the grasper or suture tests, therefore not reaching their native footprint without undue tension or further tearing. The RCT is considered reparable, and patients undergo RCT repair instead of arthroscopic SCR, if after adequate release of adhesions, the torn tendons pass the grasper or suture tests, therefore successfully reaching their native footprint without undue tension.

17.7 Mid-Thigh Fascia Lata Autograft Harvesting

After the irreparable RCT is arthroscopically confirmed, the graft is harvested. The FLA is harvested through two horizontal (transverse) 2 cm-long skin incisions on the ipsilateral thigh, both 4 cm anterior to the lateral intermuscular septum: one 15 cm distal to the anterior iliac spine and the other 10 cm proximal to the lateral femoral epicondyle (Fig. 17.3).

17.8 Arthroscopic Procedure

Intra-articular LHB tenotomy is always performed, except when the LHB is intra-articularly absent. Subscapularis tendon tears should always be repaired to their native footprint. Mattress sutures using 2.8-mm all-suture double-loaded anchors are usually used. The supraspinatus and infraspinatus tendon footprints and the superior glenoid rim underneath the superior labrum are debrided using a 4 x 125-mm automated shaver and a 3.5 x 135-mm radiofrequency ablator probe. For initial graft preparation, the superior capsular defect is measured from anterior to posterior and from medial to lateral using a gauged probe. The 15 to 20 x 3-cm harvested FLA is folded 4 to 5 times, depending on the intra-articular measurements, with at least 5 mm in excess medially and laterally. This results in a 5 to 8 mm-thick final superior capsular graft, which is typically 3.5 cm long and 2.5 cm wide. This graft is peripherally sutured in a continuous fashion with 1 nonabsorbable suture (No. 2). Through the lateral portal, two 1.8-mm all-suture double-loaded anchors are implanted on the superior glenoid rim (approximately 1 cm apart) underneath the superior labrum. Additionally, two 2.8-mm all-suture double-loaded anchors are implanted on the supraspinatus footprint (approximately 1 cm apart). The distances between the anchors are measured using the gauged probe. Using a dermographic pen, the corresponding glenoid and humeral anchor placements are marked on the graft. After passing all-suture limbs from the glenoid and humeral anchors through the graft and with the suture passer ex vivo, the graft is shuttled through the lateral portal into the glenohumeral joint using the double-pulley technique (Fig. 17.4). All of the glenoid and humeral anchors' sutures are tied. Subsequently, two 4.5-mm knotless anchors are loaded with all of the suture limbs from the humeral footprint anchors and are implanted lateral to the humeral footprint in a transosseous-equivalent configuration (Fig. 17.5). When feasible, the limbs of the sutures from the humeral footprint anchors are passed through the supraspinatus and/or infraspinatus remnants with the suture passer before being loaded into the knotless lateral anchors and used in an onlay partial RCT repair to the superior capsular graft. Otherwise, two sutures (No. 2) are passed from the superior margin of the teres minor, or from the anterior margin of the remaining infraspinatus tendon, when available, to the posterior margin of the superior capsular graft. All knots are tied with the shoulder at 70 degrees of forward flexion and 10 degrees of abduction

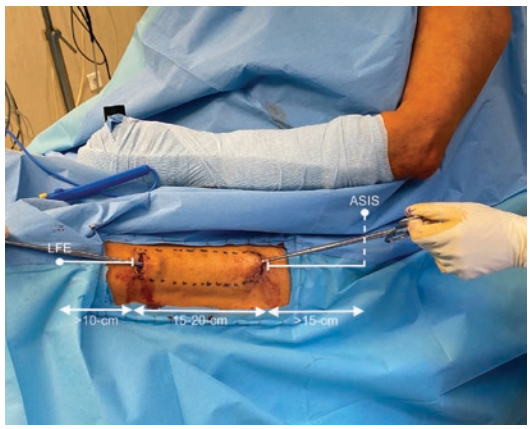

Fig. 17.3 Minimally invasive harvesting of the mid-thigh fascia lata autograft.Patient surgically draped in the beach-chair position, with the left arm temporarily detached from the arm positioner to improve the access to the donor site and harvest the fascia lata autograft from the ipsilateral mid-thigh. The planned area to be harvested is framed by the dashed rectangle drawn using a dermographic pen, at least 10-cm proximal to the lateral femoral epicondyle (LFE), more than 15-cm distal to the anterior-superior iliac spine (ASIS), and 4-cm anterior to the intermuscular septum, with an average of 15 to 20-cm of length and 3-cm of width. Two forceps hold the proximal and distal ends of the fascia lata through the 2-cm horizontal skin incisions

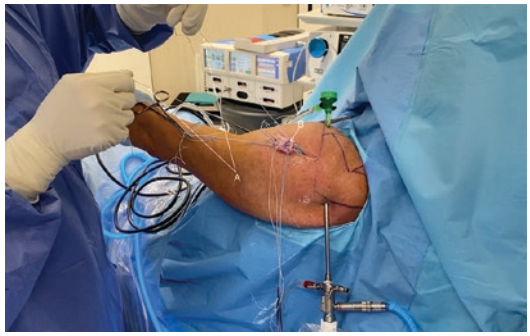

Fig. 17.4 Intra-articular shuttling of the fascia lata autograft construct. Left shoulder with all the suture limbs from the glenoid and humeral medial row anchors passed through the fascia lata autograft construct ex vivo; (A) one suture limb from each glenoid anchor is simultaneously pulled by the surgeon causing the (B) double-pulley knot to push the graft construct into the glenohumeral joint

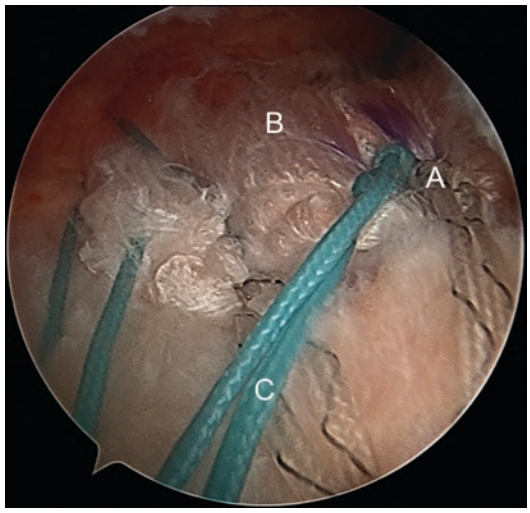

Fig. 17.5 Arthroscopic image of the transosseous-equivalent configuration, with the arthroscope through the lateral portal, on a right shoulder. (A) the knots of the humeral medial row anchors were tied in a mattress-configuration over (B) the fascia lata construct before (C) the limbs of the sutures were loaded into the humeral lateral row push-in anchors

and in neutral rotation. A dynamic subacromial arthroscopic examination is performed to exclude any subacromial conflict with the graft and knots throughout shoulder ROM. Whenever the subacromial space is considered to be in conflict with the graft or knots, anterior acromioplasty is performed using a 4 x 125-mm automated shaver blade.

17.9 Tips and Tricks

17.9.1 Failed Rotator Cuff Repairs

Knowledge of the type, amount and location of any previously implanted anchors is important to plan the ideal geometry of the SCR. In patients who had all-suture anchors implanted in the index procedure, the same drill-holes may be drilled over and reused to implant either the glenoid or humeral anchors for the SCR; this option allows the surgeon to preserve bone stock which may be valuable in future revision surgeries.

17.9.2 Long Head of the Biceps

The tenotomized intra-articular LHBT should be preserved in a saline solution on the side table until the final thickness of the FLA construct is known. A 5 mm-thick final FLA construct may be difficult to obtain after folding the layers of the FLA of a patient who has an unusually thin mid-thigh FLA. In this rare subset of patients, the tenotomized intra-articular LHBT may be used as an augmentation graft which is sutured on the FLA ex vivo to obtain a final graft construct of increased thickness (Fig. 17.6).

17.9.3 Subscapularis Tendon Tear Repair

Subscapularis tendon tears should be repaired to their native footprint because the subscapularis tendon is one of the main stabilizers of the glenohumeral joint. This repair should be performed before reconstructing the superior capsule. The subscapularis tendon should not be repaired or sutured to the superior capsular graft to avoid stiffness in external rotation.

17.9.4 Thickness of the Graft

The FLA should be folded to achieve an at least 5 mm- or ideally 8-mm-thick graft construct because 8 mm-thick grafts have been shown to

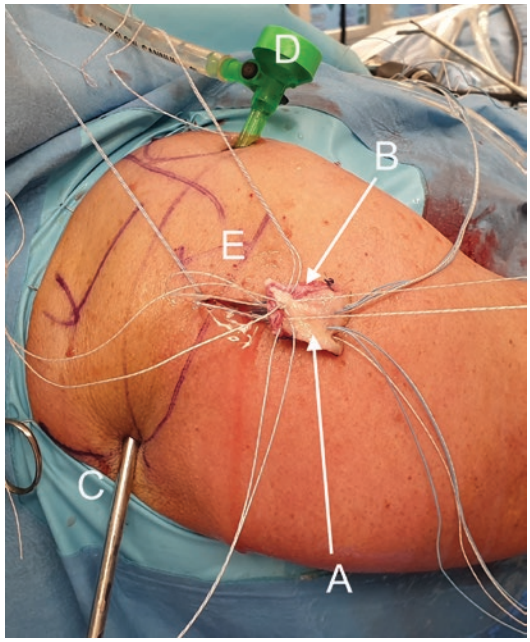

Fig. 17.6 SCR with a mid-thigh fascia lata autograft augmented with a long head of the biceps tendon autograft. Right shoulder with a (A) Tenotomized intra-articular long head of the biceps sutured over the (B) 4-mm-thick fascia lata autograft construct to obtain an 8-mm final graft construct; (C) Arthroscope through the posterior portal; (D) Outflow cannula through the anterior portal; (E) Suture limbs from the glenoid and humeral anchors through the lateral portal and passed through the graft construct

restore glenohumeral stability [31] and may result in lower graft tear rates.

17.9.5 Medial-to-Lateral Length of the Graft

The medial-to-lateral length of the graft construct should include at least 5 mm in excess laterally because the wide attachment of the capsule on the humerus has been shown to compensate for the lack of tendinous insertion and to complement the insertion of the rotator cuff [2, 32]. Humeral anchor placements should be marked on the graft construct at least 5 mm medially to the lateral border to achieve an at least 5 mm-wide attachment of the superior capsule on the humerus.

17.9.6 Shuttling of the Graft

The 5 to 8 mm-thick final FLA construct is flexible, easy to handle, easy to suture, and easy to shuttle intra-articularly in the direction of the angle of the implanted anchors, as long as the suture limbs are kept tensioned and thus unentangled throughout the double-pulley shuttling process. Therefore, there is no need to use a cannula in the lateral portal. The assistant controls the tension of the suture limbs, and these are held by different forceps to distinguish anterior from posterior anchors to avoid any twisting of the graft inside the joint.

17.9.7 Graft Fixation Site on the Superior Glenoid Rim

The superior capsular graft is attached to the superior glenoid rim, underneath the superior glenoid labrum, preserving it; this allows for both the glenoid and humeral suture anchors to be implanted through the lateral portal with a good attack angle, without the need to use additional accessory portals (e.g., the Neviaser portal) that have been used by other authors to implant the glenoid anchors medial to the superior labrum [27–30, 33].

17.9.8 Configuration of Graft Fixation on the Humerus

A transosseous equivalent fixation of the graft on the humerus is always used because among studies using FLA higher graft tear rates have been reported with a simple row fixation of the graft, [6] whereas lower tear rates have been reported using a double row or a transosseous equivalent fixation on the humerus [7, 34, 35]. The knots of the humeral medial row anchors are tied over the FLA construct before the limbs of the sutures are loaded into the humeral lateral row push-in anchors (Fig. 17.5) to minimize the risk of complete failure of graft fixation in the event of failure of the lateral row push-in anchors.

17.9.9 Donor Site

Respecting the mid-thigh FLA proximal, distal and posterior harvesting limits avoids damage to the tensor fascia lata muscle superiorly and the iliotibial band inferiorly and posteriorly. These aim to preserve the important postural function of the iliotibial tract and tensor fascia lata proximally which help extend, abduct, and laterally rotate the hip, and the role of the iliotibial band distally as an anterolateral knee stabilizer [36].

After the harvest, before the graft construct is prepared and the arthroscopic steps of the procedure continue, the two transverse 2 cm-long skin incisions on the thigh should be immediately sutured and compressed with a dressing to help reduce hematoma formation at the donor site. A compressive dressing is recommended for the first 48 h postoperatively [37].

17.10 Postoperative Treatment

17.10.1 Postoperative Protocol for Shoulder

For the first 3 weeks, patients wear a sling and are instructed to remove it several times a day to perform active assisted shoulder forward flexion and elbow flexion exercises. Use of the sling is subsequently diminished, and patients undergo a shoulder rehabilitation protocol with progressive passive and active ROM exercises. Until 6 weeks postoperatively, active resistant elbow exercises are not allowed. Until 6 months postoperatively, active resistant shoulder exercises are not allowed. After 6 months, a return to full activity is progressively allowed.

17.10.2 Postoperative Protocol for Donor Site

A compressive dressing is applied to the donor site for 48 h. Patients usually have an overnight postoperative hospital stay. The use of a compression stocking is advised for 6 weeks. No specific lower limb physical therapy is recommended. From 4 to 6 weeks, patients are instructed to avoid strenuous lower limb activities [7, 37].

17.11 Literature Review

Since the clinical study by Mihata et al. in 2013, [4] other authors have reported promising clinical outcomes of arthroscopic SCR in irreparable RCTs [6–11, 34, 35, 38–42]. However, studies on arthroscopic SCR available to date have a low level of evidence, and most studies are either case series, [6–11, 34, 35, 38–43] case reports, [44–48] surgical techniques, [12, 13, 26–30, 33, 49–52] or biomechanical studies [3, 14, 15, 31, 53–56].

17.11.1 Clinical Evidence

Among case series, [6–11, 34, 35, 38–43] the studies that had a minimum follow-up of 12 months, [6–10, 34, 35, 39, 40, 42] used either the FLA [6, 7, 34, 35, 39] or HDA [6, 8–10, 42]. The mean improvements of outcome scores of arthroscopic SCR in irreparable RCTs were statistically significant and clinically important among these studies, which reported improvements in American Shoulder and Elbow Surgeons (ASES) score (range of means, 29.3–56 points), [6, 8–10, 34, 35, 40, 42] active forward flexion (range of means, 27–65°), [8, 10, 34, 35, 40, 42] external rotation (range of means, 9–22°), [7, 8, 34, 40], internal rotation (range of means, two to three vertebral bodies), [7, 8, 34] visual analog scale (VAS, range of means, 2.5–5.9 points), [8–10, 35, 40] CS (range of means, 12–47.1 points), [6, 7, 34, 35, 42] SSV (range of means, 35%–44%), [7, 8, 40], SST (6.1–8.6 points), [7, 42] and abduction strength (range of means, 2.3–4.5 kilograms) [7, 10, 42].

Pseudoparalysis resolution rates of 66.7%, [34] 92.8%, [7] and 100% [35, 42] were reported. In the study by Eigenschink et al., [42] on SCR using the HDA, patients with SCR failure (28.4%) were not included in outcome analysis

of the 12-month follow-up, and the majority of patients with SCR failure (67%) had presented with a preoperative pseudoparalysis. In a subgroup analysis by Burkhart et al. [41], of a subset of 10 pseudoparalytic patients with irreparable RCTs who were previously included in the multicenter study of SCR using the HDA by Denard et al. [8], a rate of pseudoparalysis reversal of 90% was reported. In a study by Mihata et al., [38] a pseudoparalysis reversal rate of 95.3% following arthroscopic SCR with the FLA was reported; however, this study had overlapping samples with another study by Mihata et al. [34].

With regard to patient satisfaction, in the study by de Campos Azevedo et al., [7] at the 2-year follow-up, 85.7% of patients who underwent SCR with the FLA would agree to undergo the same surgery again. In the studies by Pennington et al., [10] and by Denard et al., [8], 90% and 72.9% of patients who underwent SCR with the HDA were satisfied at 1 year and at a mean 17.7-month mean follow-up, respectively.

Postoperative infection rates of 1.7%, [8] 2% [34], 4.5% [7], and 4.8% [42] were reported; infections required arthroscopic debridement and a course of intravenous antibiotic therapy, [7, 8, 34] and the superior capsular reconstruction site was kept intact after the infection resolved, [7, 34] or resulted in graft failure and led to RTSA [42].

The rate of revision to RTSA was reported in studies from countries where RTSA had been available since at least a decade before study enrollment (Portugal, [7] South Korea, [35], Austria, [42] and the United States) [8–10, 40]. In two of these seven studies, which used the FLA, [7, 35] no patients had to be revised to RTSA; in the remaining 5 studies, [8–10, 40, 42] which used the HDA, 1.1%, [10] 2.4%, [40] 11.1%, [9], 11.9% [8], and 19.0% [42] were revised to RTSA, respectively.

Among patients who underwent postoperative MRI to determine the repair integrity, the reported graft tear rate ranged from 5% to 32%, [6, 7, 34, 35, 39] in studies that used the FLA, and ranged from 15% to 75% in studies that used HDA [6, 8–10, 40, 42].

A wide range of clinical and surgical differences were found among studies, besides differences in type of graft used, which may have influenced the reported outcomes of arthroscopic SCR: number of tendons torn, grades of RCT arthropathy, fatty degeneration, or tendon retraction; differences in patient positioning and arm positioning during graft fixation, configuration of graft fixation (the highest graft tear rate among studies that used the fascia lata autograft was reported in the only study with a single row configuration of the graft fixation on the humeral side), [6] type and number of anchors, or thickness of the graft construct; differences in additional intraoperative procedures (subscapularis tendon repair, partial rotator cuff repair, tenotomy or tenodesis of the LHB, anterior acromioplasty, or distal clavicle excision); differences in the duration of follow-up and rate of loss to follow-up; and differences in outcome reporting, with studies either reporting results from all patients in the final outcome analysis, or exclusively reporting outcomes from selected cohorts of patients with an intact graft.

17.11.2 Biomechanical Evidence

Among biomechanical studies in cadaveric shoulders with irreparable RCTs, [3, 14, 15, 31, 53–55] SCR using the FLA was shown to completely restore superior stability of the humeral head, while patch grafting to the supraspinatus tendon partially restored superior translation, [3] and SCR using the HDA partially restored superior translation (although subacromial contact pressure and superior glenohumeral joint force were completely restored) [14]. SCR using a human dermal graft was compared to the subacromial balloon spacer, and both techniques were shown to decrease superior humeral head migration, restore more normal glenohumeral joint position and forces during various abduction positions, and no substantial differences were identified between these techniques at time zero [55]. SCR with the FLA normalized the superior stability of the shoulder joint when the graft was attached at 10° or 30° of glenohumeral abduction, and 8-mm-thick grafts had greater stability than 4-mm thick grafts [31]. Side-to-side

suturing to establish posterior continuity between the superior capsular FLA and the residual infraspinatus tendon was shown to completely restore the stability of the shoulder joint [53].

17.12 Summary

Biomechanical studies have shown that SCR using an 8-mm-thick FLA, attached at 10° or 30° of glenohumeral abduction, and sutured to the residual infraspinatus tendon, completely restored the stability of the glenohumeral joint in irreparable RCTs. Promising clinical outcomes of arthroscopic SCR for irreparable RCTs have been reported in studies with a minimum follow-up of 12 months using either the FLA or HDA. Pseudoparalysis resolution rates ranged from 66.7% to 100%. Postoperative infection rates ranged from 1.7% to 4.8%. In studies that used the FLA, no patients had to be revised to RTSA, and graft tear rates ranged from 5% to 32%, whereas in studies that used the HDA, the rate of revision to RTSA ranged from 1.1% to 19.0%, and graft tear rates ranged from 15% to 75%.

Active patients with supraspinatus and/or infraspinatus tendon tears, with preserved articular cartilage of the glenohumeral joint on the anteroposterior radiograph (Hamada grade ≤ 2), severe medial retraction of the supraspinatus tendon on the coronal MRI, a positive tangent sign, and fatty infiltration Goutallier grade ≥ 3 of the supraspinatus and/or infraspinatus on the sagittal MRI are considered ideal candidates for arthroscopic SCR.

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18 Augmenting Rotator Cuff Repairs with Scaffolds

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18.1 Introduction

Rotator cuff pathology is one of the most common musculoskeletal disorders, affecting as many as 17 million people in the United States [1–5] and accounting for more than 4.5 million physician visits per year [6]. Rotator cuff repair (RCR) is one of the most common orthopedic procedures performed. The number of RCRs has steadily increased over the past 2 decades, with between more than 460,000 repairs performed each year in the United States, with an estimated total cost between US$3 billion and US$12 billion [5, 7–12].

Despite the advances in surgical technique, instruments, and implants to repair rotator cuff tendon tears, studies suggest that failure after RCR occurs frequently, early, and with or without an anatomic full-thickness tissue defect [13–17], with the risk of re-rupture ranging from 20% to 60% [18, 19]. While it has been demonstrated that failure of rotator cuff tendons to heal is often associated with acceptable pain relief, most studies have shown higher patient-reported outcome scores, range of motion, and strength when the repair heals [13, 18–28]. It has been suggested that early RCR failures occurring 4–6 weeks postoperatively represent an inability of the surgical construct to mechanically maintain the integrity of the repair site, with biologic factors likely playing a small role in the healing process and thus contributing minimally to the strength of the repair [13]. Mechanical augmentation using extracellular matrix (ECM) materials—namely in the form of a graft of tissue or synthetic material (commonly referred to as a "patch") may be useful in minimizing these early mechanical RCR failures [29].

In contrast, later RCR failures occurring 3–6 months postoperatively likely result from mechanical stresses at the repair site caused by patients' attempts to regain motion and strength. These likely signify a biologic failure to heal [13]. Grafts can also provide a scaffold for delivering biologic therapies (e.g., platelet-rich plasma (PRP) or cell seeding) to augment tendon healing at the operative site while also providing a load-sharing device. This load-sharing and a more organized healing environment is thought to

Note: *Scaffold:* A temporary structure that is put in place to help build a permanent structure; scaffolds are expected to be removed or resorbed through the process they are supporting.
Graft: A segment of tissue or material used to support, or restore missing tissue, usually with favorable biomechanical properties, not expected to be complete resorbed but instead incorporated into the site. A graft can also serve in some capacity as a scaffold.

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prevent scar tissue formation at the tendon-bone interface and encourage growth of functional tissue comprised of tenocytes, chondrocytes, and osteocytes [29, 30].

As a result of the large number of RCRs performed annually and the high rate of structural failure, considerable efforts have been devoted to developing grafts that augment the RCR site by mechanically reinforcing it as well as providing a biological scaffold that can enhance the rate and quality of the healing process [13]. Because the ECM of the graft directly interacts with tissue microenvironments for stem cell proliferation, it is necessary to consider the design of the patch and how it affects cell differentiation [30]. Prior studies have shown that the composition of microenvironments alters cellular adhesion, differentiation, and morphology [30–35]. Since Neviaser et al.'s [36] first use of the interposition allograft for RCR, various graft types have expanded to include synthetic polymers, allograft, autograft, and xenograft materials with varying degrees of clinical success [37]. Common disadvantages to these efforts have included fibrous cartilage formation, strong inflammatory reactions, or rapid degradation of the graft.

The purpose of this chapter is to present the current options and clinical outcomes of synthetic grafts used to augment biological healing in RCR.

18.2 Allografts for Patch Augmentation

Multiple studies have investigated the efficacy of allografts for patch augmentation in RCR, particularly for massive rotator cuff tears. When discussing patch augmentation, it is imperative the surgeon understands the purpose and proper use of the patch. These patches can be used to provide structural integrity to the repair site, increasing the load to failure over a repair of diseased tendon alone, as well as a biological enhancement of the repair to improve healing at the repair site. However, some grafts add little mechanical support and are primarily used as a biological scaffold providing an improved retention of growth factors and cells responsible for the healing cascade. This is an important differentiation, and the surgeon should understand this so that the patch is used in the proper way. Several acellular human dermal matrices are commercially available, with one in particular (GraftJacket; Wright Medical Technology, Arlington, TN) receiving the most attention in the literature. Galvin et al. [38] note that other preliminary studies have investigated an alternative acellular human dermal matrix product, including the Arthroflex patch (Arthrex, Naples, FL), though larger studies are recommended [39]. The human dermal matrices form an acellular collagen ECM scaffold intended to provide an organized framework for host cell infiltration, vascular ingrowth, and later tissue remodeling [38, 40].

Burkhead et al. [41] evaluated 17 patients with massive rotator cuff tears who were treated with a standardized open repair technique with GraftJacket augmentation. At an average follow-up of 1.2 years, the authors reported a 25% retear rate, yet significant improvement in pain scores, UCLA scores, and active forward flexion. Barber et al. [40] found similar results in a randomized, multicenter prospective level II clinical trial comparing 22 patients undergoing GraftJacket augmentation of chronic 2-tendon rotator cuff tears with 20 patients undergoing arthroscopic repair alone. Follow-up at 12 months showed retear rate of 15% in the augmented group and 60% in the control group, as well as significant improvement in outcome scores (American Shoulder Elbow Society, Constant). No adverse reactions were recorded.

Agrawal et al. [42] performed a retrospective case series of the clinical and structural outcomes (1.5 T MRI) of arthroscopic rotator cuff repair with acellular human dermal graft Allopatch HD (MTF Sports Medicine, Edison, NJ) in 14 patients with large, massive, and previously repaired rotator cuff tears. The retear rate was 14.3% and the Constant–Murley score increased from 49.72 to 81.07 ($P = 0.009$). Pain scores improved from 13.57 to 7.73 ($P = 0.008$). Flexilevel scale of shoulder function improved from 53.69 to 79.71.

Despite the clinical successes of some allografts, important disadvantages of this repair modality include difficult accessibility in some regions, location-dependent regulation, concerns regarding sterilization techniques, high costs, as

well as increased technical difficulty in augmenting a repair with a patch when compared to RCR alone. While not reported in many studies, there is also the possibility for rejection of the graft with resorption or increase inflammation and pain.

18.3 Xenografts for Patch Augmentation

Xenograft augmentation of RCRs relies on the premise that acellularized ECM will provide a scaffold to stimulate the host inflammatory response and collagen deposition in order to strengthen tendon healing [38]. Many xenografts have been studied with variable results [43–48].

The porcine small intestine submucosa (Restore Orthobiologic Implant; DePuy, Warsaw, IN) has been thoroughly studied. Iannotti et al. [48] compared the effectiveness of the porcine xenograft augmentation versus a control group without augmentation in 30 shoulders with chronic 2-tendon rotator cuff tears. Results at 1-year follow-up revealed the rotator cuff healed in only 27% (4/15) of augmented shoulders compared to 60% (9/15) in the control group ($P = 0.11$). Clinical outcome scores were worse in the augmentation group and therefore, use of this patch was not recommended for massive rotator cuff tears. Walton et al. [47] performed a similar prospective study confirming these findings.

Bokor et al. [43] demonstrated magnetic resonance imaging (MRI) evidence of partial-thickness rotator cuff tear healing following treatment with a highly porous collagen implant arthroscopically placed over the bursal surface of the supraspinatus tendon. Patients with intermediate- to high-grade bursal, articular, or intrasubstance partial-thickness tears of the supraspinatus tendon demonstrated no tear progression and showed progressive filling in of the defects coupled with improvement in tendon quality through 2-year follow-up. As previously mentioned, the mechanism of action for this healing response is thought to be related to the ability of the collagen implant to induce new host tissue formation and ingrowth over the bursal surface of the tendon [43, 49, 50]. This increase in tendon thickness is thought to improve the local biomechanical environment of the tear by reducing tendon strain and therefore optimizing its healing potential.

Schlegel et al. [50] performed a prospective multicenter trial using a similar protocol in the United States, enrolling 33 patients with chronic, degenerative, intermediate-grade ($n = 12$), or high-grade ($n = 21$) partial-thickness tears (11 articular, 10 bursal, 4 intrasubstance, and 8 hybrid) of the supraspinatus tendon. Following arthroscopic subacromial decompression without repair, the bioinductive xenograft collagen patch was attached over the bursal surface of the tendon. The implant was made from highly purified type I bovine collagen and engineered into a highly oriented, highly porous (85%–90% porosity) scaffold that was approximately 2 mm thick once hydrated. Also included in the repair were polylactic acid tendon staples and polyether ether ketone bone staples (Rotation Medical, Plymouth, MN, USA).

Clinical outcomes were assessed using American Shoulder and Elbow Surgeons and Constant–Murley scores preoperatively and at 3 and 12 months, postoperatively. MRI was performed to assess postoperative tendon healing and thickness at the original tear site [50]. They similarly reported improvements in outcome scores ($P < 0.0001$), no tear progressions, and 94% of patients with either no progression of tears or a reduction in defect size after 1 year. MRI of complete healing was found in 8 patients and a considerable reduction in defect size was shown in 23, whereas 1 lesion remained stable. The authors concluded that arthroscopic implantation of the highly porous and purified type I bovine collagen scaffold is safe and effective for treatment of intermediate-grade to high-grade partial-thickness rotator cuff tears of the supraspinatus tendon [50].

Thon et al. [51] also reported high healing rates (96%) and sufficient functional outcomes following insertion of the same xenograft collagen patch during repair of 23 large and massive rotator cuff tears.

Other studies, however, have demonstrated higher retear rates with different collagen patches. Ciampi et al. [46] demonstrated a retear rate of 51% at 1-year follow-up when using a collagen patch for augmentation. Their findings are more consistent with Muench et al.'s [52] results, as

59% of patients in that study did not meet the substantial clinical benefit criteria for ASES at terminal follow-up and were thus considered clinical failures. Muench et al.'s results should be understood in the context of the study group which was comprised of 40% smokers and 23% diabetics, with all having had at least 1 previously failed cuff repair.

While these results are promising, there are some downsides to xenografts including lack of integration into host tissue, cost and risk of disease transmission. While xenografts have been used for quite some time in other surgical procedures, their use in RCR augmentation is still relatively new and should continue to be studied to determine their long-term benefits.

18.4 Synthetic Grafts for Patch Augmentation

Synthetic grafts for augmentation of RCR are intended to mechanically offload the repair site at surgery and during the initial period of healing after repair. Unlike human-derived ECM grafts, which are considered human tissue for transplantation and thus do not require clearance from the US Food and Drug Administration (FDA) if minimally manipulated and intended for homologous use, synthetic devices must undergo the FDA 510(k) regulatory process [13]. This entails demonstration of equivalence to other devices in performance, biocompatibility, safety, stability, sterility, and packaging.

The theoretical benefit of synthetic patch augmentation of RCRs is that the graft is immune tolerant may provide additional mechanical strength, while still serving as a scaffold for host tissue response and ECM ingrowth [38, 53]. However, given the variety of material composition and morphology of synthetic scaffolds—including size, shape, porosity, and roughness—various immune responses can be elicited [54, 55]. A number of animal, cavaderic, and clinical studies have been performed on graft and scaffolds for RCR.

Van Kampen et al. [49] cultured reconstituted collagen scaffolds made from highly purified type I collagen from bovine tendons (Collagen Matrix, Inc., Oakland, NJ) [56, 57] to the surface of the infraspinatus tendons of 23 adult sheep. Histology demonstrated complete ingrowth with fibrovascular tissue by 6 weeks and by 12 weeks the scaffold had induced the formation of a layer of dense, regularly oriented collagenous tissue which significantly increased the thickness of the native tendon. This new tissue was well-integrated into the host tissues at both the bone interface and along the length of the tendon. At 26 weeks, the scaffold was completely absorbed into the native bone, leaving a stable layer of mature tendon-like tissue over the surface of the host tendon which was still present at 52 weeks. The bony insertion of the new tissue demonstrated evidence of a fibrocartilaginous component that suggested a normal, direct insertion. It was therefore concluded that use of a reconstituted collagen scaffold consistently increased the thickness of a rotator cuff tendon by inducing the formation of a well-integrated and mature tendon-like tissue.

McCarron et al. [58] evaluated a poly-L-lactic acid (X-Repair; Synthasome, San Diego, CA) device for augmentation of repairs in 8 pairs of human cadaveric shoulders. Yield load was 56%–92% higher and ultimate load was 56%–76% higher in augmented repairs. No increase in initial stiffness was found. Failure by sutures cutting through the tendon was reduced, occurring in 17 of 20 non-augmented repairs but only 7 of 20 augmented repairs. These data showed that application of the poly-L-lactic acid device significantly increased the yield load and ultimate load of a primary RCR across all of the supraspinatus tendon and the upper half of the infraspinatus tendon but did not affect initial repair stiffness.

Several studies have evaluated both absorbable and non-absorbable synthetic patch augmentation options. These devices include the poly-L-lactide patch (X-Repair; Synthasome), polypropylene patch (Repol Angimesh, Angiologica BM Srl, Pavia, Italy), and a non-absorbable reticulated polycarbonate polyurethane patch (Biomerix, Fremont, CA). There are variable outcomes after synthetic patch augmentation, with retear rates ranging from 10% to 62% [46, 59–61]. A more comprehensive list of devices and studies are listed in Tables 18.1 and 18.2.

Table 18.1 Commercially available synthetic and biosynthetic scaffolds

Scaffold type	Company	Composition
Synthetic		
BioFiber	Tornier (Edina, MN)	Poly (4-hydroxybutyrate)
Integraft	Hexcel Medical (Dublin, CA)	Carbon fiber tow
LARS ligament	LARS (Arc-sur-Tille, Burgundy, France) Dacron Xiros (Leeds, UK)	Polyethylene terephthalate
Marlex	C.R. Bard (Mullayhill, NJ)	High-density polyethylene
Mersilene mesh	Ethicon, Inc. (Somerville NJ)	Polyethylene terephthalate
Poly-tape	Neoligaments (Leeds, UK)	Polyethylene terephthalate
Repol Angimesh	Angiologica BM Srl (Pavia, Italy)	Polypropylene
Teflon	Dupont Company (Wilmington, DE)	Polytetrafluoroethylene
X-repair	Synthasome (San Diego, CA)	Poly-L-lactic-acid
Nanofiber, unwoven	Atreon Orthopedics. (Columbus, OH)	Polyglycolic acid (PGA) and Polylactide-co-caprolactone (PLCL)
Biosynthetic		
BioFiber-CM	Tornier (Edina, MN)	Poly (4-hydroxybutyrate) + bovine collagen

Table 18.2 Studies Evaluating Outcomes of rotator cuff repair augmentation with synthetic scaffolds

Study	Level of evidence	Inclusion criteria	No. of patients	Surgical technique	Graft used	Retear rate and outcomes	Imaging assessment
Lenart et al. [53]	IV	Large, massive RCTs	Aug: 13	Open	Poly-L-lactic acid (X-repair; Synthasome Inc., San Diego, CA)	62% retear rate. Significant improvement in clinical outcome scores (PENN/ASES)	MRI at 1 year
Proctor [60]	IV	Large, massive RCTs	Aug: 18	Arthroscopic	Poly-L-lactic acid (X-repair; Synthasome Inc., San Diego, CA)	17% retear rate at 1 year, 22% retear rate at 42 months. Significant functional improvement	Ultrasound at 1 year
Ciampi et al. [46]	III	Massive RCTs	Syn aug: 52 Xeno aug: 49 Control: 51	Mini-open	Polypropylene (Repol Angimesh, Angiologica BM Srl, Pavia, Italy)	Retear rates: Synthetic augmentation: 17% Xenographic augmentation: 41% Control: 41% Significant improvement in function, strength at 3-years	Ultrasound at 1 year
Encalada-Diaz et al. [61]	III	Small, medium RCTs	Aug: 10	Mini-open	Polycarbonate polyurethane (Biomerix, Fremont, CA)	10% retear rate Significant improvement in VAS, SST, ASES, & ROM	MRI at 1 year

ASES American Shoulder and Elbow Surgeons score, *Syn* synthetic, *Aug* augmentation group, *Xeno* xenographic group, *RCTs* rotator cuff tears, *ROM* range of motion, *SST* simple shoulder test, *UCLA* University of California, Los Angeles, *VAS* visual analog scale, *MRI* magnetic resonance imaging, *PRP* platelet-rich plasma, *cBMA* concentrated bone marrow aspirate, *SCB* substantial clinical benefit

18.5 Future Directions

Recent attention has been focused on the development of synthetic nanofiber scaffolds for the potential augmentation of the biological component of tendon repair. The scaffold is placed in between the bone and the rotator cuff utilizing the high tensile sutures from the medial row anchors that are passed through the scaffold, then passed through the rotator cuff, and then secured into a lateral row of anchors in a knotless fashion (Figs. 18.1, 18.2, 18.3, and 18.4). Erisken et al.

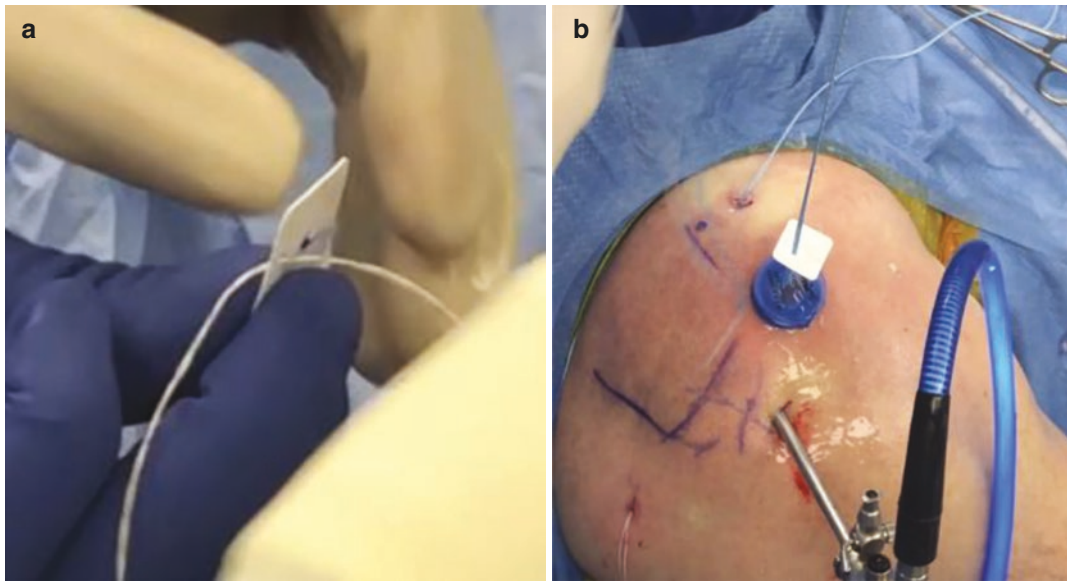

Fig. 18.1 (**a**, **b**) Intraoperative image demonstrating the high tensile suture used in the rotator cuff repair from the medial row anchors placed through the nanofiber scaffold

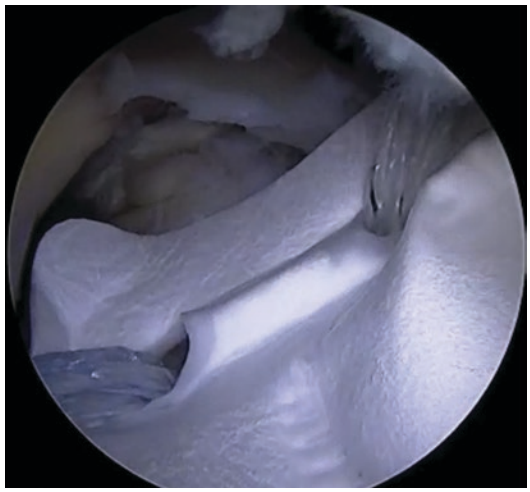

Fig. 18.2 Intraoperative image demonstrating the nanofiber scaffold placed in the shoulder after the high tensile sutures from the medial row anchor have been passed through the scaffold. The sutures will then be passed through the rotator cuff and secured into a lateral row, allowing the scaffold to sit in between the bone and tendon to augment healing

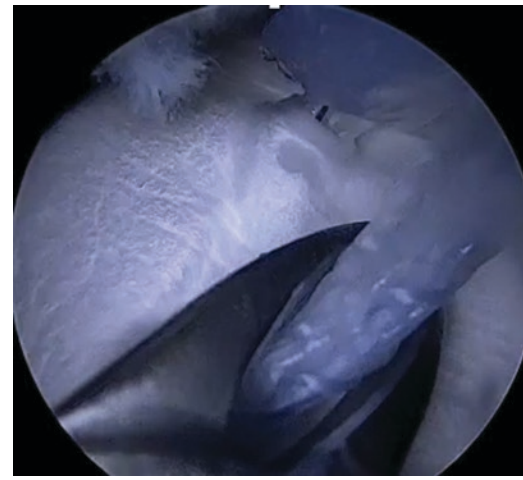

Fig. 18.3 Intraoperative image demonstrating a looped retriever used to grab the high tensile sutures that have been passed through the nanofiber scaffold that will then be passed through the rotator cuff

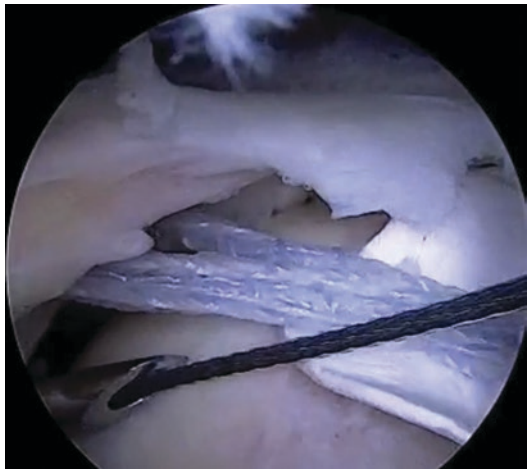

Fig. 18.4 Intraoperative image demonstrating passage of the sutures through the rotator cuff tear that have been previously passed through the nanofiber scaffold

[62] demonstrated that scaffold fiber diameter regulates human tendon fibroblast growth and differentiation. Moreover, this study showed higher cell growth, collagen, and GAG production on nanofibers compared to microfibers, clearly demonstrating the effect of structural properties of scaffolds on cell behavior and delineating the importance of fiber diameter as a design parameter in the fabrication of biomimetic scaffolds. Electrospinning shows enormous potential in the construction of scaffolds with controllable geometric and architectural structures and may enable researchers to design and develop novel scaffolds that more closely mimic the structural environment of the native ECM [63]. Future studies should assess the in vitro and in vivo use of these electrospun nanofiber scaffolds on tendon-to-bone healing.

Using an acute rotator cuff tear model in sheep, a recent study compared the use of a nonwoven nanofiber scaffold to augment rotator cuff repair to a control group of standard RCR and assessed healing at the repair site using biomechanical investigation as well as histological analysis. The scaffold was uniquely placed as an interposition graft between the tendon and the bone. The authors found a significant increase in ultimate failure force at both 6 and 12 weeks when compared to controls. In fact, the nanofiber treatment group force to failure was 47% higher than the control group at 12 weeks. Furthermore, histological assessment demonstrated collagen fiber bundles penetrating into bone in a manner similar to Sharpey's fiber formation. These findings suggest that this nanofiber scaffold may provide benefits in both the early return of mechanical strength of the tendon-to-bone healing site related to the ability of the scaffold to provide a healing environment where Sharpey's fiber formation at the enthesis can occur. The next study will include the same model but use a chronic rotator cuff tear protocol to potentially be more translational to the care of rotator cuff tears in humans.

18.6 Summary

As the number of RCR continues to rise and the healing rates remain stagnant, graft and scaffold augmentation in RCR surgery has become increasingly popular in recent years. Early studies have shown favorable outcomes for several of the devices. Further work is needed to understand the long-term effects and the utility of these grafts and scaffolds to improve the rate of rotator cuff tendon healing to bone.

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The Subacromial Balloon Spacer: Indications and Technique

19

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19.1 Introduction

Shoulder injuries are the third most common musculoskeletal complaint behind knee and back pain [1]. While estimates vary, irreparable rotator cuff tears may represent up to 30% of a dedicated shoulder practice [2]. These injuries are challenging to treat and represent a significant cause of shoulder pain and disability [3]. Treatment options for massive rotator cuff tears are numerous including nonoperative management, debridement, biceps tenotomy, full or partial rotator cuff repair, various release and slide procedures, tendon transfers, superior capsular reconstruction, implantable subacromial spacers, and shoulder arthroplasty [2]. In complex or irreparable rotator cuff tears (iRCTs), however, final treatment options are somewhat limited, with partial repair, superior capsular reconstruction (SCR), and reverse shoulder arthroplasty (RSA) being three commonly used surgical techniques.

The subacromial balloon spacer is a treatment currently being employed for iRCTs. During this surgery, a biodegradable spacer is implanted between the acromion and humeral head. The spacer depresses the humeral head, decreases contact between the humeral head and acromion, increases the deltoid moment arm to facilitate rehabilitation, and attempts to restore normal shoulder biomechanics. Early prospective trials have shown excellent results with regard to clinical outcomes, however, little data in the form of level 1 clinical trials exist [4]. A cost-effectiveness analysis comparing the cost and outcomes of subacromial spacers to nonoperative management, RSA, and partial rotator cuff repairs found that the subacromial spacer is the most cost-effective method of treatment for irreparable rotator cuff tears [5]. These data were based on the Italian healthcare system and have not been extrapolated to a US Healthcare model. The subacromial balloon may be a viable treatment option in patients with an irreparable rotator cuff tear who are not candidates for SCR or RSA due to age, activity level, medical comorbidities, bone quality, or inability to perform long-term shoulder rehabilitation.

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19.2 Biomechanics

The preshaped subacromial balloon is made from a copolymer poly interposition device composed of poly-L-lactide-co-e-caprolactone in a 70–30 mix (InSpace). It is inserted between the acromion and humeral head, creating a physical barrier that mimics native glenohumeral joint biomechanics. The copolymer is inflated with saline during surgery and then gradually degrades until it is completely resorbed in 12 months after implantation [6]. In this principle, spacer implantation reduces subacromial friction during shoulder movement by lowering the head of the humerus and simultaneously facilitating humeral gliding [7]. Recently, biomechanical work by Lobao et al. found that the subacromial balloon spacer immediately restored, intact-state glenohumeral contact pressures at most abduction angles and significantly lowered the humeral head at most abduction angles in 14 cadavers using both digital and spring scale measurements. Lowering the humeral head potentially decreases pain at the acromiohumeral articulation and tensions the deltoid to facilitate rehabilitation of the deltoid and periscapular muscles. Other authors have found it reduces subacromial pressures when combined with rotator cuff repair, potentially decreasing tendon tension and lowering retear rates [8]. The glenohumeral stability and elongating effect on the deltoid are similar to the effects of reverse shoulder arthroplasty for the rotator cuff deficient shoulder, and the implantation of a physical barrier above the humerus and lowering of the humeral head to its native positioning mirrors the goal of SCR, leading authors to postulate that this may be a viable alternative to these therapies for iRCTs [9].

19.3 Surgical Indications

The use of the subacromial balloon spacer is primarily indicated for the treatment of massive irreparable rotator cuff tears and failed rotator cuff repairs. It is a treatment option for retracted rotator cuff tears with significant atrophy and fatty infiltration (Goutallier 4) that are not completely repairable, or when the quality of tissue is so poor that tendon healing and functional recovery are unlikely. The subacromial balloon can be used as a primary procedure, or in the revision setting for failed rotator cuff repair when the remaining tendon quality is low and greater tuberosity bone is deficient. Additionally, the balloon has been used as an augment to partial rotator cuff repair by placing the balloon on top of the repaired tendon to decrease tension on the repair and acromiohumeral contact pressures. Some authors have completed a partial repair of the rotator cuff prior to inserting the balloon, however, this does not appear to result in a significant improvement in pain or functionality versus balloon implantation without repair [6].

In the revision setting, the balloon can be used in cases of tendon deficiency where debridement along was previously performed. This includes recurrent tears at the muscle-tendon junction where the remaining rotator cuff muscle is retracted and lacks a sufficient tendon stump for repair. Prior to device implantation, irritating loose sutures can be excised, proud suture anchors can be removed from the greater tuberosity, and a tuberoplasty can be performed if large bone spurs are present on the proximal humerus. The balloon can even be utilized in cases with deficiency of the coracoacromial arch as the contact pressure between the humeral head and acromion will keep the spacer in place.

The subacromial balloon is a viable treatment option for patients of advanced age or with multiple medical comorbidities in which a long surgical procedure is not ideal, and the healing environment is not optimal for tendon transfers or SCR (due to medical comorbidities, tendon quality, or lack of greater tuberosity bone). It also serves as an alternative to RSA when glenohumeral arthritis is not present, or arthroplasty is not a feasible option to the patient due to the required activity restrictions.

19.4 Surgical Technique

The patient is prepped and draped in the normal sterile fashion, in either beach chair or lateral decubitus position as per surgeon preference. Following a diagnostic arthroscopy in which the rotator cuff is deemed irreparable, the decision is made to proceed with the insertion of the subacromial balloon spacer (Video 19.1). Biceps tenodesis or tenotomy can be performed at the discretion of the surgeon. Arthroscopic subacromial bursectomy is performed, and a tuberoplasty can be performed if large excrescences are present on the greater tuberosity. A limited acromial smoothing can be performed; however, care should be taken to maintain the coracoacromial arch to prevent dislodgement of the balloon or anterior superior escape of the proximal humerus.

The balloon is available in multiple sizes. The distance is measured from 1 cm medial to the superior edge of the glenoid to the lateral tip of the greater tuberosity, and the appropriate balloon size is selected (Video 19.2). While viewing from the posterior portal, the balloon is inserted through the lateral portal into the subacromial space (Video 19.3). A cylindrical plastic insertion tube protects the balloon and is retractable once the device is in the subacromial space. No cannula is required for insertion. The balloon is filled with sterile saline to a predetermined level via a 60 cc syringe to depress the humeral head to a more native, anatomical position in the glenoid fossa. A small amount of saline is removed, based on the size of the balloon from previous measurements, to make the balloon pliable, and the device is sealed by pulling the trigger on the insertion handle. The shoulder is then passively ranged to ensure the balloon is adequately positioned with maintenance of full range of motion (Video 19.4). Superior migration of the humeral head can be attempted and is blocked by the subacromial spacer. Finally, the balloon is visualized in the subacromial space following the range of motion to confirm correct position and to confirm that no migration of the device has occurred.

Of note, the surgical technique has been noted to be safe and effective using both beach chair and lateral decubitus positioning. In addition, balloon insertion is possible under fluoroscopy without arthroscopy, however, this is not our standard practice (Figs. 19.1 and 19.2).

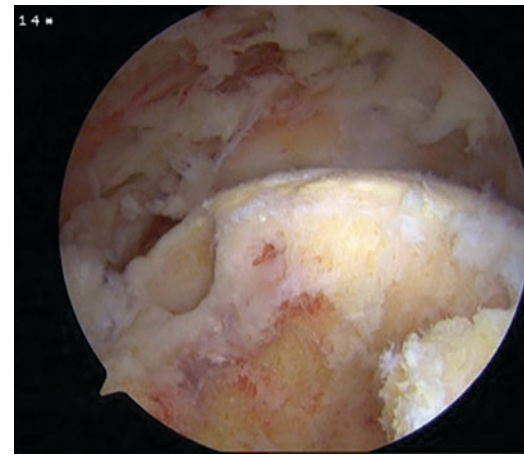

Fig. 19.1 This is a right shoulder in the beach chair position, viewing from the lateral portal, after removal of multiple suture anchors following a failed repair of a massive rotator cuff tear. Note the extensive bone loss in the greater tuberosity, and a massive rotator cuff tear of supraspinatus and infraspinatus with atrophy, scarring, and retraction medial to the glenoid

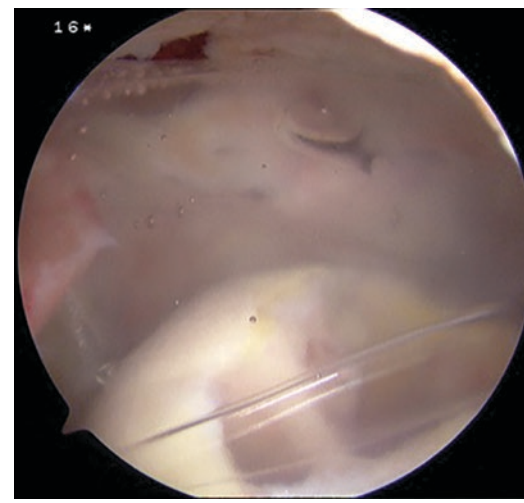

Fig. 19.2 This image is viewing from the lateral portal in the same right shoulder after the subacromial balloon has been inflated and deployed in the subacromial space

19.5 Postoperative Protocol

The patient is immobilized in an abduction pillow sling or shoulder immobilizer for 1 week. We allow for pendulums of the shoulder passive external rotation, and active range of motion of the wrist and hand during this time period. At 1-week postoperative, active-assisted range of motion is initiated, and physical therapy can commence, with progression to full active range of motion. Strengthening is started at 6 weeks, progressing rotator cuff, deltoid, and periscapular strengthening as tolerated. Some authors do not routinely employ formal physical therapy following the procedure [7]. Physical therapy protocols vary and may progress slower if the balloon spacer is deployed with a concomitant rotator cuff repair.

19.6 Clinical Outcomes

The procedure can safely be performed in the outpatient setting with limited surgical time. The surgical procedure is much faster than advanced reconstructive procedures such as SCR or tendon transfers. Postoperative rehabilitation can be performed with a regimented home exercise program and minimal formal physical therapy visits, allowing a rapid recovery function. The speed of recovery is generally faster than SCR, tendon transfers, or shoulder arthroplasty, all of which may take 1 year to regain full function.

To our knowledge, there are no level 1 randomized control trials available on this procedure. However, numerous prospective studies have been completed. Senekovic et al. prospectively looked at the use of biodegradable spacer (InSpace) implantation in 24 patients with 23 full-thickness tears, with 84.6% of the patients showed a clinically significant improvement of at least 15 points in their total constant score (TCS) at a mean follow-up of 5 years [4]. Pieknaar et al. found similar results in their prospective study of 44 patients with iRCTs at mean 34-month follow-up, with a significantly improved oxford shoulder score and significant pain reduction, as well as 82% of patients reporting satisfaction with their outcome. Of note, the authors reported zero complications with balloon spacer implantation [10].

However, not all prospective studies have demonstrated excellent results. Iban et al. looked at 11 patients following subacromial spacer implantation for posterosuperior cuff tears, with success of the procedure defined as a clinically relevant variation of the constant score and no surgical reintervention at 24 months. According to the authors, only 40% seemed to benefit from surgery, and five required conversion to reverse shoulder arthroplasty [11].

These mixed results have led to questioning of the validity of the procedure, as well as a call for more clear indications for this surgery. Similarly, the improvement in pain following the subacromial spacer implantation may come from sacrificing the long head of the biceps tendon, which has been demonstrated to reduce pain in patients with iRCTs, leading some authors to argue that this may be sufficient for pain relief in these patients [12, 13]. Although preliminary outcomes are promising, further long-term data are necessary before definitive conclusions can be made on the pain relief and clinical outcome improvement from the spacer.

19.7 Complications

There are few reported complications surrounding balloon implantation. In a systematic review of 284 patients treated with balloon implantation for massive/irreparable RCTs, 6 (2.1%) experienced complications, with 3 patients (1.0%) having balloon migration (2 anterior, 1 not specified). Three patients required subsequent balloon removal, 1 for infection and 2 for implantation-related complications. If balloon migration occurs, it is theoretically possible to locate the device with ultrasound and pop the balloon with a spinal needle. Other complications noted in the systematic review include transient lateral antebrachial cutaneous (LABC) nerve palsy, superficial wound complications, and deep wound infection. Of note, there were 24 patients lost to follow-up, possibly confounding this complication rate.

The polymer material used is believed to be safe for subcutaneous and intra-articular implantation, with no toxic or tumorigenic properties [14]. As the balloon deflates by roughly 3 months and disintegrates fully by 1 year postoperatively, there is the potential for radiographic progression of arthritis. Deranlot et al. found that the Hamada score progressed 1 radiographic stage in four shoulders and three stages in two shoulders, whereas the rest of their sample (82%) remained in the same stage at follow-ups of at least 1 year [15]. In contrast, other studies have reported on continued increase in the acromiohumeral interval at each subsequent follow-up for 2 years, suggesting a protective effect against arthritis. Similarly, it is possible that a fibrotic capsule forms around the balloon that lasts after it is fully degraded and may have implications for continued joint stability [9]. Preliminary data appear to indicate that the clinical improvement following spacer implantation does not dissipate after it degrades, however, further research on fibrosis of the spacer capsule and progression of protection against arthritis following spacer implantation is warranted [16].

19.8 Alternatives to Treatment (SCR, RSA) and Cost-Effectiveness

The subacromial spacer is available in the European market since 2010, while it is only available in the United States through multicenter prospective trials and is not yet approved by the FDA. Therefore, data are somewhat limited with regard to device feasibility compared to other treatments. Theoretical advantages versus reverse shoulder arthroplasty include cost, faster surgical time, absence of activity restrictions, speed of recovery, and ease of implantation performed on an outpatient basis, particularly in a patient with severe medical comorbidities. While outpatient shoulder arthroplasty has been safely performed in appropriately selected patients [17], this has not become a widely adopted practice at this time, and inpatient care remains the norm at many institutions.

SCR has been advocated for irreparable or massive rotator cuff tears, with the theory that the superior capsule is a critical structure in maintaining the depression of the humeral head and in compensating for rotator cuff function [18]. The fascia lata autograft or dermal allograft prevents humeral head superior migration thus enabling relatively normal shoulder biomechanics, while also acting as a physical spacer between the humeral head and acromion, similar to the subacromial balloon [19]. Early biomechanical and clinical results are promising for SCR, with increased range of motion and an absence of graft failures [20], however, a paucity of long-term data on this procedure exists. Additionally, prospective trials have noted radiological failure rates of up to 55% [21]. Woodmass et al. found that SCR using a dermal allograft for large to massive rotator cuffs had a failure rate of 65% in 34 patients at 12-month follow-up, with additional patients considered clinical failures. Savoie also recently noted much less success using dermal allografts versus Mihata's original technique of using a fascia lata allograft [20]. Additionally, recent changes in the technique for SCR, advocating a minimum of seven anchors (three medial and four lateral) along with a more costly, thicker dermal patch may increase the success and healing rate of the dermal patch but also confer significantly greater healthcare expenses. SCR also requires a longer period of postoperative immobilization and rehabilitation, with full recovery taking up to 12 months.

Both SCR and the subacromial balloon are treatment options for younger patients who have massive, irreparable RCTs without glenohumeral arthroses. Biomechanical studies of both procedures have demonstrated the ability to restore the humeral head to a native position within the glenoid vault. Given their biomechanical superiority to biceps tenotomy, current literature should focus on demonstrating improved long-term clinical outcomes in the form of increased range of motion and decreased pain over that of a simple biceps tenodesis or tenotomy. Furthermore, future studies must seek to minimize or justify costs as the price of these treatments remains a potential socioeconomic issue [22].

19.9 Cost-Effectiveness

Much of the initial work on cost-effectiveness in shoulder surgery has occurred in the past century. Vitale et al. prospectively reported on the cost-effectiveness of rotator cuff surgery after following 87 patients for 1 year, finding a surgery yielded a cost-effectiveness ratio of $13,092.84/QALY by use of the HUI and $3091.90/QALY by use of the EuroQoL. The authors concluded that rotator cuff surgery is cost-effective [23]. Castagna et al. also studied the treatment paradigm for irreparable rotator cuff tears using an expected value decision analysis. They found that the subacromial spacer was a cost-effective alternative to partial rotator cuff repair and reverse total shoulder arthroplasty, with a gain of 0.05 QALYs for the additional cost of 522€, resulting in an ICER of 10,440€/QALY gain. The authors used a cost methodology consisting of costs derived from Medicare pricing, which was subsequently converted to an Italian healthcare model [5].

More recently, numerous studies have shown that reverse total shoulder arthroplasty also appears to be a cost-effective procedure for different shoulder pathologies. While implant longevity at the 9- to 10-year mark remains as high as 95% in some studies, there are concerns regarding lower outcome scores and radiographic deterioration over time [24]. Given its cost-effectiveness and high implant survival rate, RSA will continue to be used as a primary treatment for end-stage rotator cuff arthropathy in association with glenohumeral arthroses, and as a salvage procedure after the failure of other shoulder surgeries and rotator cuff degeneration. Rather than replacing RSA, subacromial spacers will likely continue to be used as a preliminary treatment prior to RSA in patients with irreparable RCTs lacking glenohumeral arthritis, or those deemed not medically fit or reticent to undergo a joint replacement procedure. When compared to SCR, patients with poor tendon quality or a lack of adequate bone stock may be more amenable to the subacromial spacer, which does not require tendon repairs of any kind and may also be a more affordable alternative to the cost of implants or multiple anchors.

Cheaper implants that offer similar outcomes have greater value, with value being defined as outcomes/costs [25]. Black et al. looked at implant costs and surgical time for transosseous versus transosseous equivalent (TOE) rotator cuff repair, concluding that the transosseous was a cheaper alternative to TOE with no difference in case time [26]. Similar studies comparing the subacromial spacer to other therapies for irreparable rotator cuff tears with long-term follow-up are warranted, and the cost of OR time will be an important variable in these analyses. The subacromial balloon spacer offers the theoretical advantage of a less invasive, shorter surgical procedure with minimal postoperative rehabilitation versus SCR or RSA, however, these data have not been validated with level 1 clinical trials.

19.10 Conclusion

The subacromial balloon spacer is a novel treatment option for massive irreparable rotator cuff tears and failed rotator cuff repairs that lack sufficient tendon to perform a rotator cuff repair. The procedure is safe with relative ease of implantation, decreased surgical time, quick postoperative recovery, and a low complication rate. Biomechanical studies demonstrate a similar mechanism to SCR with humeral head depression and excellent restoration of native anatomy in cadaver subjects. Additionally, preliminary cost-effectiveness is promising when compared with other treatments for iRCTs. Although prospective short- to medium-term data are promising, long-term level 1 studies are needed to further validate this potentially promising therapy.

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Balloon: Soft-Tissue Options for the Failed Balloon

20

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20.1 Introduction

The interpositional subacromial balloon spacer (Stryker, Inc) is a relatively new treatment option for irreparable rotator cuff tears. It is generally used in the treatment of massive, irreparable, or recurrent cuff tears [1]. The balloon just received FDA approval in July 2021 following a multicenter FDA trial. The balloon has been used extensively in Israel and Europe for approximately 11 years [2]. The limited data thus far have been mixed, but mostly encouraging. Although the spacer does not lead to rotator cuff healing, it has been shown to decrease the pain and improve functional outcomes in multiple series [3–9], and has been found to be cost-effective [10]. This is thought to be due to the improvement in glenohumeral mechanics imparted by the spacer's resistance to the superior translation of the humeral head by the deltoid [11]. Other studies, however, have shown minimal improvements at short-term follow-up [12, 13].

Although the short to midterm data currently available shows many patients are satisfied with their outcome, a minority of patients require revision. Reverse total shoulder arthroplasty is an option in this scenario, however, the procedure is definitive, and in patients who do not have glenohumeral arthritis or either too young or too frail other soft-tissue options should be explored. Revision replacement of the balloon spacer can be considered in these groups, as should tendon transfers or partial cuff repair when possible.

20.2 Balloon Failure

Modes of balloon failure include balloon migration, subscapularis deficiency, infection, or patient dissatisfaction due to continued pain and poor functional outcome. Balloon migration most often occurs posteriorly into the supraspinatus or infraspinatus fossa. It is likely the result of excessive bursectomy at the time of placement leading to extensive posterior dead space [2]. Subscapularis deficiency is a contraindication to balloon spacer placement as the balloon cannot compensate for the lost anteroposterior force couple [14]. If the subscapularis fails after balloon placement, the patient will need to undergo a revision procedure to address the anterior cuff. Additionally, this may allow the balloon to migrate anteriorly. Although most series show that patients are generally satisfied with the outcomes of their balloon spacer, some have shown inconsistent results. In a small series of 16 consecutive patients, Ruiz Ibán et al. found that only 40% of patients demonstrated clear benefit from the surgery [15]. No infections have been reported to date.

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20.3 General Balloon Revision Considerations

One of the advantages of the balloon spacer is that its placement does not preclude any revision option [2]. The spacer is designed to biodegrade over the course of 12 months although only one study has confirmed balloon degradation via MRI in vivo [9]. Assuming that revision balloon placement is performed after the balloon degradation, the procedure and results should not be too dissimilar than the primary procedure. If revision is undertaken before spacer degradation, then the balloon would need to be removed or debrided, which should present minimal issues. When revising a failed cuff after most traditional rotator cuff repairs, attention is directed to suture anchor location or the quality and availability of humeral bone stock, but neither of these is an issue after balloon placement. However, consideration when revising a failed balloon is that additional time has passed since the initial evaluation of the patient. Further cuff atrophy and tendon retraction are likely to have progressed limiting the surgeon's repair options at the time of revision.

20.4 Revision Balloon Spacer Placement

No data currently exist on revision balloon spacer placement, although multiple occurrences of the procedure have been reported in the literature [3, 4]. Mode of failure will dictate if revision balloon spacer placement is an appropriate option after initial balloon failure. Patients who have failed due to balloon migration are likely to benefit from removal and proper replacement of a balloon. The migrated balloon can often be found posteriorly where it cannot provide the opposing force to counteract superior humeral migration, and thus the patient will continue to have pain from acromial abutment. Migration occurs after excessive bursectomy resulting in excess posterior dead space. Removal of the misplaced balloon may only exacerbate that situation, and immediate replacement may not be advisable. In this case, a staged procedure may be beneficial allowing for the posterior dead space from the previous balloon to scar in and then placing a new balloon spacer at a later date.

In the case of balloon failure due to patient dissatisfaction, it is unlikely that simply placing another balloon into the subacromial space will generate a satisfactory outcome. It is possible, however, that the previous balloon did not elicit the expected inflammatory response resulting in a durable membrane to resist superior humeral migration. In that case, placement of another balloon could be an option until it again dissolves.

20.5 Tendon Transfers

Tendon transfers are another treatment option for massive, irreparable rotator cuff tears, and can also be used in the setting of a failed balloon spacer. Surgical indications are not clearly defined but the technique is most often used in younger patients without significant glenohumeral arthritis [16]. Tendon transfers function by biomechanically restoring the force couples about the glenohumeral joint [17]. Multiple options are available depending on the rotator cuff deficiency.

Latissimus dorsi transfer has been the historic standard for posterosuperior cuff tears [18], however, lower trapezius transfer is gaining in popularity [19]. Latissimus transfers have been shown to reliably decrease pain in patients but with variable functional outcomes [16]. Unfortunately, in one series, about one-third of patients still went on to develop glenohumeral arthritis after tendon transfer [20]. Additionally, biomechanical evidence suggests that latissimus transfer may be inferior to lower trapezius transfer [21]. The lower trapezius more closely replicates the force vector of the infraspinatus and thus better restores shoulder kinematics and joint reactive forces. However, due to poor excursion of the muscle, an allograft tendon is usually necessary to allow for attachment to the greater tuberosity, introducing additional issues regarding healing [17]. This may be beneficial, however, in circumstances where there is a greater tuberosity bone defect that can be filled with an allograft calcaneal bone block.

For anterosuperior defects, pectoralis major transfers can compensate for an irreparable tear involving the subscapularis [22]. This may be particularly useful in the revision balloon setting if the balloon failure is secondary to subscapularis deficiency. In a small series of 27 patients over 10 years follow-up, eight of ten patients were satisfied after their pectoralis major transfer. Unfortunately, rotator cuff arthropathy progressed in two-thirds of patients, however, only one patient required revision to a reverse total shoulder arthroplasty [22]. Latissimus dorsi transfer can also be used for anterior cuff insufficiency, but outcome data is limited [23].

20.6 Partial Cuff Repair

After balloon failure, partial cuff repair is another available soft tissue option in a shoulder without evidence of glenohumeral arthritis. The goal of partial cuff repair is to restore the force couples of the transverse rotator cuff cable without sacrificing healthy shoulder anatomy as occurs with tendon transfer [24]. In massive cuff tears, properly executed partial repairs have been shown to have similar outcomes to complete cuff repairs [25]. This provides more evidence that restoring the force couple relationship is crucial to shoulder function, but not necessarily footprint coverage. These partial repairs, however, may not be as durable as complete repairs, with half of the patients in one series reporting dissatisfaction with their outcome at 2 years follow-up, although their initial outcomes were good [26]. Partial cuff repair is generally considered at least to be a useful adjunct in most irreparable cuff repair scenarios, for example, the cuff should be repaired as much as possible when placing a balloon spacer [27].

20.7 Conclusion

Although current data, while limited, show that most patients do well after balloon spacer placement, treatment failure has been shown in some patients. Balloon spacer placement is minimally invasive and does little to limit a surgeon's revision treatment options after failure. In the properly selected patient, multiple soft tissue revision options are available including revision balloon spacer placement, tendon transfers, or partial cuff repair. All soft tissue revision options have been shown to have at least some benefit in patients without glenohumeral arthritis [1, 16, 24]. In patients with arthritis, a reverse total shoulder arthroplasty is the treatment of choice [28].

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21 The Role of the Suprascapular Nerve in the Failed Rotator Cuff Repair

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21.1 Background

The rotator cuff repair (RCR) is one of the most common procedures performed in daily practice. Even though performed by experienced surgeons, failures and re-ruptures are frequently seen. The revision surgery of symptomatic patients with failed repairs is a considerable challenge. Mobilizing and repairing large chronic tears according to the tear pattern are demanding. These tears are often associated with significant retraction and muscle atrophy. Due to muscle retraction, scar tissue, and adhesions, the suprascapular nerve (SSN) may be at risk. There has been much awareness in the association between retracted rotator cuff tears and suprascapular neuropathy. The real incidence of this situation is undetermined, but it has been reported to be present in 8–27% of massive rotator cuff tears [1].

21.2 Suprascapular Nerve Anatomy with Regard to Revision Cuff Surgery

After its origin in C4–C5 cervical spine roots, the suprascapular nerve arises from the upper trunk of the brachial plexus. It runs posterior to the clavicle and arrives at the suprascapular notch by passing beneath the transverse scapular ligament (TL). It provides two collateral motor branches to innervate the supraspinatus (SSP), and the nerve reaches the spinoglenoid groove to innervate the infraspinatus (ISP) [2]. Several anatomic studies have demonstrated that the suprascapular nerve also provides sensory branches to the coracoclavicular, coracoacromial, coracohumeral ligaments, subacromial bursa, and even to the acromioclavicular and glenohumeral joints. Based on these findings, the release of the SSN may have a favorable inference with regard to strength and pain after ARRCR.

In a chronic retracted cuff repair setting, the surgeon must perform a posterior cuff interval split between the SSP and ISP tendons. This critical step of the procedure may jeopardize the SSN at the spinoglenoid notch [3]. The suprascapular nerve usually courses at a mean distance of 3.42 cm from the glenoid rim, 5.34 cm from the articular insertion site of the rotator cuff, and 6.09 cm to the lateral border of the acromion [4]. For these reasons, when we decide to perform a posterior interval split, we make some pen marks

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of these distances at the radiofrequency wand to avoid cutting too far medially above the glenoid.

21.3 The Rationale of the Suprascapular Nerve Release in Revision Cuff Repair

Dysfunction of the suprascapular nerve is intimately associated with rotator cuff pathology; nerve dysfunction can lead to cuff disease and vice versa. The suprascapular nerve injury diagnosis rests on electromyography (EMG) and nerve conduction velocity (NCV) examinations. The current indications for performing these studies are: (1) persistent posterior shoulder pain without a diagnosis, (2) atrophy and weakness of the SSP and/or ISP muscles, (3) MRI demonstrating muscle edema suggestive of nerve injury, (4) massive rotator cuff tendons with retraction and tension on the nerve [5, 6].

The primary suprascapular nerve entrapment syndrome is an often recognized cause of disability in overhead athletes. Microtrauma and overstretching of the SSN at the suprascapular notch can produce posterior shoulder pain with weakness and atrophy of the SSP and ISP muscles. The dysfunction is determined by the physical examination, muscle denervation signals at the MRI, among a positive electromyography and nerve conduction velocity. The arthroscopic section of the TL and the SSN release usually solve these young athletes' problems with, other than that, healthy rotator cuff tendons [7, 8].

In the setting of a chronic retracted cuff tear, the mechanism of nerve entrapment is different. The muscle atrophy (MA) and fatty infiltration (FI) may be produced by the tendon tear, the SSN neuropathy, or both. Even though different resonance imaging patterns of MA and FI have been described, the precise role of the SSN neuropathy in the occasion of massive cuff tears is difficult to be evaluated by the MRI [6, 9].

Anatomic studies have assessed the risk to the suprascapular nerve elongation by quantifying the nerve's tension and the angle between the nerve and its motor branch at the scapular notch with medial supraspinatus tendon retraction. With 3 cm of retraction of the SSP, the motor branch of the SSN was stretched. With the supraspinatus muscle in its anatomic position, the suprascapular nerve and its first motor branch angle measured 142.6° at the suprascapular notch. After muscle retraction of 1 cm, the angle decreased to 98.7° and with 5 cm retraction, the angle dropped to 34.6° [5, 10]. However, these anatomic findings have not been proven clinically, and Hoellrich et al. reported no difference at the EMG preoperative and postoperative studies in RCR with tendon reductions up to 3.5 cm [11].

The degree of muscle atrophy observed after a massive rotator cuff tear may be explained by increased tension in the nerve due to muscle retraction [12]. Reducing the tendon to the original footprint during cuff repair may be advantageous to nerve function and improve postoperative pain and strength. However, the SSN native angle correction by tendon repair can be insufficient, and an SSN release may help to decrease the pain and achieve better muscle recovery.

21.4 Surgical Technique

The procedure can be performed with the patient in a beach chair position or lateral decubitus under an interscalene block with or without adding general anesthesia. After arthroscopic diagnostic inspection, pulling from the tendons in different directions, the surgeon must recognize the tear pattern and keep it in mind during the repair. Second, an extensive rotator cuff tendon release is performed to achieve adequate tendon reduction to the greater tuberosity without tension. Articular capsulotomies, the resection of the adhesions between the tendons and the bony structures, are essential steps to entirely or at least partially repair the cuff in this demanding revision scenario. The radiofrequency device releases the tendons from bones such as the glenoid rim, coracoid, and acromion spine. Care should be taken to avoid damage to the SSN at the spinoglenoid notch during these releases. Finally, after the revision cuff repair and sometimes the addition of a superior capsule reconstruction with auto or allograft, we proceed to free the

SSN at the suprascapular notch. With the scope at the posterior–lateral portal and an anterior–lateral portal as a working portal, the coracoacromial ligament that arises from the coracoid tip is identified. Following the coracoid body, the coracoclavicular ligaments (trapezoid laterally and conoid medially) are found at the coracoid base. The radiofrequency wand cleans the coracoid bone and allows us to follow the conoid ligament. We use a spinal needle to locate two retro-clavicular portals between the clavicle and the acromion spine. These habitually called "SSN portals" are 7–10 cm from the lateral acromion edge [2, 13, 14]. A switching stick is used to separate and retract the fat tissue and to see the medial border of the conoid ligament. The conoid ends at the suprascapular notch and the transverse ligament. After an adequate blunt dissection with a trocar, the artery over and the nerve under the transverse ligament are easily identified. The SSN lays at the suprascapular groove. The surgeon must be aware of the shape of the notch and the suprascapular artery's location, which may vary [15, 16]. Through the SSN medial portal, a blunt trocar is used as a retractor, and the nerve is released by sectioning the transverse ligament with an arthroscopic punch from the lateral SSN portal. After doing so, we must see the nerve moving freely out of the groove Fig. 21.1.

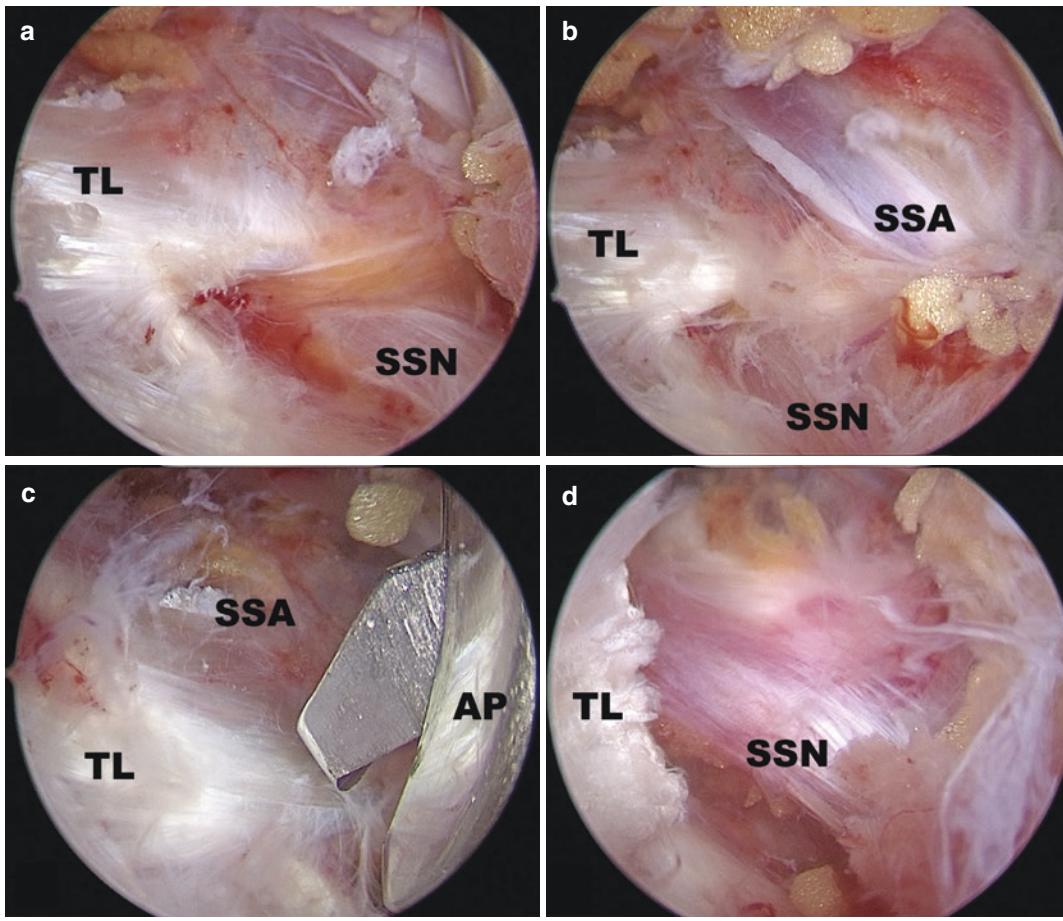

Fig. 21.1 Left shoulder. Arthroscopic view from the lateral portal. (**a**) *TL* Transverse ligament that arises from the Conoid ligament, *SSN* Suprascapular nerve under the TL and compressed by the transverse ligament. (**b**) *TL* Transverse ligament, *SSN* Suprascapular nerve. SSA: Suprascapular artery over the TL. (**c**) *TL* Transverse ligament, *SSA* Suprascapular artery. *AP* Arthroscopic punch. The SSN and the SSA are retracted medially by a switching stick. The AP gets access to the TL. (**d**) *TL* Transverse ligament cut by the AP. SSN free after its release

21.5 The Role of the Suprascapular Nerve Release for the Failed Rotator Cuff Repair

Gereli et al. describe the influence of the SSN injury as an underlying factor leading to compromise in the rotator cuff enthesis structure and the neuropathy with an impact on the healing after repair [17]. Some authors reported improvements after SSN release, in pain and strength, even when the cuff was not repaired [18]. Furthermore, Kenyon et al. recommended the SSN neurotomy to decrease pain in patients with unrepairable cuff tears [19].

Other researchers reported significant clinical, EMG, NCV postoperative improvements after cuff repairs with or without SSN [20–22]. Tsikouris et al. compare athletes with cuff or labrum tears treated by arthroscopic repairs with or without SSN release and concluded the release of the nerve improves the outcomes and the return to sports [22, 23]. Nevertheless, Yamakado described the results of primary massive rotator cuff repairs with (n = 70) and without (n = 61) release of the SSN, and no significant difference with regard to pain and function was found between the two groups [24].

Savoie et al. were the only ones who reported the results of patients undergoing revision cuff repair and compare their results in two groups of patients with or without SSN release (n = 22 each group). The average age of both groups was similar, and the mean follow-up 28 months. All the cuff tears were massive, retracted to the glenoid, and with grade IIIB or IV Goutallier fatty atrophy. The preoperative indication to release the nerve was done based on the fat atrophy's severity and the tendon retraction. The preoperative UCLA scores (sub-scores pain, function, active forward flexion, strength, and satisfaction) were worse in the released group than in the control group. With similar scores at the final follow-up, the liberated group achieved a better postoperative improvement. They concluded the patients with the nerve released presented better functional recovery and less pain at the final follow-up [25, 26].

21.6 Final Thoughts

The current indications of the SSNR in massive cuff tears and revision cuff surgery for failed RCRs are still controversial. The level of evidence about if the SSN needs to be released in the setting of RCR is low. The role of suprascapular neuropathy and suprascapular nerve decompression in the context of failed rotator cuff surgery also remains imprecisely defined. Moreover, no recommendations regarding SSN release in conjunction with revision rotator cuff repair can be made at this time.

Additional studies are needed to fully determine if the SSN release in the revision cuff repair setting is worth it or not and to delineate its indications more precisely in the future.

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Part III

Muscle Transfers

Open Latissimus Dorsi Transfer

22

Lukas N. Muench, Daniel P. Berthold,
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22.1 Introduction

The treatment of irreparable, massive posterosuperior rotator cuff tears remains a major challenge in shoulder surgery, especially in young, physically active patients without glenohumeral osteoarthritis [1]. Numerous surgical treatment options exist without clear evidence-based guidelines being proposed in the literature, including debridement and tenotomy or tenodesis of the long head of the biceps, partial repair, tendon transfers, and superior capsule reconstruction or reverse total shoulder arthroplasty [1, 2].

In absence of severe cuff tear arthropathy and integrity of the subscapularis muscle, transfer of the latissimus dorsi tendon has been proposed as a viable treatment option, especially in young patients with loss of active external rotation [3–6]. Transfer of the latissimus dorsi tendon is thought to restore external rotation and reestablish the anterior–posterior force couples on the humeral head, thus leading to significant improvement of shoulder function along with pain relief [3–6]. First described by Gerber et al. [7], the procedure has demonstrated promising long-term results for irreparable posterosuperior rotator cuff tears in several studies [3–6]. However, insufficiency of the subscapularis muscle and fatty infiltration of the teres minor muscle has been shown to be associated with inferior results. In addition, postoperative outcomes are varying dependent on patients' psychomotor learning skills as well as compliance with the rehabilitation program.

22.2 Indication and Contraindication

Indications for latissimus dorsi transfer include symptomatic irreparable chronic massive tears of the posterosuperior rotator cuff in patients without severe cuff tear arthropathy. The main indication is the loss of active external rotation and flexion in a physically active patient with good to excellent psychomotor learning skills and sufficient compliance [8].

Contraindications include lesions of the axillary or thoracodorsal nerve, functional limitations of the deltoid muscle, shoulder stiffness with limitation of passive glenohumeral motion, advanced cuff tear arthropathy, ongoing infections, or lack of patient's compliance, which is critical for a successful postoperative

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rehabilitation. Further, in cases with concomitant irreparable tears of the subscapularis muscle, this procedure should not be performed, as a sufficient reconstruction of the force couples is impossible [3, 9]. Tears of the teres minor muscle are considered relative contraindications, as these injuries have been shown to result in poorer outcomes when compared to an intact muscle [3]. Further, an acromiohumeral distance of less than 7 mm and high-grade fatty infiltration was found to be significant preoperative risk factors for clinical failure [10].

22.3 Preoperative Assessment

22.3.1 Patient History and Physical Examination

Prior to the physical examination, a detailed history regarding the patients' symptoms, duration of complaints, and previously performed therapies or surgeries is critical. Further, the patients' expectations of their future shoulder function should be assessed. Following the history of the patient, physicians should focus on a thorough physical examination including glenohumeral joint, sternoclavicular joint, cervical spine, and ipsilateral upper extremity. Active and passive motion of the involved shoulder should be assessed. The integrity of the supraspinatus (starter test and jobe test), infraspinatus (external rotation strength, external rotation lag sign), teres minor (Hornblower test), and subscapularis (lift-off test, belly-press test, and internal rotation strength) muscle needs to be evaluated. In addition, a detailed neurovascular examination including the axillary nerve, radial nerve, and thoracodorsal nerve is important to assess if the patient is eligible for this procedure.

22.3.2 Imaging

A series of three plain radiographs of the involved shoulder should be performed (true a.-p., Y-view, axial) to assess the integrity of bony structures, degree of osteoarthritis, and centering of the humeral head. The acromiohumeral distance can be measured on radiographs using the true a.-p.-view.

Magnetic resonance imaging (MRI) scans are required for assessing the morphology and size of the rotator cuff tear, including tendon retraction, muscle atrophy, and fatty infiltration. It is of importance to obtain an MRI including far medial parasagittal images to ensure full visualization of the rotator cuff muscles. Additionally, concomitant pathologies should be evaluated.

22.4 Operative Technique

This surgical procedure aims to transfer the latissimus dorsi to the supraspinatus and infraspinatus footprint at the greater tuberosity, in order to restore the muscular force couple. Re-centering of the humeral head may lead to significant functional improvement and reduction of pain.

22.4.1 Positioning and Preparation

The patient is positioned in the lateral decubitus position with the operative arm placed in an arm holder device to allow for a sufficient release of the latissimus dorsi muscle and transfer to the humeral footprint. After induction of general anesthesia, examination of the index shoulder is performed, followed by standard preparation and draping of the shoulder.

22.4.2 Step-by-Step Technique

Prior to the tendon transfer, a diagnostic arthroscopy is performed. Intra-articular concomitant pathologies should be addressed after completing the tendon transfer. Subsequently, the dorsal incision is performed, which runs arch-shaped from the inferior angle of the scapula along the lateral scapular rim to the apex of the axilla (Fig. 22.1). The latissimus dorsi and teres major muscle are identified and digitally separated, circularly dissected, and carefully mobilized, until visualization of the neurovascular pedicle (Fig. 22.2).

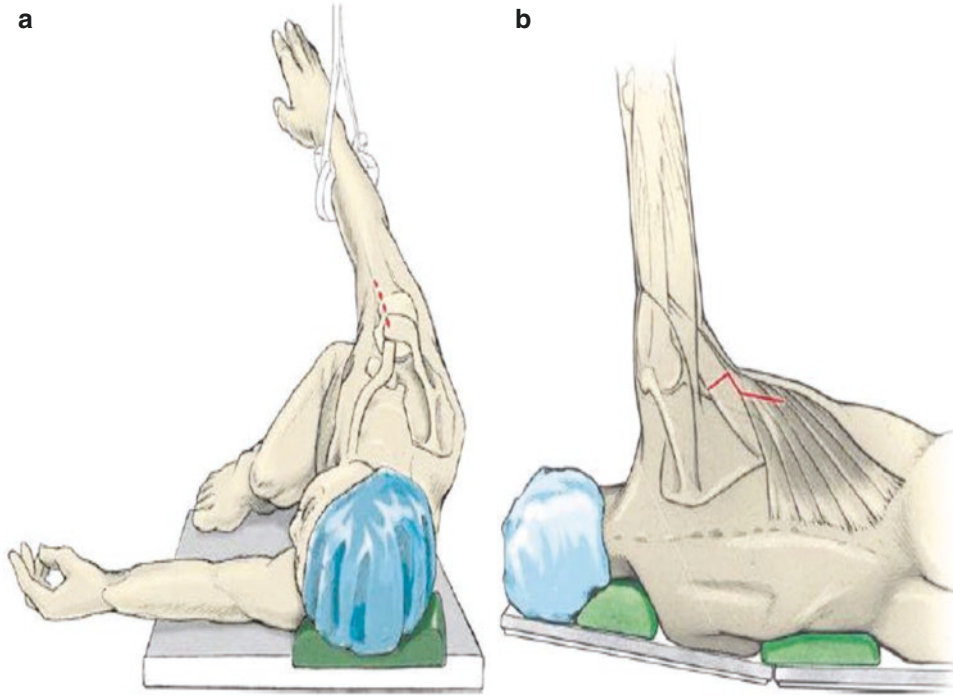

Fig. 22.1 Illustration of the lateral decubitus position. (**a**) Demonstrating the anterolateral incision for refixation of the transferred tendon. (**b**) Dorsal incision for tendon mobilization and detachment. (From: Imhoff AB, Feucht MJ. Surgical atlas of sports orthopaedics and sports traumatology. Springer; 2017. eBook ISBN 978-3-662-43776-6, Fig. 3.30a, b)

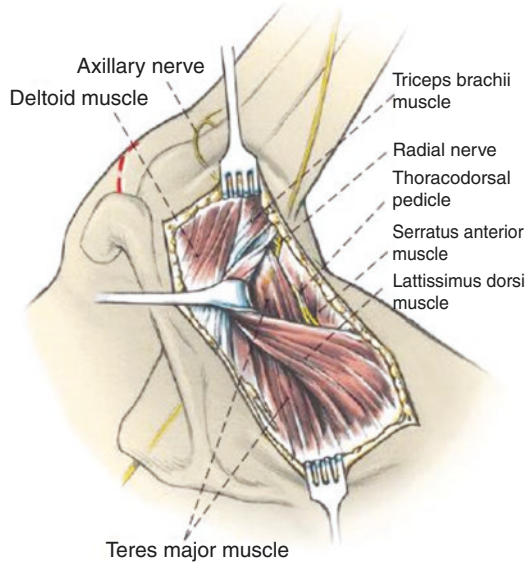

Fig. 22.2 Preparation and mobilization of the upper part of the latissimus dorsi. (From: Imhoff AB, Feucht MJ. Surgical atlas of sports orthopaedics and sports traumatology. Springer; 2017. eBook ISBN 978-3-662-43776-6, Fig. 3.31)

After adequate mobilization of the tendon is achieved, the arm is brought to 45° of flexion and maximum internal glenohumeral rotation. Keeping the arm in this position allows for detaching the latissimus dorsi tendon over a length of approximately 12 cm from its insertion at the intertubercular sulcus of the humerus and thorax, while preserving the radial nerve. The latissimus dorsi tendon is then looped at the medial and lateral side with a nonabsorbable tear-proof suture using Krakow stitches (Fig. 22.3).

Subsequently, the anterolateral delta split is performed. To improve intra-articular visualization, a bursectomy along with a debridement of the footprint of the greater tuberosity may be considered (Fig. 22.4). Additionally, a tenotomy or tenodesis of the long head of the biceps tendon can be performed.

To allow for transferring the tendon, preparation between the dorsal deltoid muscle and the long head of the triceps is performed in a proximal direction, while protecting the axil-

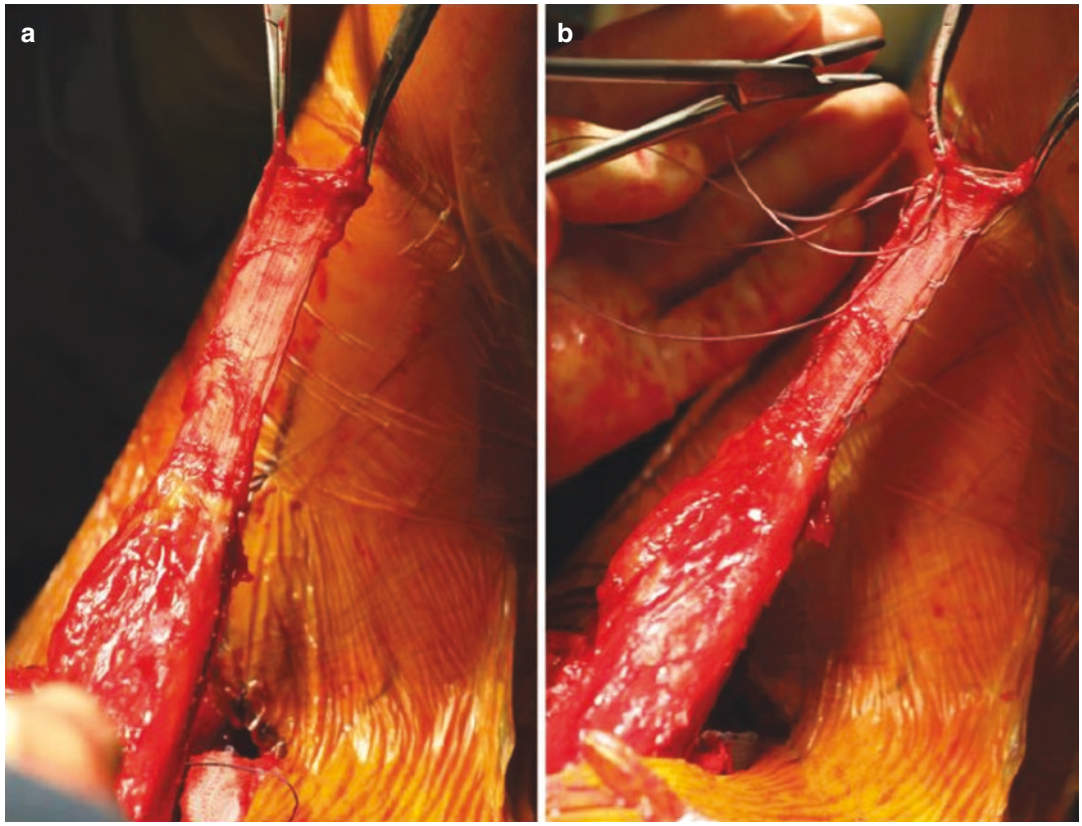

Fig. 22.3 (**a**) Latissimus dorsi tendon after mobilization and detachment. (**b**) The latissimus dorsi tendon is looped at the medial and lateral side with nonabsorbable suture using Krakow stitches. (From: Imhoff AB, Savoie FH. Rotator cuff across the life span, ISAKOS Consensus Book. Springer; 2019. eBook ISBN 978-3-662-58729-4, Fig. 43.2)

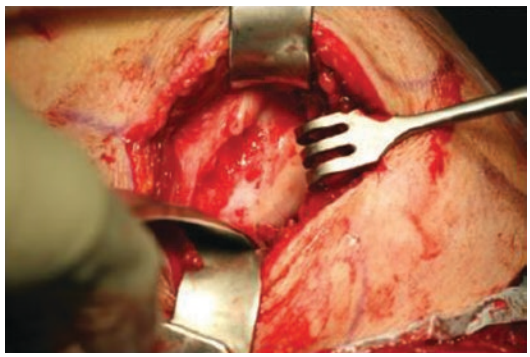

Fig. 22.4 Preparation of the footprint at the greater tuberosity. (From: Imhoff AB, Savoie FH. Rotator cuff across the life span, ISAKOS Consensus Book. Springer; 2019. eBook ISBN 978-3-662-58729-4, Fig. 43.3)

lary nerve. Once the tendon has been passed through the dorsal deltoid and triceps (Fig. 22.5), the tendon should be carefully evaluated for distortion (Fig. 22.6). The latissimus dorsi tendon can be attached to the posterosuperior part of the greater tuberosity using suture anchors in a Mason-Allen suture technique by bringing the arm to 45° of flexion and neutral glenohumeral rotation. To avoid subacromial impingement, the tendon is fixed using knotless suture anchors at the anterior area of the greater tuberosity. If possible, additional reconstruction of the supraspinatus to the LDT could be performed.

Overall, when performing latissimus dorsi tendon transfer, three variations of humeral

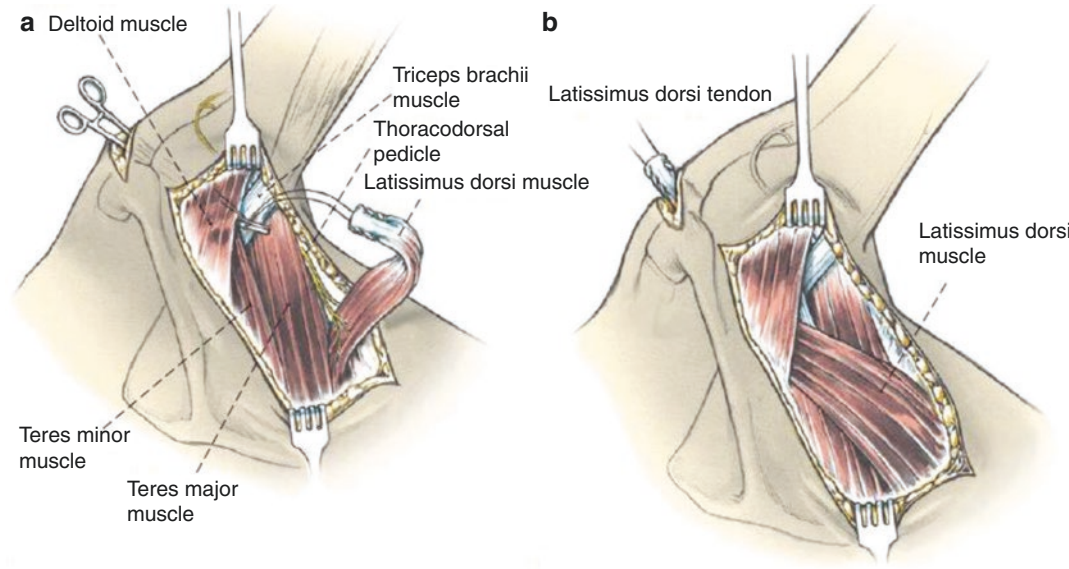

Fig. 22.5 (**a**) A clamp is passed through the deltoid split incision into the interval between the deltoid and long head of the triceps brachii, (**b**) followed by pulling the detached latissimus dorsi tendon anteriorly. (From: Imhoff AB, Feucht MJ. Surgical atlas of sports orthopaedics and sports traumatology. Springer; 2017. eBook ISBN 978-3-662-43776-6, Fig. 3.32a,b)

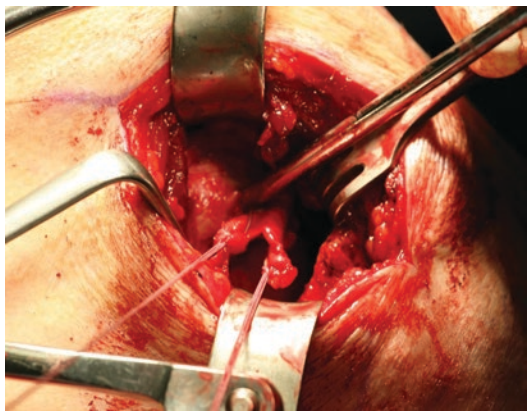

Fig. 22.6 Once the tendon has been passed through the dorsal deltoid and triceps, the latissimus dorsi tendon should be carefully evaluated for distortion

fixation should be considered, depending on the initial indication (Fig. 22.7):

1. If reconstruction of both the supraspinatus and infraspinatus tendon is not possible, the latissimus dorsi tendon is fixed to the anterior border of the greater tuberosity, leaving the remaining torn tendons in place. In this case, the transferred tendon improves active external rotation and might function as a humeral head depressor.
2. If the infraspinatus tendon is suited for reconstruction, but the supraspinatus tendon might be deemed irreparable or can only be reconstructed partially, the latissimus dorsi tendon is transferred over the infraspinatus tendon and fixed on the anterior border of the greater tuberosity. In this case, the vector of the transferred tendon mimics the vector of the supraspinatus tendon, thus allowing for greater abduction when compared to the defect state.
3. If the remaining infraspinatus tendon allows for reconstruction and the supraspinatus tendon can be mobilized to the footprint, the supraspinatus tendon can be attached medially to the transferred latissimus dorsi tendon. Consequently, the defect created by the rotator cuff tear can be completely or partially closed with the transferred tendon functioning as an augmentation for the reconstructed rotator cuff.

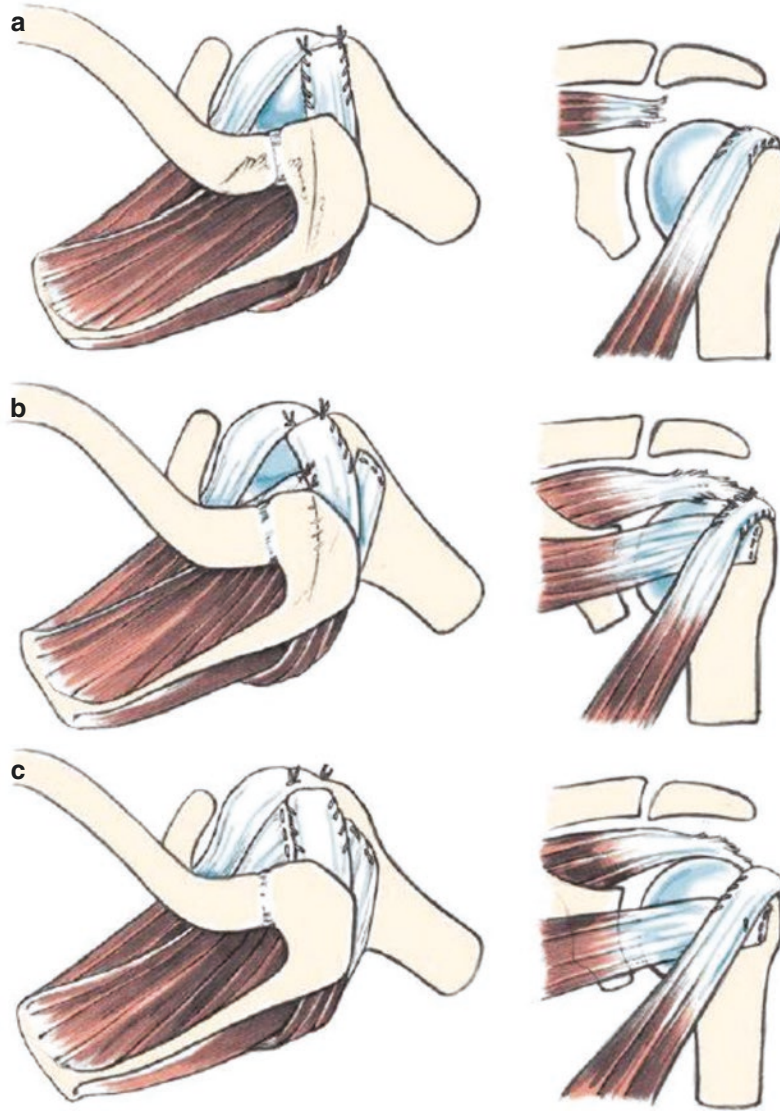

Fig. 22.7 Demonstrating the three variations (**a–c**) of humeral fixation when performing the latissimus dorsi tendon transfer. (From: Imhoff AB, Feucht MJ. Surgical atlas of sports orthopaedics and sports traumatology. Springer; 2017. eBook ISBN 978-3-662-43776-6, Fig. 3.33a–c)

22.5 Postoperative Management and Rehabilitation

Initial rehabilitation comprises an immobilization period of 6 weeks in a shoulder brace (45° of abduction, flexion, and external rotation). Additionally, control of peripheral circulation, motor function, and sensibility is essential. To ensure correct anchor placement, a postoperative X-ray control should be performed.

Passive range of motion exercises can be initiated during the 1–3 postoperative week with free external rotation and restricted internal rotation as well as limited abduction/adduction to 90°/45°/0°. However, the patient should be encouraged to perform active range of motion exercises of the cervical spine, elbow, and hand. Within the 4. postoperative week, active-assisted abduction/adduction limited to 90°/45°/0° with only passive rotational motion is initiated. Physiotherapeutic treatment including active-assisted abduction/adduction limited to 90°/0°/0° and active-assisted internal/external rotation to 30°/0°/free should be intensified

6 weeks after surgery to learn the modified motion patterns. Eight weeks postoperatively, the patient is allowed for unlimited active-assisted motion, whereas unlimited active motion is allowed at 10 weeks postoperatively. If progressing appropriately, the patient may resume unrestricted activity 6 months after surgery.

22.6 Tips, Tricks, and Pitfalls

The delta split should not be performed further than 5 cm distally to the edge of the anterolateral acromion, in order to preserve the axillary nerve. Further, sufficient dissection and mobilization of the latissimus dorsi muscle should be performed to ensure a tension-free fixation.

22.7 Outcomes

Transfer of the latissimus dorsi tendon has demonstrated promising mid- to long-term results for irreparable posterosuperior rotator cuff tears in several studies [3–6]. At a minimum follow-up of 10 years, Gerber et al. reported a significant increase in flexion (118°–132°), abduction (112°–123°), and external rotation (18°–33°) from pre- to postoperatively [3]. More importantly, insufficiency of the subscapularis muscle and fatty infiltration of the teres minor muscle has been shown to be associated with inferior results [3]. Additionally, El-Azab et al. reported significant improvement in clinical outcome scores along with pain relief at a mean follow-up of 9.3 years [11]. However, postoperative outcomes are varying dependent on patients' psychomotor learning skills as well as compliance with the rehabilitation program [8].

To this, open latissimus dorsi transfer has been shown to come along with the inherent risk of wound complications, damage to the deltoid muscle, and axillary or brachial nerve lesions [12]. While the procedure is thought to restore external rotation and reestablish the anterior–posterior force couples on the humeral head, orientation of the tenodesis also places a non-physiologic vector across the shoulder joint [13]. This may be a reason for the high progression of osteoarthritis that has been observed following the procedure [5, 14].

In addition, latissimus dorsi transfer as a salvage procedure for posterosuperior rotator cuff tears was found to result in significantly poorer outcomes with a late rupture rate of 44% compared to 17% in primary transfers at a mean follow-up of 19 months [15]. Similarly, Muench et al. showed a clinical failure rate of 41% along with a complication rate of 27% after latissimus dorsi transfer in revision massive rotator cuff tears [10]. Further, an acromiohumeral distance of less than 7 mm and high-grade fatty infiltration was found to be significant preoperative risk factors for clinical failure [10].

22.8 Summary

Transfer of the latissimus dorsi tendon has been proposed as a viable treatment option for massive posterosuperior rotator cuff tears without severe cuff tear arthropathy and integrity of the subscapularis muscle, especially in young patients with loss of active external rotation. The procedure is thought to restore external rotation and reestablish the anterior–posterior force couples on the humeral head, thus leading to significant improvement of shoulder function along with pain relief. Current literature has demonstrated promising mid- to long-term outcomes for the treatment of irreparable posterosuperior rotator cuff tears, however, insufficiency of the subscapularis muscle and fatty infiltration of the teres minor muscle has been shown to be associated with inferior results. Thus, in cases with concomitant irreparable tears of the subscapularis muscle this procedure should not be performed, as sufficient reconstruction of the force couples is impossible. In addition, postoperative outcomes are varying dependent on patients' psychomotor learning skills as well as compliance with the rehabilitation program.

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Arthroscopic-Assisted Lower Trapezius Tendon Transfer

23

Gia Rodriguez-Vaquero, Natalia Martínez Catalán, and Emilio Calvo

23.1 Introduction

Rotator cuff tears (RCTs) are a common cause of shoulder pain and disability. Management of massive irreparable posterior–superior rotator cuff tears is challenging, particularly in patients who are not candidates for reverse shoulder arthroplasty, such as young patients, or in those with a high level of activities.

Classically, RCTs have been classified as "massive" and "irreparable" if they (1) involve two or more tendons, (2) are retracted and shortened to the level of the glenoid, and (3) are associated with advanced fatty infiltration of the muscle belly as described by Goutallier et al. [1–3]. Attempted repair of these tears results in the failure to heal in up to 94% of patients [4]. However, the terms "massive" and "irreparable" do not exactly mean the same [5]. "Massive" rotator cuff tear refers to size. Cofield defined massive tears as those that are >5 cm and Gerber et al. [2] as those involving two complete tendons. Nevertheless, an acute tear involving the whole rotator cuff is massive but can often be repaired primarily. In contrast, some chronic tears are not "irreparable" because even if they can be surgically secured to its footprint, they may have extensive muscle atrophy and fatty infiltration. And a repair may not lead to tendon healing [6–9] or a good clinical outcome [8]. Thus, massive does not always equal irreparable. Finally, the term "functionally irreparable rotator cuff tear" is intended to capture patients who would experience failure of an attempted primary rotator cuff repair [10]. Failure can be defined as the need for reoperation in case of re-rupture, lack of restoration of motion or strength, osteoarthritis progression, or poor patient-reported outcomes, including persistent pain [4].

Nonoperative management can be beneficial for patients with irreparable RCTs. Guided physical therapy should focus on strengthening of remaining cuff tissue, periscapular strengthening, and deltoid reconditioning to relieve pain and improve shoulder function [11]. Patients who fail nonoperative management should be considered for surgical management. When RCTs cannot be reliably repaired, reverse shoulder arthroplasty is a successful alternative with good predictable outcomes and pain relief, especially in elderly patients with arthritis [5, 12–14]. Nevertheless, in younger patients considered to have a functionally irreparable tear with intact articular cartilage, joint-preserving procedures are preferred. This

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group includes patients presenting a tear involving more than two tendons and any of the following risk factors: advance fatty infiltration 3 or 4, tendon length of <15 mm measured on MRI, retraction beyond the rim of the glenoid, fixed subluxation, tear at the infraspinatus muscle tendon junction, or failure of a prior rotator cuff "well-done" repair [10]. Joint-preserving procedures range from debridement or partial repair to tendon transfers, with many different options in between, including balloon spacer or superior capsular reconstruction (SCR).

Static soft-tissue restraints to abnormal glenohumeral head translation, such as implantation of an absorbable balloon in the subacromial space or superior capsular reconstruction (SCR), appear to reduce pain and improve function, although some studies have reported a relatively high structural failure rate with SCR [15]. Cuff debridement, biceps tenodesis, and/or partial repair of the torn rotator cuff may reduce pain and improve function for selected patients with an irreparable rotator cuff tear. However, these procedures do not stop progressive shoulder osteoarthritis [16].

When improvement in strength is the primary goal of treatment, tendon transfers provide a viable treatment alternative. In the shoulder, muscle-tendon units around the glenohumeral joint may be considered for transfer to the greater or lesser tuberosity. Transfer of tendons has the potential to provide a source of vascularized autograft, a tenodesis effect, and powered tendon fibers. The basis of the procedure follows several key principles of the glenohumeral joint anatomy and rotator cuff balance. The glenohumeral joint is an unstable joint and relies on the dynamic stabilization of the rotator cuff musculature [17]. To maintain a concentric joint to facilitate shoulder function, the anterior subscapularis must be balanced relative to the posterior portion of the infraspinatus and teres minor while the superior force provided by the deltoid must be balanced relative to the rotator cuff musculature inferior to the humeral head equator. Disruption of the normal force couples causes abnormal kinematics in the anterior–posterior and superior–inferior planes [18]. Tendon transfers work because they restore the anterior–posterior force couple lost in massive rotator cuff tears and recenter the humeral head independent of arm position.

Tendon transfers were originally developed for posterosuperior tears (supraspinatus and infraspinatus with or without extension into the teres minor) [19], but currently, there is some interest in using it for the irreparable anterosuperior tear (a chronic subscapularis tear with various degrees of extension into the supraspinatus) [20].

When considering tendon transfer reconstruction, all procedures should adhere to the following important principles [21]: (1) the transferred muscle should be expendable without compromising the donor site, (2) the transferred and recipient muscle should have a similar excursion and tension, (3) the line of pull of the transferred tendon and recipient muscle should be similar, and (4) the transferred muscle should replace the function of the recipient's muscle. As a general rule, transferred tendons are expected to provide at least one less level of strength compared to their native function (Table 23.1).

Following these principles, options for posterosuperior tears include the transfer of the latissimus dorsi with or without the teres major and transfer of the lower portion of the trapezius to infraspinatus insertion; and options for anterosuperior tears include the transfer of the pectoralis major or latissimus dorsi to subscapularis insertion. The first and most studied transfer for irreparable posterosuperior rotator cuff tear is the latissimus dorsi transfer (LDT), originally described by Gerber in 1988 [22]. Medium- and long-term follow-up studies report good pain relief and improvement in shoulder motion [22–25]. When the subscapularis and deltoid muscles are intact, the latissimus dorsi works as an external rotator and humeral head depressor compen-

Table 23.1 Principles for a tendon transfer

1. Expendable donor muscle
2. Similar strength and excursion of the donor muscle
3. Straight line of pull
4. Synergistic action
5. Supple joints
6. Force couples balance
7. One transfer for one lost function
8. Compliant patient

sating the missing infraspinatus function [21]. Less predictable results are seen in the presence of fatty infiltration grade 3 or higher osteoarthritis, subscapularis insufficiency, or preoperative forward elevation <90° [26–28]. Particularly, in cases with subscapularis or deltoid insufficiency, transfer of the latissimus dorsi may cause inferior humeral head subluxation due to the vertically oriented force vector of the transferred muscle [26]. Therefore, LDT requires intact subscapularis and no pseudo paralysis in elevation.

Elhassan and Bertelli first described LTT to restore external rotation in patients with brachial plexus palsy [20, 21, 29–31]. Biomechanical and clinical studies support the use of this muscle to mainly restore external rotation when the posterosuperior cuff is deficient or irreparable [29–31]. Because of the variability in outcomes after the latissimus dorsi transfer in patients with irreparable rotator cuff tears, isolated transfer of the lower trapezius (LTT) with Achilles tendon has emerged as a successful alternative instead of the latissimus dorsi transfer in case of irreparable posterosuperior cuff tears in young people with no significant glenohumeral osteoarthritis changes.

23.2 Applied Anatomy and Biomechanics

The trapezius is the most superficial periscapular muscle and its primary role is to contribute to scapular stabilization and scapulothoracic motion. It originates from the occiput and the ligamentum nuchae to the spinous processes of C7-T12. We identify three components: upper, middle, and lower trapezius, which function together to elevate, retract, and externally rotate the scapula. The upper portion inserts over the lateral third of the posterior clavicle, while the middle and lower portions attach over the medial acromion and spine of the scapula. The lower part of the trapezius originates from T4 to T12, and its insertion is located on medial 2–3 cm of the spine of the scapula. The tendon insertion was described by Omid et al. [32] as a triangular bony region at the junction of the scapular spine and the medial border of the scapula. Proper identification of the lower trapezius is essential to avoid denervation during the splitting of the lower trapezius for the transfer.

The spinal accessory nerve (cranial nerve XI) provides motor innervation and the superficial branch of the transverse cervical artery provides the blood supply [33]. The neurovascular pedicle goes along the underside of the muscle to innervate the middle and lower trapezius. The spinal accessory nerve runs 2.3–5.8 cm (average 3.25 cm) medial to the distal part of the tendon [32].

As shown in a recent cadaveric study, the lower trapezius is an ideal transfer option, as its origin is cranial to the latissimus dorsi and medial to the infraspinatus fossa of the scapula with a nearly identical line of pull as the infraspinatus, good strength, and synergism [34]. It has been demonstrated that the moment arm in external rotation (i.e., distance from a muscle's line-of-action to a joint's center of rotation) is superior for the lower portion of the trapezius in adduction compared to LDT [34, 35], although external rotation moment arm with the arm in abduction is greatest with the Latissimus Dorsi tendon transfer. In this way, Hartzler et al. [34] conducted a biomechanical cadaveric study to analyze the effectiveness of different types of tendon transfer around the shoulder to restore external rotation evaluating the external rotator moment arms of latissimus dorsi, teres major, and lower trapezius transferred in different humeral head positions. Omid et al. [36] compared in a biomechanical study the effects of the LTT and LDT in a model with a massive posterosuperior cuff tear. They demonstrated that the native glenohumeral kinematics and joint reactive forces were most accurately recreated when the LTT was performed and the osseous concentricity of the joint was best recreated allowing for the greatest improvements in range of motion. Subsequent clinical and biomechanical studies have confirmed the effectiveness of this transfer in restoring shoulder external rotation when the posterosuperior cuff is insufficient and not amenable [29–31, 37, 38].

The procedure may be performed through an open or arthroscopically assisted technique.

We favor the arthroscopic-assisted technique described by Elhassan et al. [39] because of the less invasive approach, the avoidance of acromial osteotomy and partial deltoid disinsertion, and the potential advantages with arthroscopic surgery as diminished postoperative pain or infection risk. Additionally, arthroscopy improves visualization of other lesions such as subscapularis tendon tear and facilitates concomitant treatment.

Although excursion and tension force is very similar to the infraspinatus [20], it lacks enough amplitude to reach the greater tuberosity, requiring an indirect transfer extended with an allograft, frequently an Achilles allograft because of its suitable length and size. However, it is possible to transfer the lower portion of the trapezius directly without the use of tendon grafts as long as the integrity and caliber of the infraspinatus tendon are adequate, although there is a high risk of spinal accessory nerve traction injury as demonstrated in a cadaveric study by Gracitelli et al [40].

Because of the favorable outcomes, the similar excursion to the insufficient infraspinatus and teres minor tendons, the simplicity of the procedure and the easier postoperative rehabilitation training, transfer of the lower trapezius has become our procedure of choice to restore motion and strength in external rotation and, although some authors have expressed concerns about violating the lower trapezius due to the fact that trapezius dysfunction could be associated with scapular dyskinesia [41], published results so far using this transfer for irreparable cuff tears have been promising in terms of pain relief and restoration of function without scapular dyskinesia.

23.3 Indications

The main indication for LTT is the case of a relatively young and active patient with limited function and/or refractory shoulder pain secondary to irreparable posterior–superior rotator cuff tear with minimal or no glenohumeral osteoarthritic changes and substantial external rotation lag/weakness due to irreparable infraspinatus tear.

Absolute contraindications include active soft tissue infection or trapezius muscle paralysis. Relative contraindications include subscapularis insufficiency or advanced glenohumeral degenerative changes. Advanced degenerative changes have an effect on outcomes, resulting in less pain improvement, decreased range of motion, and greater need for reoperation with conversion to reverse total shoulder arthroplasty.

23.4 Preoperative Assessment

23.4.1 Clinical Examination

An accurate clinical history to ascertain whether the patient has undergone a previous rotator cuff repair, the chronicity of the injury and whether it was traumatic or atraumatic in origin, demographic factors (including age and body mass index), social factors (tobacco use and occupational demands), and comorbidities (diabetes mellitus, renal failure, and poor nutritional status) should be recorded.

Physical examination should include inspection for muscle atrophy, especially over the supraspinatus and infraspinatus fossae, and scapular dyskinesia, passive and active range of motion of the affected and unaffected shoulders, and provocative maneuvers to rule out different shoulder pathologies, cervical spine problems, neurovascular compressive syndromes, or scapular examination, including testing the integrity and strength of the trapezius and serratus anterior muscles.

Patients with an irreparable RCT may present with a wide variety of active shoulder ROM, from full ROM to pseudo paralysis. Specific maneuvers are key to obtain a precise differentiation on the affected tendons and their degree of incompetence. Diagnosing insufficiency of the posterior–superior cuff involves assessment of the supraspinatus, infraspinatus, and teres minor.

Large supraspinatus tears will be detected by the presence of weakness in abduction with the shoulder at 45° of abduction and the elbow flexed. The insufficient infraspinatus will manifest as an important external rotation strength loss in

adduction and lag or dropping sign in case of massive posterosuperior cuff tear. In the external rotation lag sign, the examiner places the shoulder in 20° of abduction and passive external rotation; the patient is asked to maintain this position of the shoulder actively, and the arm drops into internal rotation toward the abdomen when there is posterior cuff insufficiency. The drop sign is identically performed with the shoulder in 90° of abduction. Teres minor is assessed with the arm in 90° of abduction while evaluating external rotation against resistance. A positive hornblower's sign indicates insufficiency of the teres minor; the patient is asked to bring both hands to the mouth, and on the side where there is a teres minor insufficiency, the only way the patient can get the hand to the mouth is by abducting the shoulder, typically over 90° [42]. Walch et al. reported for dropping and Hornblower's signs 100% sensitivity and specificity for the presence of stage 3 or stage 4 fatty degeneration of the infraspinatus; they found that Hornblower's sign had 100% sensitivity and 93% specificity for irreparable degeneration of teres minor on the CT scan [43].

It is important to assess the insufficiency of subscapularis because although subscapularis insufficiency is not considered an absolute contraindication for LTT, worse results were obtained in patients with a nonfunctional and/or irreparable subscapularis when LD transfer has been performed. Patients presenting an anterior–superior deficiency often describe internal rotation weakness and anterior shoulder pain, and these tears often allow an anterosuperior scape of the humeral head [44–46].

23.4.2 Imaging

Conventional radiographs should be obtained in any patient evaluated for cuff disease. Plain radiographs (AP, Axial, and lateral scapula Y view) allow to evaluate acromial changes (shape, acetabularization, and Os acromiale), proximally migrated or decentered humeral head, tuberosity sclerotic changes and cysts, or signs of cuff tear arthropathy. Advanced imaging studies are recommended in these patients with a high index of suspicion for massive rotator cuff tear. Magnetic resonance imaging (MRI) is the advanced study of choice across the world. MRI allows to precisely evaluate bony and soft tissue structures such as muscle belly, fatty infiltration, tendon length and quality, level of retraction of the damaged tendons, cartilage state, or even bony structural changes. MRI includes coronal T1- and T2-weighted images to assess supraspinatus and infraspinatus tendon integrity, tendon length and retraction, cartilage lesions, and axial T1- and T2-weighted images to evaluate subscapularis, infraspinatus, teres minor tendon integrity, biceps subluxation, and cartilage integrity. Sagittal T1-weighted image is useful to understand the true extent of the tear from anterior to posterior and to assess for fatty atrophy in the subscapularis, supraspinatus, infraspinatus, and teres minor muscle bellies (Fig. 23.1). The Goutallier grading system was first recognized using computed tomography [1]; nowadays, it is most easily assessed on MRI non-fat saturated oblique-sagittal T1 sequences that have superior fat-to-muscle contrast. Computed tomography arthrography can be used for patients who are unable to undergo MRI to assess the rotator cuff for both tears and atrophy; intra-articular injection

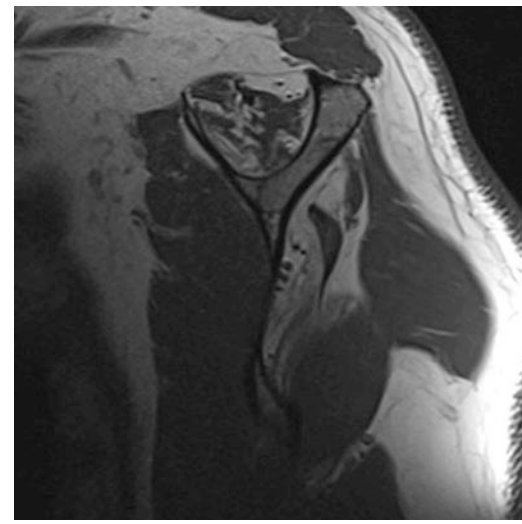


Fig. 23.1 Sagital view of an MRI of a shoulder showing infraspinatus atrophy

of iodine contrast (CT arthrogram) provides better images for evaluation of the rotator cuff.

23.5 Surgical Technique

The procedure is a seven-step technique performed under general anesthesia as described by Elhassan and coworkers [39, 47, 48] (Table 23.2).

23.5.1 Positioning and Preparation

Anesthesia is carried out following a standardized protocol based on an interscalene blockade under ultrasound control (L-bupivacaine 0.5% 30–40 ml plus epinephrine) combined with general anesthesia (propofol 2–2.5 mg/kg iv and alfentanil 20–150 μg/kg iv initially, plus 15 μg/Kg bolus, and maintenance with sevoflurane).

Table 23.2 Summary of key points of the surgical technique [39]

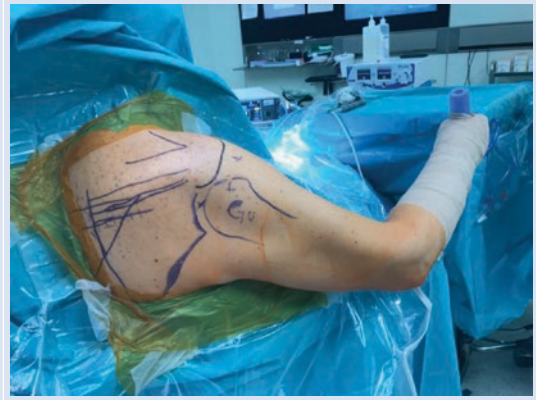
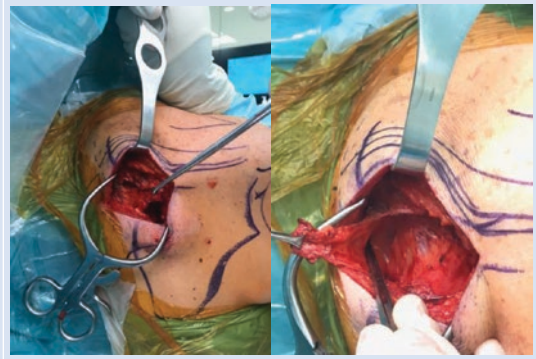
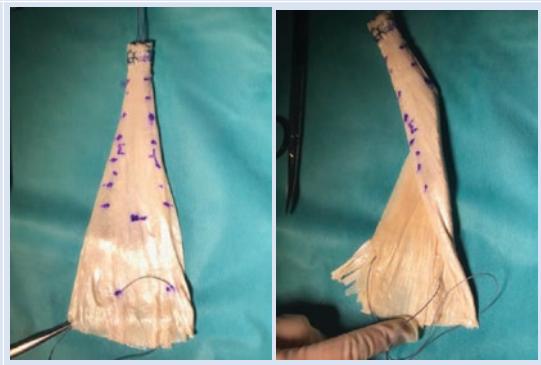
Step 1	Patient positioning	
Step 2	Lower trapezius harvest	
Step 3	Allograft preparation	

Table 23.2 (continued)

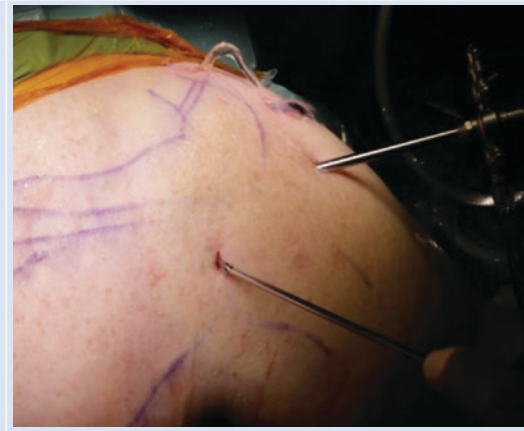
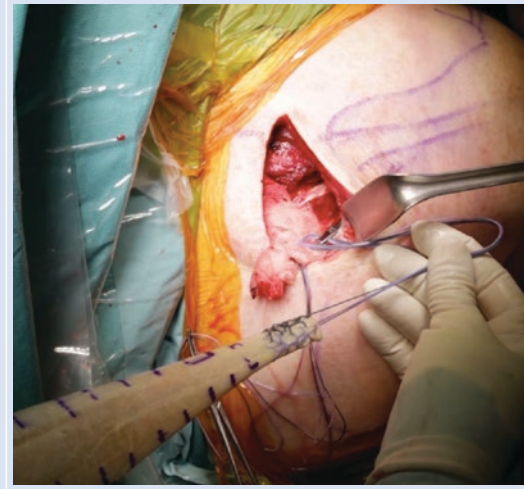
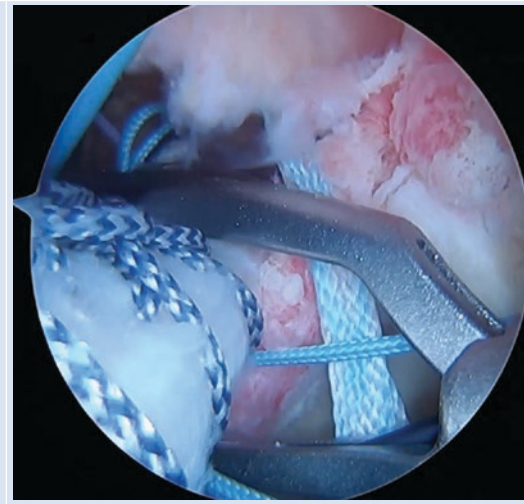
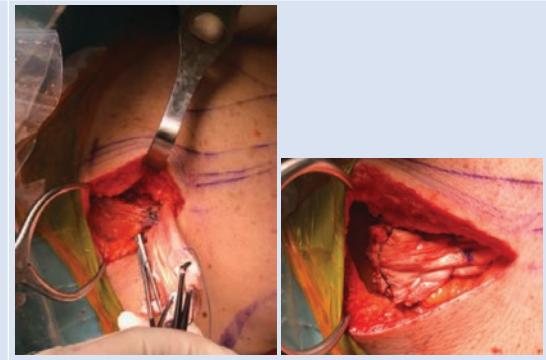
Step 4	Portal placement and joint preparation	
Step 5	Allograft passage	
Step 6	Intra-articular allograft insertion	

Table 23.2 (continued)

Step 7	Lower trapezius-allograft attachment	

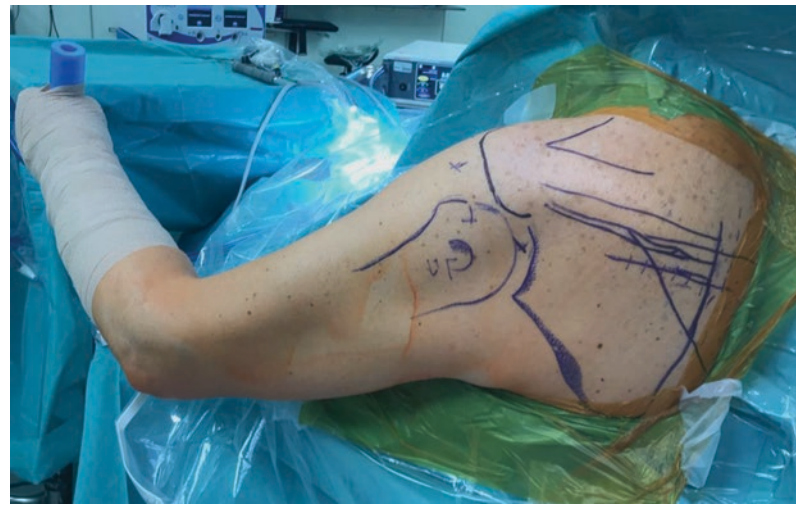


Fig. 23.2 Patient's position in beach position and surgical field with landmarks for lower trapezius tendon harvesting approach

Antibiotic prophylaxis (2 g cefazolin or 1 g vancomycin as an alternative for patients with b-lactam allergy) is administered 30 min before surgery.

The patient can be placed in lateral decubitus or beach chair position; usually, the lateral decubitus position is preferred for the open technique as described by Elhassan et al. in 2014 [20]. The beach chair position is the option of choice for the arthroscopic-assisted technique; a Beta classic mobile or Maquet® table or equivalent with a head holder system allows full access to the posterior aspect of the scapula facilitating the graft harvesting. The arm is placed in a pneumatic arm holder allowing movement during the surgery. The operative extremity is pre-scrubbed with chlorhexidine solution and draped conveniently leaving the entire ipsilateral half of the back uncovered until midline (Fig. 23.2). The greater trochanter must be aligned with the break in the operating table to allow hip flexion preventing sciatic nerve compression, and the torso must be kept in a neutral position using straps to prevent any lateralization of the patient during the procedure; keep the head centered maintaining a neutral position of the neck with no rotation. This setup allows the surgeon to stands in front or behind the shoulder alternatively moving around easily the arm depending on the surgery stage that is being carried out. It is also important to adequately pad the patient's heels, hands, and forearms.

During the arthroscopic time, controlled hypotension and muscular relaxation are desirable as it may allow better visualization, decrease blood loss, and reduce the operative time which

secondarily can affect the quality of the repair and patient safety. Because of the risk of neurological ischemic events, caution should be exercised with hypotensive anesthesia in the beach chair position. We maximize patient safety using routinely near-infrared spectroscopy (NIRS), which provides a noninvasive continuous assessment of cerebral perfusion. For fluid management, we use an automated pump system with dual, pressure and volume, control.

23.5.2 Lower Trapezius Harvest

The border of the scapula and the lower trapezius insertion site on the spine of the scapula on the medial 2–3 cm of the spine of the scapula is marked before incision. It is recommended also to mark the osseous eminences of the shoulder and the arthroscopic portals.

Lower trapezius (LT) can be reached by a vertical or horizontal incision. A 6-cm vertical incision is made approximately 1 cm medial to the medial border of the scapula starting from the upper-medial border edge of the lower trapezius tendon. Alternatively, a 6-cm transverse incision just inferior to the scapular spine from 1 cm medial to 3 cm lateral to the medial border of the spine of the scapula. The skin and subcutaneous tissue are dissected until the fascia overlying the LT and/or the infraspinatus is exposed. Once the LT muscle fibers traveling oriented toward the medial spine of the scapula are identified, it is important to expose the inferior edge of the muscle belly. Blunt dissection can be utilized to mobilize the inferior edge of the muscle, separating the muscle from the underlying infraspinatus fascia. The inferior edge of the LT muscle belly should be traced to its musculotendinous junction and tendon, adjacent to a fat triangle. The LT tendon forms a triangle with an approximate height of 23 mm, and length of the tendinous portion of the LT of 49 mm [21]. The footprint of the lower trapezius tendon is a triangular bony region with a mean length of 30 mm at the junction of the medial border of the scapula and the scapular spine.

The lower trapezius tendon is dissected up to its insertion in the medial aspect of the spine of the scapula and the dissection is carried medially along the upper border of the tendon, between the middle and the lower trapezius (Fig. 23.3). A fat stripe separates the LT from the middle trapezius muscle belly. An inadequate superficial medial release of the upper and lower borders of the lower trapezius may compromise the lower trapezius tendon excursion. Deep fascial dissection should be performed with caution to avoid injury to the neurovascular pedicle. The spinal accessory nerve lies within the fascial layer, underneath the trapezius, approximately 2 cm medial to the medial border of the scapula; thus, deep

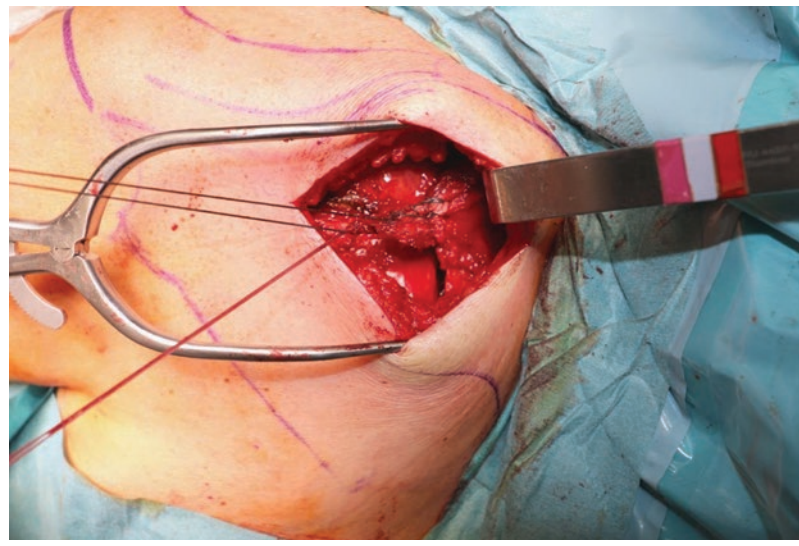


Fig. 23.3 Lower trapezius harvest appearance after dissection and preparation with Krakov suture with Orthocord. The pooling line of the lower trapezius muscle is similar to the infraspinatus muscle

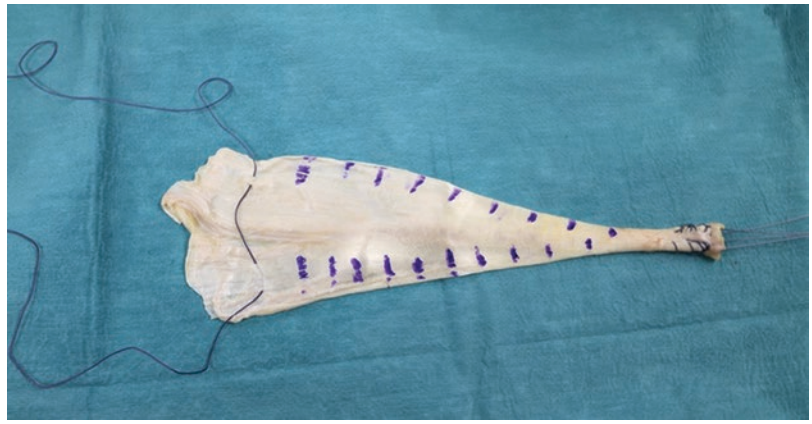


Fig. 23.4 Allograft preparation with No. 2 Orthocord sutures (DePuy Synthes, Warsaw, IN) in a Krakow configuration at the thick and narrow end of the Achilles tendon allograft. Note that the dorsal marks are drawing to assure the graft won´t be flipped inside the join

dissection should be performed with caution. Identifying the nerve is not mandatory, but it is advised if there is not enough excursion of the tendon to detect over tensioning.

When the lower trapezius tendon is dissected and the muscle is freed from the deep fascia tissues, two high-resistance sutures are placed in a Krakow configuration at each side of the tendon. It is important to avoid piercing the suture with the needle and check resistance at the end of suture placement.

23.5.3 Allograft Preparation

Preparation can be performed simultaneously while the lower trapezius is harvested. An Achilles tendon allograft without the osseous calcaneus portion is the graft of choice, although good outcomes have been reported as well with semitendinosus tendon autograft described by Valenti [49]. The osseous portion of the calcaneus is removed and, again, two #2 high-resistance sutures (DePuy Synthes, Warsaw, IN) in a Krakow configuration are placed along the superior and inferior edges of the Achilles tendon to prepare the thick and narrow end of the allograft; it is recommended using different suture colors for better identification of the sutures during the arthroscopic time. To avoid allograft twisting during graft passage, it is recommended to marking with a surgical pen dorsal–ventral sides of the allograft.

One suture is placed at the thin expanded side of the allograft to avoid lateral migration during the passing and fixation of the graft and also to facilitate suturing to the lower trapezius portion by creating some tension from pulling once the allograft is fixed in the humeral head (Fig. 23.4).

23.5.4 Portal Placement and Joint Preparation

The main portals needed for this procedure are a posterior portal for visualization, an anterolateral portal, and a lateral portal for instrumentation. Additional portals could be created as needed. The posterior portal is placed more proximal and lateral than usual for better visualization of the tuberosity, and the anterolateral portal is placed 1–2 cm lateral from the anterolateral edge of the acromion. The scope is introduced on the posterior portal for visualization of the tuberosity and the cuff tear while the other portals are used initially for bursectomy to prepare the tuberosity and to perform additional technical steps as needed depending on the findings. Any healthy rotator cuff tissue should be either partially repaired or secured to the tendon transfer.

23.5.5 Allograft Passage

The next step is to create a passing track for the allograft underneath the infraspinatus fascia which is usually distended with the arthroscopic

fluid. Adequate enlargement and opening of the infraspinatus fascia medially is crucial to allow adequate allograft passage. After the interval is developed, sharply incise the infraspinatus fascia from the medial incision, creating adequate room for the transfer.

From the anterolateral portal, a long grasping clamp is introduced into the subacromial space to reach the medial incision. The Krakow configuration sutures in the thick end of the allograft are grabbed by the clamp to pull them out through the anterolateral portal. A hemostat is attached at each end of the allograft, and the graft is passed back and forth within the shoulder to assure adequate passing plane and graft mobilization.

23.5.6 Allograft Intra-Articular Attachment

Before the definitive fixation of the graft over the greater tuberosity, it must be checked that there is an optimal gliding of the graft pulling from it backward and forward using prearranged sutures in both ends (Fig. 23.5).

Suture anchors are needed for allograft attachment to the tuberosity. The allograft must be visualized into the joint looking for the dorsal mark which indicates that our graft is not flipped. Two 5.5-mm Healix Advance Knotless™ anchors (DePuy Mitek Sports Medicine, Raynham, MA) are utilized, one for each Krakow suture, and buried anteromedial and anterolateral in the footprint area of the greater tuberosity. It is important to adjust the tension pulling of the hemostat at the medial aspect of the allograft. The extra suture of the anchor can be used to get additional fixation of the allograft to the remnant of the native rotator cuff. One or two Healix™ Advance 5.5-mm double-threaded anchors (DePuy Synthes, Warsaw, IN) are recommended as medial row anchors; the sutures are passed through the allograft using a Cleverhook instrument (DePuy Mitek Sports Medicine) or any other direct or indirect suture passer device. Hold the graft tensioned during the transfer and knotting to avoid fixation in a wrinkled position.

When the intra-articular allograft fixation is finished, adequate allograft excursion must be checked with several cycles of shoulder external and internal rotations holding the free part of the allograft increasing the tension.

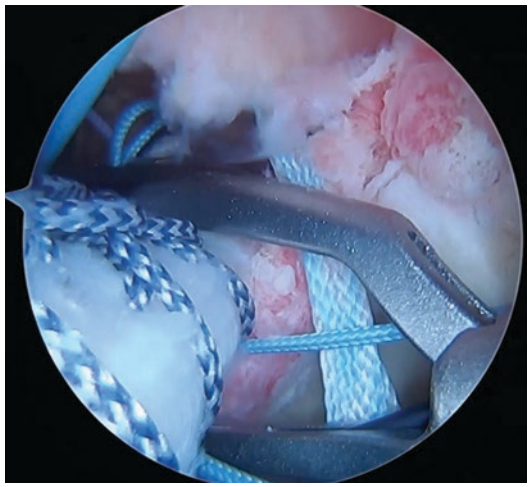


Fig. 23.5 Intra-articular fixation of the allograft

23.5.7 Lower Trapezius Allograft Attachment

Finally, the attachment of the Achilles allograft to the lower trapezius tendon is performed. Using the arm holder, the arm is placed in maximal external rotation with some flexion and no abduction. In this position, the Krakow sutures that we prepared at the beginning of the surgery are passed with a free needle laterally through the allograft. It is recommended to reinforce the fixation with some free sutures medially removing the remaining allograft (Fig. 23.6).

Arthroscopic portals are closed using 3–0 Monocryl® suture (Ethicon, Johnson & Johnson, Somerville, NJ); the open wound is closed in layers using 0 and 2–0 vicryl, and a running 3–0 Monocryl stitch is used for skin closure with no drain; the wound is covered with a sterile dressing, and the patient's arm is placed in a brace with an anti-rotatory pillow.

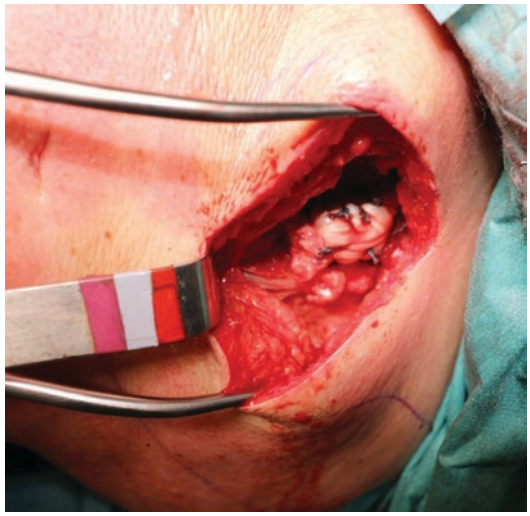


Fig. 23.6 Final appearance of attachment of the allograft to the lower trapezius tendon. Note that is important placed the arm in maximal external rotation, some extension and without abduction during the fixation

23.6 Postoperative Management and Follow-Up

The postoperative rehabilitation period begins with 6 weeks of immobilization in a brace avoiding internal rotation. This brace can be removed only during this period for bath and flexion-extension exercises of the elbow. It is recommended to do some isometric exercises of the deltoid even with the brace on. After 6 weeks, the patient starts proper physical therapy, including the progression from passive to active-assisted motion and finally unassisted active motion around 12 weeks. External rotation strengthening exercises with elastic bands begins at 16 weeks. Unrestricted activity is allowed after 6 months from surgery. Standard shoulder AP and Axial radiographic views are recommended at 3–6 and 12 months to detect any precocious off-center humeral head change from the previous X-ray (1).

23.7 Results

We do not know of any clinical studies comparing the LD and LT tendon transfers using open or arthroscopic techniques. The LT transfer was developed much more recently than the LD transfer. Lower trapezius transfer was initially used to restore shoulder external rotation in patients with brachial plexus injuries [29–31, 38, 39]

Bertelli reported, on seven adult patients with longstanding upper type palsies of the brachial plexus, mean recovery of 104° of active external rotation as measured from the abdomen [37].

In another study of 52 patients [30] with traumatic brachial plexus injuries, lower trapezius transfer was performed alone or as part of multiple transfers. Significant improvements were reported in external rotation, pain scores, and SSV scores. Since then, this technique has been performed in many other cases [21] offering satisfactory results concerning external rotation. Duncan et al. in 2014 [50] proposed to widen the indication to include massive irreparable postero-superior cuff tears with a lack of active external rotation.

In 2014, Elhassan et al. [20] reported good clinical outcomes in a group of 111 patients with paralytic shoulders lacking external rotation treated with open LTT. External rotation improvement was achieved in all patients, with a mean improvement in external rotation of 70°. The most common complication after the procedure was seroma in 11 patients (10%) after transfer due to subcutaneous tunneling for the transfer. Due to these encouraging clinical results, the use of the lower trapezius transfer was expanded with multiple studies demonstrating effectiveness in restoring external rotation. In 2016, Elhassan et al. [38] published for the first time an article showing results for open LTT with Achilles tendon allograft in 33 patients with symptomatic irreparable rotator cuff tears. The cohort study included 11 patients with evidence of fatty infiltration of the teres minor muscle, and all the patients had an irreparable supra- and infraspinatus tear. One-third of the patients had an associated tear of the upper part of the subscapularis. The tear of the upper part of the subscapularis was repaired when present, and the infraspinatus was advanced medially after release to reduce the size of the rupture. Teres minor dysfunction did not seem to influence outcomes. At an average follow-up of 47 months, 32 of the 33 patients

experienced significant improvement in their shoulder pain and motion. An external rotation lag sign, which was present in 82% of patients, resolved universally, and all patients had a minimum of grade 4 out of 5 muscle strength on manual external rotation strength testing. At the final follow-up of nearly 4 years, the range of active motion increased considerably with mean improvements of 50° in forward flexion, 50° in abduction, and 30° in external rotation. Additionally, patients with more than 60° of preoperative flexion achieved more significant range of motion gains. Worse results were obtained in patients with a nonfunctional and/or irreparable subscapularis; however, since the LTT does not impact the balance between external and internal rotator muscles, subscapularis insufficiency is not considered an absolute contraindication. Regarding the results in clinical scores, the mean SSV improved from 54% preoperatively to 78% postoperatively ($P < 0.01$), and mean DASH score improved from 52 ± 19 to 18 ± 10 ($P < 0.01$). In the clinical examination, palpation of the transferred lower trapezius demonstrated active muscle contraction during shoulder external rotation. The acromial osteotomy healed radiographically in 25 of the 33 patients, but clinically, there was no difference in the examination results between patients whose osteotomy had healed and those whose osteotomy did not heal radiographically, and this did not change at the last follow-up evaluation. When radiographs were evaluated for arthritic changes, the authors noticed a mild increase in joint narrowing in patients who did not have full correction of the proximal migration of the humeral head; however, none of these patients showed signs of progressive arthritis on radiographs at the final outcome. In addition, interestingly, the authors did not find a correlation between the extent of correction of the proximal migration of the humeral head and the outcome of the tendon transfer reconstruction [37].

In a recent publication of arthroscopically assisted lower trapezius tendon transfer on 51 patients [51], at a mean follow-up of 14 months, 37 (90%) patients were found to have improvements in all outcomes measures. Pseudo paralysis was reversed in more than 90% of patients. Reparable subscapularis tears did not affect outcomes. However, three patients who had preoperative rotator cuff arthropathy changes in the shoulder had persistent pain and limited range of motion of the shoulder after surgery, and two of them underwent reverse shoulder arthroplasty.

Valenti and Werthel [49] recently published a variation of the original technique of LLT extended with a semitendinosus tendon and fixed to the insertion of the infraspinatus via arthroscopy. They included 14 patients with a mean follow-up of 24 months (range: 12–36 months). The semitendinosus graft is introduced at the level of the insertion of the infraspinatus into an anteroposterior bone tunnel and locked with a ZipTight device for fixation. Mean active forward flexion improved from 150° to 160°, external rotation with the arm at the side improved from −20° to 24°, and external rotation with the arm at 90° of abduction improved from −10° to 40°. The mean Constant–Murley score improved from 35 to 60. Mean VAS decreased from 7 to 2 (visual analog scale, 0–10), and mean SSV improved from 40 to 70% ($P < 0.01$). Both the lag sign and Hornblower sign were negative after this transfer.

23.8 Complications

From the experience in patients with brachial plexus injury and paralytic shoulder, when LTT was performed as single-tendon transfer, complications from the surgery were unusual and generally not serious.

Elhassan in 2014, from a total of 111 patients with this diagnosis, reported seroma in patients with no drain (11 patients) and worsening postoperative pain in patients who had pain from the brachial plexus injury (23 patients) [20]. Most of the complications they encountered in this group of patients with single-tendon transfer were related to the postoperative custom-made brace as skin irritation and soreness related to pressure from the brace which can lead to intolerance and poor compliance.

In a study of 33 patients with irreparable RC tears treated with open LTT [38], four patients

were noted to have a seroma, which was successfully treated with conservative treatment. One patient sustained a fall during his first month of rehabilitation and lost some of the gains; ultrasound imaging of the lower trapezius showed some redundancy in the Achilles tendon with external rotation, indicating stretch injury of the transfer. One patient required a glenohumeral arthrodesis for a persistent infection.

The arthroscopic approach is associated with faster short-term recovery, reduced infection rate, and less complications related to the open technique because of the transacromial approach needed which increases the risk of acromial malunion/nonunion and deltoid insufficiency [39]. In the series recently reported by Elhassan et al., two patients had a traumatic rupture of the transfer as a result of the fall. One underwent revision arthroscopic repair and did well after surgery, and the other had good pain relief but recurrent weakness and limited range of motion and elected not to have revision surgery.

23.9 Summary

Arthroscopic transfer of the lower trapezius using Achilles tendon allograft to reconstruct irreparable posterior–superior rotator cuff tear leads to good outcomes in most patients, especially those with preoperative flexion over 60°. Longer follow-up is required to confirm the durability of the transfer; prospective randomized studies comparing the LTT with other therapeutic options as the latissimus transfer or combined SCR in the long term will further help to elucidate the difference between the two transfers and other therapeutic options.

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24 Latissimus Dorsi and Pectoralis Major Tendon Transfers for Subscapularis Insufficiency

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24.1 Introduction

Irreparable subscapularis tendon tears cause significant shoulder dysfunction and remain a very challenging problem for treatment. The subscapularis is the largest of the rotator cuff muscles, providing compression of the glenohumeral joint, contributing to anterior stability, and assisting in arm elevation and internal rotation strength [1]. The compressive force provided by an intact rotator cuff allows the deltoid and periscapular muscles to move the humerus around the glenoid through a full arc of motion. Disruption of the normal force couples causes abnormal kinematics of the glenohumeral joint in both the anterior–posterior and superior–inferior planes. Subscapularis insufficiency results in anterior–posterior imbalance, with pain and loss of active internal rotation. Furthermore, when combined with large posterosuperior rotator cuff tears, vertical imbalance results in anterior–superior migration of the humeral head and loss of active elevation of the shoulder.

Subscapularis tendon tears can occur from overuse or chronic attenuation secondary to age but are more likely to result from traumatic events such as falls or shoulder dislocation (Fig. 24.1). Subscapularis tears are often missed early in the course of treatment because patients lack the classic rotator cuff symptoms [2]. Additionally, diagnosis may be delayed as magnetic residence evaluation of the subscapularis has lower sensitivity than the supraspinatus and infraspinatus [3, 4]. This delay in diagnosis makes irreparable subscapularis tears less common than posterosu-

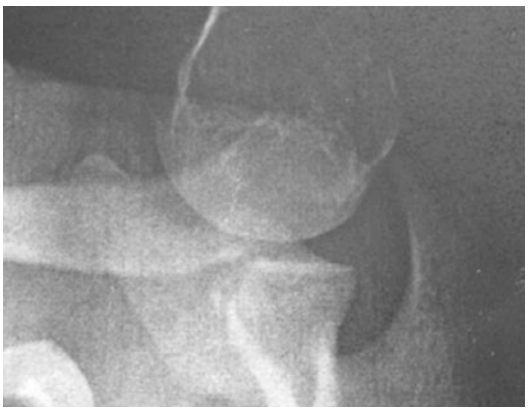

Fig. 24.1 A Bernageau lateral radiograph of a right shoulder following reduction of an anterior shoulder dislocation demonstrating anterior glenoid bone loss, and anterior subluxation of the glenohumeral joint indicating tearing of the subscapularis. An ossific density anterior to the lesser tuberosity represents an avulsion injury of the subscapularis

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perior tears [5, 6]. Delay in diagnosis leads to tendon retraction with atrophy, fatty infiltration, and scarring, which makes late primary repair difficult with decreased clinical outcomes [7–9].

Tendon transfers are a viable treatment option for patients with certain patterns of rotator cuff insufficiency. Most commonly, tendon transfers are indicated in younger patients with irreparable rotator cuff tears, shoulder pain, and dysfunction. Few techniques for subscapularis reconstruction have been introduced for irreparable tears. Anterior capsular reconstruction with human dermal allograft has been described for the treatment of subscapularis insufficiency [10–12]. While biomechanical studies show improvement over the deficient condition [13], long-term clinical data are lacking. Tendon transfers, specifically pectoralis major and latissimus dorsi tendon transfers, for subscapularis insufficiency are proven techniques that provide improvements in functional outcomes, range of motion, and pain. Musculotendinous transfers to substitute for subscapularis muscle function remain a viable option in active young patients without arthritis, as well as following shoulder arthroplasty in younger patients, and will be the focus of this text.

24.2 Management Options

When considering tendon transfer reconstruction, all procedures should adhere to the following important principles [25]. (1) The transferred muscle should be expendable without compromising the donor site. (2) The transferred and recipient muscle should have a similar excursion and tension. (3) The line of pull of the transferred tendon and recipient muscle should be similar. (4) The transferred muscle should replace one function of the recipient muscle. In general, tendon transfer for subscapularis insufficiency is indicated for any irreparable subscapularis tears, either traumatic or degenerative in nature. Contraindications to tendon transfer for subscapularis insufficiency include concomitant massive irreparable posterosuperior rotator cuff tears, static anterior glenohumeral subluxation or dislocation, nerve injury or brachial plexopathy, and glenohumeral arthritis. In these instances, reverse shoulder arthroplasty or shoulder arthrodesis may be better treatment options.

Various tendon transfers have been described as substitutes for subscapularis function, including the pectoralis major, pectoralis minor, and latissimus dorsi tendons [6, 14–17]. Both open and arthroscopic transfer techniques have been described. Among musculotendinous transfers, the pectoralis major transfer has been the most commonly used. It was first described in 1997 by Wirth and Rockwood [6] as a salvage procedure in the treatment of irreparable subscapularis tears. Biomechanically, pectoralis major transfer partially restores the function of the subscapularis by recreating the anterior force couple and exerting an internal rotation centering force on the glenohumeral joint.

Pectoralis major transfer has been described in different forms, with transfer of the tendon in its entirety or split, and the tendon may be passed along different courses. The tendon may be passed in the plane of its normal course but merely rerouted in a more superior direction and attached to the lesser tuberosity of the proximal humerus [6, 18]. The sternal and clavicular heads may be split, and the sternal head may be passed deep to the clavicular head but superficial to the conjoined tendon [19]. Finally, the tendon, complete or partial, can be routed deep to the conjoined tendon but superficial to the musculocutaneous nerve [20–23]. If a split-tendon transfer is performed, the two heads are bluntly separated for selective transfer. The clavicular head is retracted proximally and dissected free from the sternal head to the level of the musculotendinous junction. The split can be propagated both medially and laterally, taking care to protect the medial and lateral pectoral nerves. Medial dissection is limited to 6–8 cm to avoid injury to the medial pectoral nerve and lateral thoracic artery. The sternal head is sharply released from the humeral attachment, routed deep to the clavicular head, and attached to the lesser tuberosity.

The sub-conjoined tendon transfer has several theoretical advantages, including a force vector better simulates that of the native subscapularis

tendon, balancing the superior pull of the deltoid and keeping the humeral head centered, as well as producing a static soft tissue interposition between the humerus and the coracoid process, minimizing anterior humeral translation and decreasing coracoid impingement. The subcoracoid transfer carries a higher risk of neurovascular injury as dissection must be performed medial and deep to the conjoined tendon. In addition, the bulk of transferring the entire tendon may place traction on the musculocutaneous nerve [23]. In a cadaveric dissection, Klepps et al. [23] found that a split tendon transfer produced less tension on the musculocutaneous nerve than transferring the tendon in its entirety.

More recently, latissimus dorsi tendon transfer for irreparable subscapularis tears has been attempted. The latissimus dorsi transfer has two advantages over the pectoralis major transfer. First, the latissimus more closely replicates the line of pull of the subscapularis muscle fibers, as opposed to the pectoralis major [16, 17]. Second, the latissimus originates posterior to the chest wall, similar to the subscapularis on the ventral surface of the scapula, and contraction provides a posteriorly directed force on the humeral head aiding with glenohumeral compression. The pectoralis major, in contrast, originates on the anterior chest wall and sternum, and contraction creates an anterior pull to the humeral head which may exacerbate anterior subluxation [24]. In an anatomic cadaveric study, Elhassan at al [16]. demonstrated that latissimus dorsi transfer for subscapularis insufficiency is possible, with low risk for nerve compression. In 20 cadaveric specimens, the authors found the latissimus dorsi had an average tendon length of 5.9 cm and average width of 2.2 cm. In all cases, the tendon could be transferred to the center of the lesser tuberosity with low risk of injury to the axillary and radial nerves.

24.3 Anatomic Considerations

The musculocutaneous nerve and axillary nerve must be identified during pectoralis major transfer, as the pectoralis major tendon is transferred between the conjoined tendon and musculocutaneous nerve. Klepps [23] demonstrated that transfer of the entire pectoralis major placed excess tension on the musculocutaneous nerve in 6 of 20 cadaveric specimens. The innervation of the pectoralis major conveniently allows for the separation of its two muscle bellies. When performing a split-tendon pectoralis transfer, medial dissection between the clavicular and sternal heads is limited to 6–8 cm medial to avoid damage to the medial pectoral nerve and lateral thoracic artery. During latissimus dorsi transfer, the radial nerve must be identified as it crosses at the lower border of the latissimus tendon. The latissimus is dissected free from the pectoralis major, teres major, and radial nerve to prevent traction on the radial nerve during transfer. In a cadaveric study, Elhassan showed the latissimus tendon could safely be transferred to all sites of the lesser tuberosity with low risk of nerve injury to the axillary and radial nerves [16].

24.4 Preferred Surgical Technique

The authors' preferred surgical technique is to perform latissimus dorsi tendon transfer for subscapularis insufficiency. After the induction of general endotracheal anesthesia and interscalene nerve block, the patient is placed in the beach-chair position. The head is placed in neutral alignment. A small bump is placed along the medial border of the scapula and the arm is draped free to allow full motion of the shoulder joint. A standard deltopectoral incision is used. Extending the incision 3 cm distally helps to allow for dissection of the latissimus dorsi tendon and identification of the radial nerve. The cephalic vein is routinely retracted laterally with the deltoid. The conjoined tendon from the coracoid origin is retracted mediately. The axillary and musculocutaneous nerves are identified and protected throughout the case. Residual tissue of the subscapularis tendon on the lesser tuberosity is identified. The biceps tendon is often subluxated out of the groove, and a biceps tenodesis is routinely performed. The stump of the subscapularis tendon is identified in the subcoracoid recess,

often retracted mediately and scarred into the surrounding soft tissues. Careful circumferential dissection is necessary to isolate the subscapularis from the axillary nerve, taking great caution to protect the nerve. In all cases, every effort is made to mobilize and repair the subscapularis. In some instances, the upper rolled border of the subscapularis can be mobilized enough to allow for partial repair to the proximal aspect of the lesser tuberosity.

When subscapularis repair is not possible, the latissimus dorsi tendon is harvested. The pectoralis major is dissected free and retracted distally, exposing the latissimus dorsi tendon (Fig. 24.2). The latissimus dorsi lies between the pectoralis major and teres major tendons. The latissimus tendon should be dissected free from the pectoralis major and teres major both proximally and distally. The deltopectoral incision can be extended distally, if necessary, to improve visualization. It is important to identify the radial nerve in the distal aspect of the incision, crossing the lower border of the latissimus dorsi before the nerve courses posterior to the humerus. The latissimus tendon is sharply released from the humerus from proximal to distal. Two running locked Krakow nonabsorbable sutures are placed in the tendon (Fig. 24.3). While pulling gentle traction on the sutures, the tendon is carefully dissected circumferentially with scissors and blunt finger dissection medially to mobilize the muscle and remove all soft tissue adhesions between the latissimus muscle, teres major, and radial nerve. This will increase tendon excursion and prevent traction on the radial nerve when the tendon is transferred more proximally to the lesser tuberosity.

The lesser tuberosity is prepared. All soft tissue attachments are removed, and the bone is lightly decorticated with a rongeur or a high-speed burr. The harvested latissimus tendon is brought to the midportion of the lesser tuberosity, or to the upper border of the tuberosity if adequate tendon excursion is present, and attached through drill holes entering the medial portion of the lesser tuberosity and exiting in the bicipital groove. Suture anchor fixation is also an option with either single-row or double-row repair. If possible, a partial repair of the subscapularis is performed to the upper border of the tuberosity. If a concomitant posterior–superior rotator cuff tear is present, it is repaired at the same surgical setting. The wound is closed in standard layered fashion.

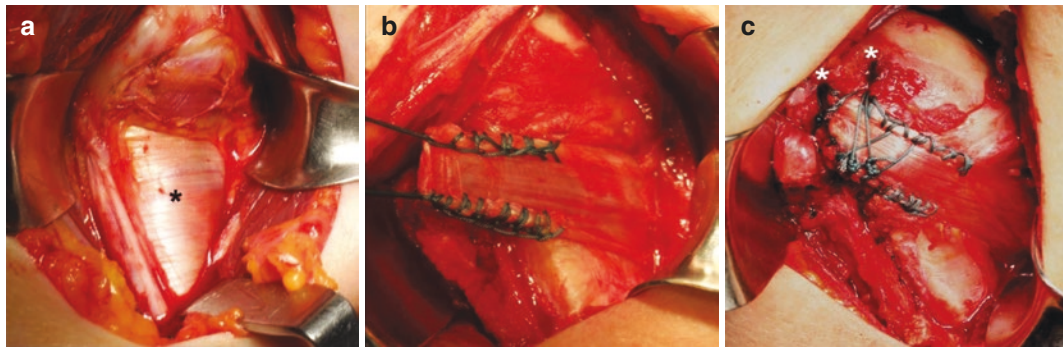

Fig. 24.2 (**a**) An intraoperative image of a right shoulder showing the exposure of the latissimus dorsi tendon (*asterisk*). The pectoralis major tendon is retracted distally to expose the latissimus dorsi tendon. From Mun et al. [28]. (**b**). Two running, locked Krackow sutures are placed in the tendinous portion of the latissimus dorsi. The latissimus dorsi tendon, fully dissected and separated from the teres major and radial nerve, is ready to be transferred. From Mun et al. [28]. (**c**) An intraoperative image after transfer of the latissimus dorsi tendon to the mid-aspect of the lesser tuberosity. The location of two knotless suture anchors is shown with *white asterisks*. From Mun et al. [28]

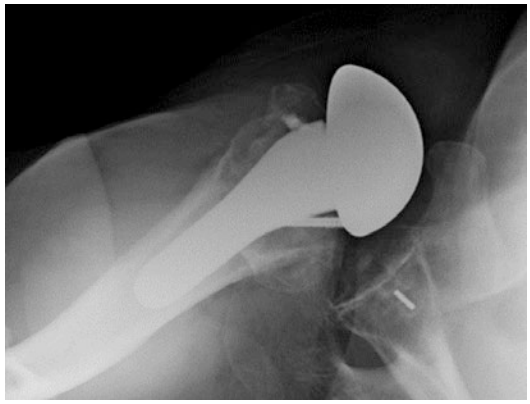

Fig. 24.3 Axillary lateral radiograph of a left shoulder following total shoulder arthroplasty with anterior subluxation of the glenohumeral joint, indicating subscapularis insufficiency. Reproduced with permission from Mun et al. [28]

24.5 Postoperative Rehabilitation

The operative shoulder is placed into an abduction pillow brace with the arm in internal rotation for 6 weeks. Scapular retraction exercises are initiated at 1 week, as well as passive external rotation to neutral. At 6 weeks postoperative, passive and active-assisted shoulder exercises are initiated, with a focus on posture and scapular retraction. A gradual return to daily activities is permitted. Support of body weight is prohibited for 3 months. Resistive exercises and strengthening are started at 12 weeks and progressed slowly. Return to full activities is allowed at 6 months.

24.6 Clinical Outcomes

Tendon transfers for subscapularis insufficiency provide reliable pain relief, glenohumeral stability, and improvements in forward elevation and internal rotation strength. Shin et al. [26] performed a systematic review of pectoralis major transfer for irreparable subscapularis tears. The authors reported on eight studies with 195 shoulders and a mean follow-up of 33.4 months. Pain reduction was noted in all papers, and constant scores improved from 37.8 to 61.3. Constant scores were significantly higher in patients following subcoracoid transfer of the pectoralis major compared to patients who received supracoracoid transfer. Functional outcomes were lower in patients with previous shoulder arthroplasty. The overall incidence of postoperative nerve palsy was low, with one musculocutaneous nerve palsy and one axillary nerve palsy out of 195 cases.

Multiple studies report improvements in subjective shoulder scores and range of motion following pectoralis major transfer for subscapularis insufficiency. Resch et al. [14] found a mean increase in constant scores from 22.6 to 54.4, and improvements in forward elevation to 129° and abduction to 113°. Elhassan et al. [19] showed improvements in constant scores from 40.9 to 60.8 in a younger cohort with mean age of 37 years. Jost et al. [18] reported a final mean relative constant score of 79% in a series of isolated irreparable subscapularis tears. Wirth and Rockwood [6] achieved active elevation to a mean 143° following supracoracoid pectoralis major transfer. In many studies, external rotation is limited after a successful transfer due to a tenodesis effect of the transferred tendon.

Mun et al. [28] reported on 24 patients with a mean age of 58 years who underwent latissimus dorsi tendon transfer for irreparable subscapularis tears with mean follow-up of 27.8 months. Mean Constant scores improved from 46 to 69, ASES scores improved from 40 to 70, and pain scores improved from 6 to 2. Forward elevation increased from 135 to 166° and internal rotation increased from L5 to L1. At final follow-up, the belly-press test was negative for 18 of 24 patients, and the lift-off test was negative for 16 of 24 patients. No nerve palsies were noted.

The most guarded prognoses are reserved for patients with symptomatic subscapularis insufficiency following shoulder arthroplasty (Fig. 24.3). Miller et al. [27] reported two of four patients were satisfied following pectoralis major transfer. Elhassan et al. [19] reported poor outcomes following pectoralis major transfer for subscapularis insufficiency after shoulder arthroplasty, with only one of eight patients reporting significant improvements in pain and function. The belly press remained positive in all patients,

and there were no significant improvements in constant scores or pain scores.

24.7 Conclusions

Pectoralis major and latissimus dorsi tendon transfer can be effective treatment options for irreparable subscapularis tears. These tendon transfers reliably reduce pain and improve function when other nonoperative treatments have failed. This is especially true for patients too young or too active for reverse shoulder arthroplasty. It appears the best outcomes occur in patients with subscapularis tears in isolation or combined with repairable supraspinatus tears. Results are less favorable when performed following shoulder arthroplasty. The pectoralis major transfer has the longest reported outcomes with improvements in pain, range of motion, and functional outcome scores. Latissimus dorsi transfer holds promise as the latissimus dorsi muscle replicates the line of muscle contraction of the subscapularis and has a posterior-directed force vector to restore compression of the glenohumeral joint.

Conflict of Interest

Disclaimer: None.

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Part IV

Replacement Options

ESR HH: When and How?

25

Benno Ejnisman, Gyoguevara Patriota, Bernardo Barcellos Terra, Carlos Vicente Andreoli, and Paulo Santoro Belangero

25.1 Introduction

Patients with massive chronic rotator cuff tears associated with degenerative glenohumeral arthropathy present cuff tear arthropathy. It causes elevation of the humeral head, subchondral cysts, synovial fluid changes, flattening of the greater tubercle, osteophytes, joint destruction, and acetabularization of the acromion [1–3]. Cuff tear arthropathy mainly affects elderly women on their dominant side and triggers chronic symptoms such as progressive pain, weakness, and functional limitation specifically for elevating the arm. Physical examination reveals a reduction in regular range of motion, weakness mainly for external rotation and forward elevation [4, 5]. Seebauer classified the patients into four groups, according to the glenoid erosion and anterosuperior scape: IA—a stable joint with minimum migration due to an intact contention, with the presence of acetabularization of the coracoacromial arch and femoralization of the humeral head; IB—presence of medial glenoid erosion that compromises the articular stability, but it remains contained; IIA—involves superior translation of the humeral head; IIB—shows an anterosuperior dislocation of the humeral head due to the loss of anterior contention and the coracoacromial arch (Table 25.1) [2].

Patients who have failed conservative treatment are referred to surgery. The current arthroplasty options for cuff tear arthropathy are nonconventional (CTA®) partial arthroplasty and reverse shoulder arthroplasty (RTSA). The extend shoulder replacement (ESR), also known as extended humeral head hemiarthroplasty or Cuff Tear Arthroplasty (CTA®) was introduced in 2004 with the objective of maximizing the contact area between the coracoacromial arch and the component articular surface for patients with Cuff Tear Arthropathy (Global Advantage® CTA humeral head—DePuy/Johnson & Johnson) [2].

25.2 What Is ESR?

ESR is a nonanatomical partial arthroplasty designed specifically for cuff tear arthropathy. The rationale is that the arthroplasty allows improved contact to the inferior portion of the coracoacromial arc and, in that way, improves the contact with the coracoacromial arch and, enhances deltoid tension. These characteristics allow for the improvement of the lever arm of the deltoid muscle in arm elevation movement and reduction of pain [1, 6, 7].

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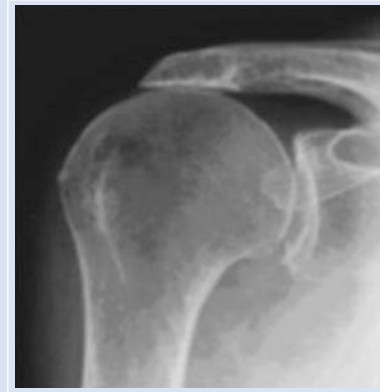
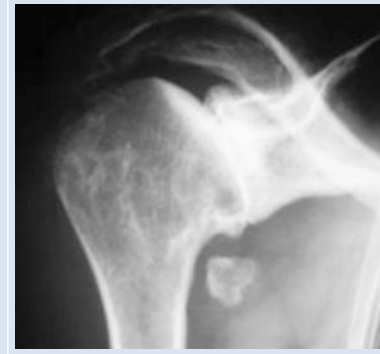
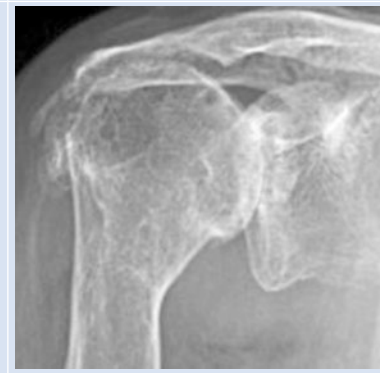
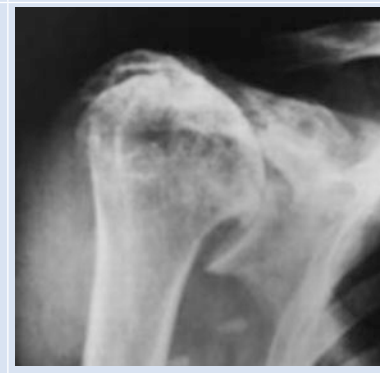
Table 25.1 Seebauer's classification of cuff tear arthropathy [2]

Type I A Centered Stable	✓ A stable joint ✓ Acetabularization of the coracoacromial arch ☑ Femoralization of the humeral head ☑ Minimal superior migration	
Type I B Centered medialized	✓ Medial glenoid erosion ✓ Acetabularization and Femoralization ☑ Compromised dynamic joint stabilization ☑ Minimal superior migration	
Type II A Decentered stable	✓ Minimum stabilization by coracoacromial arch ✓ Acetabularization and Femoralization ☑ Insufficient dynamic joint stabilization ☑ Superior translation of the humeral head	
Type II B Decentered unstable	✓ No stabilization by coracoacromial arch ✓ Acetabularization and Femoralization ☑ Absent dynamic joint stabilization ☑ Anterosuperior dislocation/ escape	

25.3 When to Indicate ESR?

The safety and efficacy of ESR are optimized when patients with rotator cuff tear arthropathy are selected according to three criteria: active elevation greater than 90° (without pseudoparalysis), stability of the humeral head under the coracoacromial arch (absence of anterosuperior escape—Seebauer classification IA, IB, and IIA), and the patient's desire to avoid the risk of complications potentially associated with RTSA (Table 25.2) [2]. Therefore, the key to better postoperative results is a correct indication and selection of patients [8].

25.4 When to Avoid ESR?

The CTA arthroplasty should be avoided in patients with anterosuperior instability (Seebauer IIB), pseudoparalysis, suspicion of infection, neuropathic arthropathy, or acromial fracture. In patients with pseudoparalysis or anterosuperior instability, a reverse total shoulder arthroplasty is a better option (Table 25.2) [2, 8].

25.5 Surgical Technique for ESR

The surgical technique used can be described as follows: with the patient in regular beach chair position, a standard deltopectoral approach is performed, tenotomy of the long head of the biceps followed by the detachment of the tendon of the subscapular tendon (our preferred option is tenotomy). Dislocation of the humeral head should be easy by the absence of posterosuperior cuff attachments. Osteotomy of the humeral head and greater tuberosity with specific guides is performed. Regular humeral arthroplasty preparation is followed and the ESR is fitted. Reduction and arthroplasty accommodation is checked with fluoroscopy before suture of subecapularis tendon (Figs. 25.1, 25.2, 25.3, 25.4, 25.5 and 25.6) [9]. Patients are initially placed in a shoulder sling for 2 weeks and then allowed to start passive range of motion of the operative shoulder to 150° forward flexion and 30° external rotation with the elbow at the side [10].

Table 25.2 Indications and contraindications to ESR [2]

Three criteria to indication
✓ No pseudoparalysis ✓ Absence of anterosuperior escape (Seebauer IA, IB, and IIA) ☑ Potentially high risk of complications potentially
Contraindications to ESR
✓ Anterosuperior instability (Seebauer IIB) ✓ Pseudoparalysis ☑ Suspection of infection ☑ Neuropathic arthropathy ☑ Acromial fracture

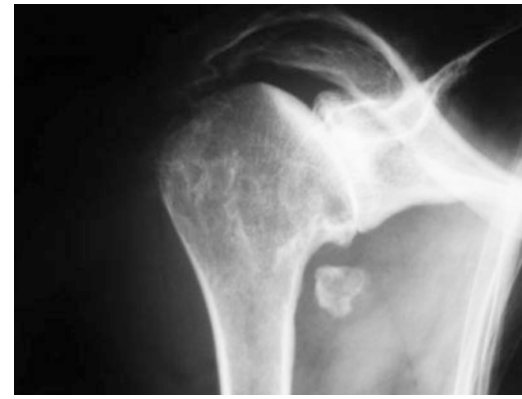


Fig. 25.1 Preoperative radiograph with glenohumeral arthrosis (Seebauer type IB)

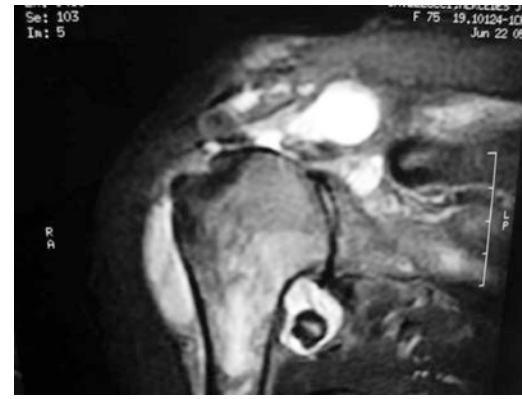


Fig. 25.2 Magnetic resonance imaging with massive rotator cuff tears

25.6 What Are the Functional Results of ESR?

The main objective of the CTA prosthesis is pain relief and function improvement. Visotsky et al., in 2004, published the first results of 60 patients (Seebauer's classification IA, IB, and IIA) without pseudoparalysis. They reported excellent postoperative results and revealed substantial improvement in pain relief, range of motion, and functional goals [2].

In 2012, Firestone et al. presented the results of 21 patients (22 shoulders with types IA, IB, and IIA), with minimum 2 years follow-up. The mean preoperative Simple Shoulder Test (SST) was 4, and the mean postoperative score was 9 (p = 0.00007); the mean preoperative constant score was 37 and the mean postoperative was 62 (p = 0.0008); Shoulder range of motion was maintained or improved after surgery. Within the first 2 years after surgery, only one patient was revised to RTSA [11].

In the same year (2012), Filho et al. described 23 patients (5 type IA, 9 type IB, and 9 type IIA; no type IIB) submitted to CTA prosthesis. Improvement in pain was observed in all patients after arthroplasty. The mean UCLA pain score was 9.22 (ranging from 10 to 8) and 95% of satisfaction with the surgery. Active frontal flexion showed an increase in mean value from 57.61° to 77.83° after the operation; lateral rotation increased from 19.78° to 26.09°; the mean medial rotation didn't present any changes (level of third lumbar vertebra). None of the patients needed surgery revision during follow-up [12].

In 2015, Filho et al. brought out an update of their results with 18 patients (5.4-years' follow-up). Satisfaction with surgery dropped to 78%, mean UCLA score was 23.94 and this was a significant improvement in comparison with the preoperative mean of nine ($p < 0.001$) [1].

Ejnisman et al., in 2016, described 34 patients with cuff tear arthropathy (around 73% Seebauer IA/IB/IIA, and 27% type IIB) associated with comorbidities (cardiopathy, lung disease, stroke, diabetes mellitus, and myocardial revascularization) and submitted to CTA prosthesis. The mean follow-up was 21.7 months. There was a statistically significant variation between the pre- and postoperative evaluations of VAS ($p < 0.0001$), with a mean reduction of 6.6 points (standard deviation of 1.3 points), varying between reductions of 3–9 points. On the constant score, there was also a statistically significant variation between the pre- and postoperative evaluations ($p < 0.0001$), with a mean increase of 24.1 points (standard deviation of

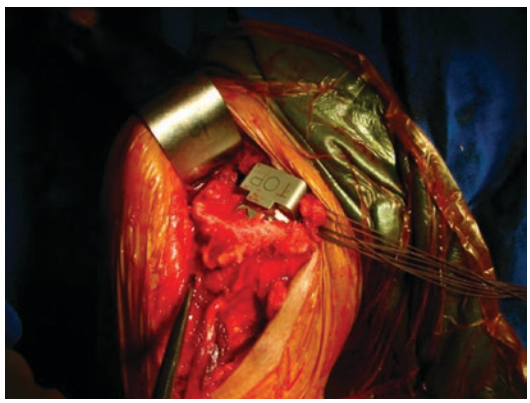


Fig. 25.3 Prosthesis (test) with a guide for resection of the humeral head and greater tuberosity of the humerus through the standard deltopectoral approach

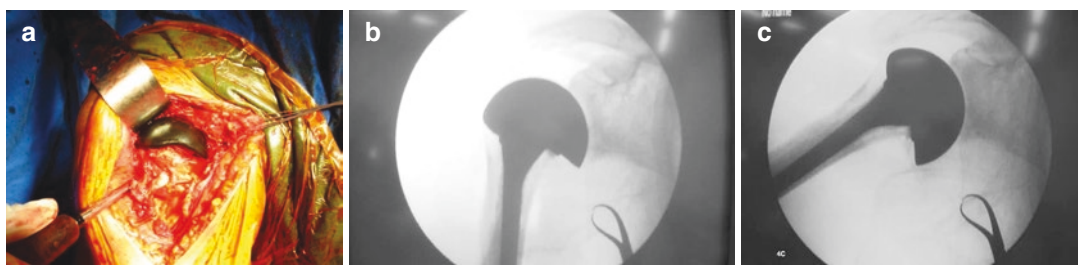


Fig. 25.4 (**a**) CTA prosthesis (test). (**b** and **c**) Radioscopy imaging (intraoperative)

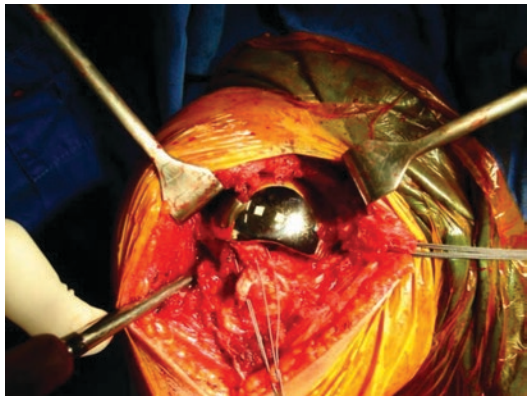


Fig. 25.5 CTA prosthesis shown on intraoperative (final implant)

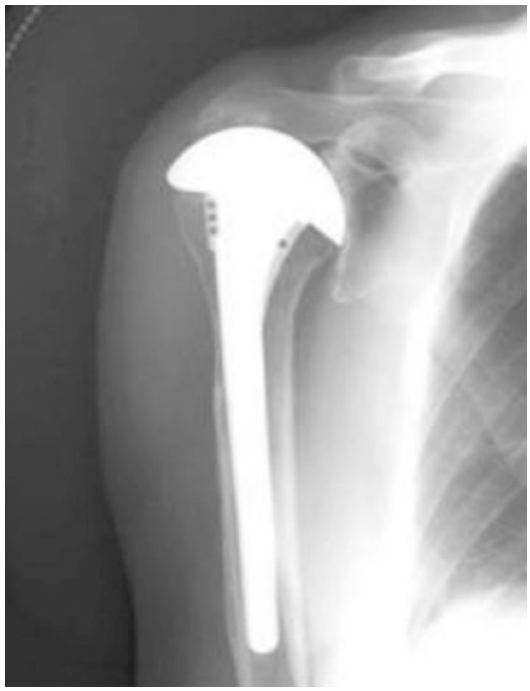


Fig. 25.6 CTA prosthesis shown on postoperative radiograph (right shoulder)

6.4 points), varying between 13 and 39 points. All cases of type IIB showed pain relief, but no significant increased functional scores. There was no case of infection [9].

In 2019, Matsen third et al. published results of 50 patients (but only 42 with 2-years' follow-up) mostly Seebauer IA and IB without complications or revisions. The patients presented significant improvement in daily life activities [8].

Although there is a lack of long follow-up studies, the results of the available literature show that this procedure may be a fair option for patients with low-demand, comorbidities, intact coracoacromial arch, and no pseudoparalysis.

25.7 Radiographic Complications in Patients with ESR

In 2017, Leung et al. published the results of 97 CTA prostheses (patients with Seebauer IA, IB, and IIA). Twenty-six (26.8%) experienced at least one radiographic complication. Radiographic complications included acromion remodeling (19.5%), anterior-posterior humeral head subluxation (5.2%), glenoid remodeling (3.1%), periprosthetic fracture (4.1%), hardware loosening (2.1%), subsidence (1.0%), and superior humeral subluxation (2.1%). There were no complications of loose joint bodies, glenoid fracture, periosteal reaction, or severe heterotopic ossification [13].

A total of 73.5% of all the radiographic complications had already occurred within 3 months of surgery. Radiographic complications plateaued at around 9 months with a cumulative rate of 31.7% through at least 36 months [13].

Of all 97 CTA prostheses, six cases of patients with radiographic complications (23.1%) and 2 cases without radiographic complications (2.8%) needed revision. The presence of acromion remodeling and any radiographic complication besides acromion remodeling was significantly associated with increased risk of surgical revision [13].

The four largest studies in the literature with a combined patient population of 300 that looked at CTA hemiarthroplasty in the setting of cuff tear arthropathy had zero cases of glenoid remodeling, prosthetic subluxation, or perihardware loosening [1, 10, 14, 15]. Radiographic complications after CTA prosthesis are common and should be taken into account as they may increase the likelihood of surgical revision.

25.8 What Is the Cost of ESR?

Coe et al., in 2012, came out with the first study to directly compare cost-effectiveness between RTSA and ESR HH for cuff tear arthropathy. Thus, it is difficult to say with certainty whether RTSA is more cost-effective than ESR [15]. The RTSA has a mean cost of US$ 23,000, while an ESR HH has a cost of US$ 12,000; a considerable difference of $ 11,000 per prosthesis.

The selection criteria for extended shoulder replacement (ESR) differed substantially from the selection criteria for an RTSA, so was not possible to compare the safety and clinical outcomes for these two procedures in similar patients. Extended humeral head hemiarthroplasty may provide a safe, effective, and less invasive alternative to RTSA for the management of selected patients with rotator cuff tear arthropathy if they have preserved active motion and a stabilizing coracoacromial arch [8].

Considering the good functional results of using a CTA prosthesis and the low cost associated with low complication rates, this type of prosthesis is an excellent option for patients with severe comorbidities [9] and for public health policies, especially in underdeveloped countries.

25.9 Standard Hemiarthroplasty × CTA Prosthesis

Several studies have shown that a standard hemiarthroplasty, although effective in pain control leads to poor functional results. Studies with longer follow-up demonstrate that complications, such as prosthesis migration and subsequent erosion of the glenoid and acromion (coracoacromial arch), are common. These complications affect even more the function of the shoulder, with significant limitation to elevation, and rotation [16–19].

25.10 Conclusions

RTSA remains the first choice for patients with cuff tear arthropathy. The extended head humeral articular surface is a good option for patients with low demand, comorbidities, intact coracoacromial arch, and no pseudoparalysis. Success depends mostly on correct patient selection.

25.11 Acknowledgments

Our sincere acknowledgment to Dr. Cassiano Diniz Carvalho (in memoriam) for all the scientific contribution to shoulder and elbow surgery.

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Standard Reverse Shoulder Prosthesis (RSP)

26

Giovanni Di Giacomo and Andrea De Vita

26.1 Introduction

Treatment options for massive cuff tear (MCT) are numerous. In the majority of cases, management should start with conservative measures with an emphasis on physical therapy. Shoulder rehabilitation exercises focusing on deltoid and periscapular muscle strengthening can help restore functional shoulder range of motion, even in the absence of a fully intact rotator cuff. In a traumatic setting, a period of rest, ice, and activity modification may be necessary to alleviate symptoms. NSAIDs and corticosteroid injections can also help relieve pain. When conservative management is unsuccessful, surgical intervention is often warranted. Specific options include debridement with or without subacromial decompression, biceps tenotomy, partial or complete rotator cuff repair, tendon transfer, various grafting and tendon augmentation techniques, superior capsular reconstruction, and reverse total shoulder arthroplasty (RTSA). We will here focus on the rationale and indications for reverse shoulder arthroplasty (RSA) in the setting of MCT. The popular use of reverse total shoulder prosthesis began to flourish after it was reengineered by Grammont in 1985 [1]. While initial reports were limited to the treatment of rotator cuff tear arthropathy, implant design and surgical techniques have evolved, and indications for RSA have rapidly expanded to include treatment of acute 4-part proximal humerus fractures [2, 3], humeral fracture sequelae [4, 5], osteoarthritis with glenoid bone loss [6], revision arthroplasty [7, 8], and oncologic reconstruction [9], as well as the treatment of MCT with or without glenohumeral arthritis. While cuff tear arthropathy (CTA) is a clear indication for RSA, the optimal treatment for patients with MCT in the absence of arthritis is less obvious and remains controversial. It is imperative that treatment be individualized for each patient. The first question is that of the reparability of the tendon. The success of rotator cuff repair (RCR) depends on a number of patient-related factors, including age, health, and preoperative function, as well as certain characteristics specific to the tear, including size, chronicity, and quality of the remaining cuff [10, 11]. There is also the variable of the surgeon's technical skill and expertise. In the case of chronic MCT, the tendon is often retracted and atrophic, and obtaining an appropriately tensioned anatomic repair may not be possible [12]. For massive cuff tears deemed to be irreparable, surgical options are limited. There are new techniques such as allograft tissue augmentation and superior capsular reconstruction, both of which have shown promise in early reports although relatively little data supports widespread use at this time [13, 14]. In certain, patients presenting MCT without osteoarthritis, reverse shoulder

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arthroplasty may be a reasonable solution. Even in the absence of articular cartilage pathology, RSA has proven to be a reliable option to relieve pain and restore function [15]. Careful consideration should be given to a patient's prior history of shoulder surgery, particularly a previously failed attempt at RCR.

Failure of rotator cuff surgery, with or without arthritis, presents a difficult and challenging problem. Patients may complain of persistent pain and/or pseudoparalysis (Fig. 26.1) of the shoulder with impairment in daily living activities [16–22]. Re-repairing the rotator cuff may not be technically feasible and even contraindicated because of rotator cuff tendon loss, muscle fatty infiltration, and/or proximal migration of the humeral head under the acromial arch [23]. Furthermore, palliative surgery, such as cuff debridement and/or biceps tenotomy or tenodesis, may also have failed to relieve pain and restore shoulder function [24, 25]. Tendon transfers can be an option for younger patients, but require extensive rehabilitation with somewhat unpredictable results and may not be as successful in older patients or those with arthritis [22]. Until recently, the only surgical option in such cases was non-constrained hemiarthroplasty with the hope that this would provide pain relief [26]. Functional results were often unpredictable, however, as elevation above the horizontal level was often not achieved after such a "limited goals prosthesis." Moreover, deterioration of functional results after hemiarthroplasty for the cuff deficient shoulder has been observed in some series with medium- or long-term follow-up because of glenoid and/or acromial erosion and wear [27].

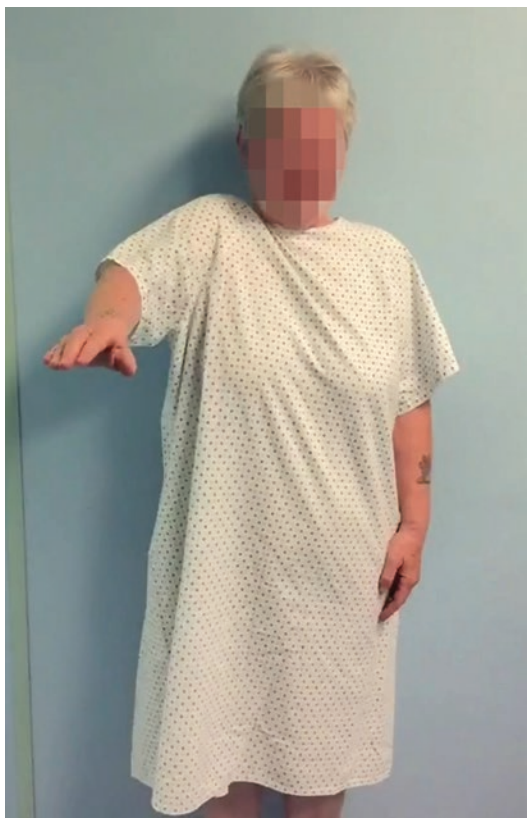

Fig. 26.1 Pseudoparalytic shoulder for massive cuff tear

26.2 Indications

Different papers hypothesize that RSA can relieve pain and restore shoulder function in patients where rotator cuff surgery has failed and when all other possibilities of treatment have been exhausted.

Denard et al. previously found that revision rotator cuff repair was able to reverse pseudoparalysis in only 43% of patients with MCT [28]. Moreover, Shamshudin et al. reported that revision cuff repair was associated with declining functional outcomes after 6 months, more retears, more pain with activities of daily living, lower activity level, and decreased overall satisfaction at 2 years postoperatively compared with primary cuff repair [29]. Importantly, Sadoghi et al. found that previously failed arthroscopic rotator cuff surgery did not have a negative impact on outcomes and survival rate after reverse shoulder arthroplasty [30]. Thus, RSA is an excellent salvage operation in these patients and may be more prudent than a repeated attempt at repair.

A recent study evaluated the cost-effectiveness of performing primary RSA compared with rotator cuff repair for patients with symptomatic large and massive rotator cuff tears [31]. The authors found that arthroscopic repair was a more cost-effective initial treatment than RSA, despite the high retear rate following cuff repair.

In a 2019 paper by Erickson et al. [32], the aim of the study was to determine whether there were differences in outcome, regarding patients with a history of ipsilateral rotator cuff repair who underwent RSA (the study group) compared with matched controls without a history of rotator cuff repair. A total of 45 patients with a previous history of rotator cuff surgery who underwent RSA were identified and formed the study group. They were matched 1:3 with a control group of 135 patients without previous rotator cuff repair who underwent RSA. Controls were matched based on age (±5 years) and gender (Table 26.1). Two- and five-year postoperative outcomes were compared. The authors recorded both subjective and objective outcomes. Subjective outcomes included pain, patient satisfaction, and whether the patient would recommend this surgery to others. Objective outcomes included the American Shoulder and Elbow Surgeons (ASES) score, physical and mental component summary scores (PCS and MCS) of the Short-Form-12 (SF-12) survey, and the shoulder activity scale (SAS) [33, 34]. At the time of RSA, the rotator cuff was torn in 43 patients (96%). There were significant improvements in ASES and SF-12 PCS scores 2 years postoperatively and no difference in SF-12 MCS and SAS scores. There was no difference in satisfaction nor in the percentage of patients who would recommend this surgery at 2 years between groups. However, pain was significantly improved at baseline and at 2 years in the study group.

In a similar paper, Sadoghi et al. [35] reported the outcomes of 66 patients, half of whom had previous rotator cuff repair and underwent RSA, with a mean follow-up of 42 months. Significant improvements in all patient-reported outcome measures in both groups were reported; no difference between patients with previous rotator cuff repair and those without were reported.

Table 26.1 Hamada classification of radiographic changes in massive cuff tear [38]

Grade 1	AHI ≥ 6 mm
Grade 2	AHI ≤ 5 mm
Grade 3	Grade 2 + "acetabulization" of the acromion
Grade 4	Grade 3 + glenohumeral arthritis
Grade 5	Grade 4 + humeral head collapse (cuff tear arthropathy)

In a 2009 series by P. Boileau [36], 46 shoulders in 44 patients underwent RSA for previous failed cuff surgery. All had a chronic or irreparable cuff tear and had failed conservative treatment. A cuff tear was considered chronic or irreparable when any of the following conditions were present:

- loss or fixed retraction of cuff tendon
- severe cuff muscle fatty infiltration (Goutallier stage 3 or 4) [37]; (Figs. 26.2 and 26.3)
- proximal humeral migration with narrowing of the acromiohumeral space to <6 mm on the A-P view in neutral position [38] (Table 26.1).

In this series, patients were divided into two groups based on preoperative active elevation. The first group, defined as pseudoparalytic shoulders (PPS) (n. 30), had preoperative active anterior elevation (AAE) <90°. The second group, defined as painful shoulders (PFS) (n. 12), had pain but retained >90° AAE. A Grammont design RSA was used in all cases: the Delta shoulder arthroplasty (Depuy, France) was used in 34 cases (81%) and the Aequalis Reversed (Tornier, France) in eight cases (19%). Clinical evaluation was systematically performed on all patients preoperatively and at follow-up to determine range of movement (ROM) and constant score (CS) [39]. Preoperative imaging shows that the supraspinatus and the infraspinatus were completely torn in all cases. The subscapularis was intact in 52%, partially torn in 24%, and completely torn in 24%. The subscapularis was repaired in all patients at the time of RSA. The teres minor was normal in 70%, hypertrophic in 7%, atrophic in 16%, and absent in 7%. No repair of the teres minor was attempted and no tendon transfers were performed. Fatty infiltration of the cuff muscles was classified using the Goutallier system by a single independent observer [37]. Stages 0, 1, and 2 were grouped together (i.e., <50% fatty infiltration), as were stages 3 and 4

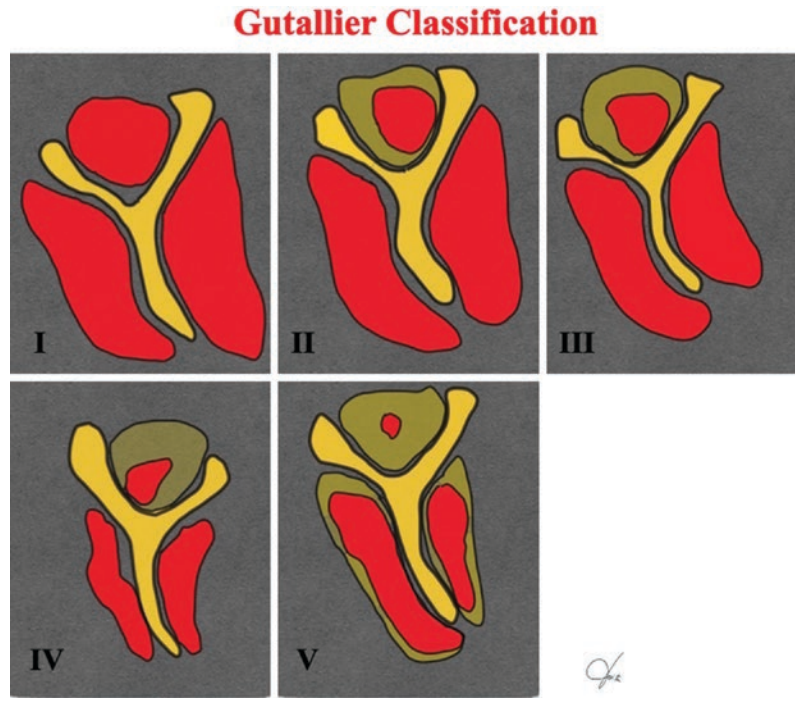

Fig. 26.2 Goutallier classification of fatty infiltration of cuff muscles

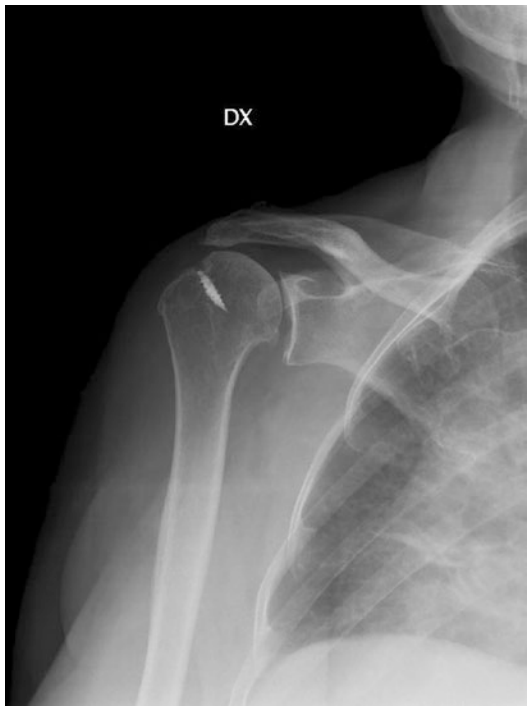

Fig. 26.3 Rotator cuff retear with proximal migration of the head (Grade 2)

(i.e., >50% fatty infiltration). Fatty infiltration of the infraspinatus was <50% in two shoulders (5%), and >50% in 35 shoulders (95%). Fatty infiltration of the subscapularis was <50% in 27 shoulders (63%), and >50% in 10 shoulders (27%). Functional results were evaluated based on AAE of the arm and constant score. AAE and all parameters of the CS were significantly improved for the entire series. Results were excellent in seven cases, good in 14, fair in 9, and poor in 12. There was no difference in postoperative ROM and functional results between the two populations (PPS and PFS). However, changes in results (preoperative to postoperative) were significantly different in the two groups, improvement was significantly better for PPS with respect to activity (9.8 vs. 4.8, $P = 0.01$), mobility (13.7 vs. − 0.7, $P = 0.0003$), CS (37.1 vs. 14.5, $P = 0.002$), adjusted CS (52.6 vs. 20.8, $P = 0.002$), and AAE (67° vs. −24°, $P < 0.0001$). Furthermore, AAE decreased significantly from preoperative to postoperative for PFS (146° −122°, $P < 0.0001$). Indeed, PPS and PFS had the same average final results, but these two populations did not start from the

same preoperative level. In PPS, AAE increased while in PFS it decreased. Gain in CS was also significantly less in PFS than PPS. The subjective satisfaction of PFS was low. Regarding RSA after failure of previous cuff surgery, it can be concluded that patients suffering shoulder pseudoparalysis with a preoperative active elevation <90°, with or without arthritis, can expect to achieve good subjective results and functional outcome. However, patients with a painful shoulder and normal mobility are at risk for potential loss of AAE and fair, but not good, subjective results. This study demonstrates that RSA can improve function in patients with cuff deficient shoulders, even after previous failed surgery, respect patients with painful shoulder ($P = 0.002$). In any case, results are dependent on preoperative active anterior elevation.

In the final analysis, a patient being considered for RSA should have a painful, irreparable rotator cuff tear, and evidence of pseudoparalysis (Fig. 26.1) with active forward elevation <90° [15, 40]. One should look closely at the patient's age, health status, and comorbid conditions.

26.3 Contraindications

We have recently found younger age to be a risk factor for poor functional improvement after RSA in the specific setting of MCT without arthritis [41]. Accordingly, we rarely consider performing RSA as an index procedure for MCT without arthritis in patients <65; caution should be exercised in this population.

In a 2017 series by Ernstbrunner et al. [42], 23 shoulders were treated with RSA for massive, irreparable rotator cuff tear and secondary pseudoparalysis of active anterior elevation in young people (mean age, 57 years). Patients were examined at a mean of 11.7 years (range, 8–19 years). RSA was the primary procedure in 8 shoulders (35%) and performed as revision surgery in 15 (65%), 5 of which underwent >1 previous shoulder surgical procedure other than RTSA. All shoulders treated with a Delta III RSA received a standard lateralized humeral polyethylene cup, whereas a 16-mm medializing offset humeral cup was implanted in anatomical replacements. Subjective and objective functional outcomes substantially improved compared with preoperative status, with a mean gain of 40% in relative constant score (rCS), and of 51% in subjective shoulder value (SSV) at the time of long-term follow-up, but the complication rate was very high. At a mean of 12 years after RTSA, the complication rate was 39%, revision rate was 17%, and failure rate was 9%. Advanced glenoid notching in 29% (6) of the shoulders was also observed radiographically. The prevalence and degree of inferior scapular notching increased over time, and greater notching was correlated with inferior shoulder function.

Therefore, we are of the opinion that a painful shoulder after failure of cuff surgery is a potential contraindication to RSA if the patient maintains >90° of preoperative active anterior elevation and is younger than 60 years of age. Some of these patients may be better treated by other procedures, such as re-repair, debridement, biceps tenotomy or tenodesis, tendon transfer, nonconstrained arthroplasty, or humeral resurfacing. However, the topic requires further investigation.

26.4 Surgical Approach and Technique

We prefer a standard deltopectoral approach to shoulder replacement. The incision begins 5 cm medial to the acromioclavicular joint at the anterior border of the clavicle and extends distally over the coracoid to the lateral aspect of the humerus at the deltoid insertion. Upon subcutaneous dissection of the deltopectoral interval, the cephalic vein is taken laterally with the deltoid, taking care to cauterize all tributaries. The medial border of the deltoid is elevated, all subdeltoid adhesions released, and the bursa debrided from the subdeltoid and subacromial spaces. The subscapularis muscle is released directly off the bone at the lesser tuberosity. The subscapularis should be adequately mobilized to facilitate possible later repair by debriding capsular tissue and releasing adhesions deep to the muscle belly from the anterior wall of the scapula, as well as those from the subcoracoid space. The proximal

humerus is dislocated anteriorly and an anatomical humeral head cut is made. Loose edges of irreparable rotator cuff should be debrided to prevent impingement with the humerus implant and glenosphere. The glenoid is exposed and prepared with thorough debridement of the labral tissue circumferentially. Many patients with retear of the rotator cuff will have superior humeral head migration. In this setting, distalizing the components may produce excessive soft-tissue tension and generate stress across the implant–bone interface and on the acromion. This problem can create complications. Furthermore, distalization of the humerus disrupts normal glenohumeral joint mechanics. Particularly in the setting of massive cuff tear without osteoarthritis when the bony structures are relatively preserved, we believe it is critical to restore patient anatomy to as close to normal as possible. By restoring the native anatomy, one can appropriately tension the remaining cuff and maximize its function. Thus, we recommend the use of an anatomic humerosocket neck-shaft angle and a lateralized glenosphere with an anatomic center of rotation.

26.5 System Choice

The initial Grammont design of the reverse shoulder arthroplasty used a neutral glenosphere and a humeral prosthesis with an inclination of 155° which medialized the center of rotation and lengthened the arm to increase the function of the deltoid and compensate for a deficient rotator cuff. This design provides reliable improvements in function and decreases pain in the short to medium term. However, this nonanatomic humeral inclination leads to a high percentage of scapular notching after surgery. Various authors have described notching in 50–96% of cases. In an effort to decrease the rate of scapular notching, some authors have advocated for a more anatomic or vertical humeral inclination with or without a lateralized glenosphere.

In a 2019 randomized controlled trial, Gobezie et al. [43] compared humeral inclinations of 135° and 155° in patients undergoing primary RSA. The hypothesis being that forward flexion (FF) would be higher in the 155° group but associated with a higher rate of scapular notching (Fig. 26.4). A total of 37 patients (74%) in the 135° group and 31 patients (62%) in the 155° group having a minimum follow-up of 2 years were included. The mean follow-up was 38 months (29–45 months). No statistically significant difference in functional outcome or range of motion (ROM) between the two groups postoperatively was found; scapular notching occurred in 21% of the 135° group compared with 59% in the 155° group. The major findings of this study were that there is no apparent difference in postoperative FF or external rotation (ER) after reverse shoulder arthroplasty using a humeral inclination of 135° or 155° with a neutral glenosphere, but that scapular notching is higher with an inclination of 155°. Cuff et al. [44] reported in a 5-year follow-up of RSA using a 135° humeral stem that FF improved from 64° to 144°, ER improved from 15° to 51°, while the notching rate by only 9% (Fig. 26.5). Ladermann et al. [45] compared an inlay 155° prosthesis to onlay prostheses with 135°, 145°, or 155° of

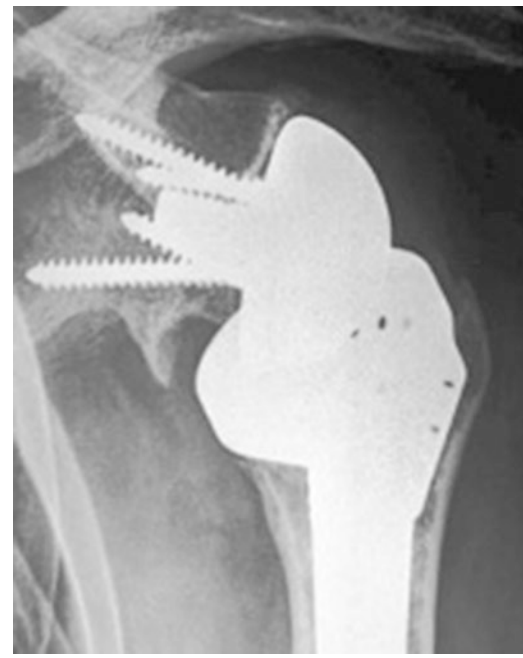

Fig. 26.4 Scapular notching in a 155° stem inclination

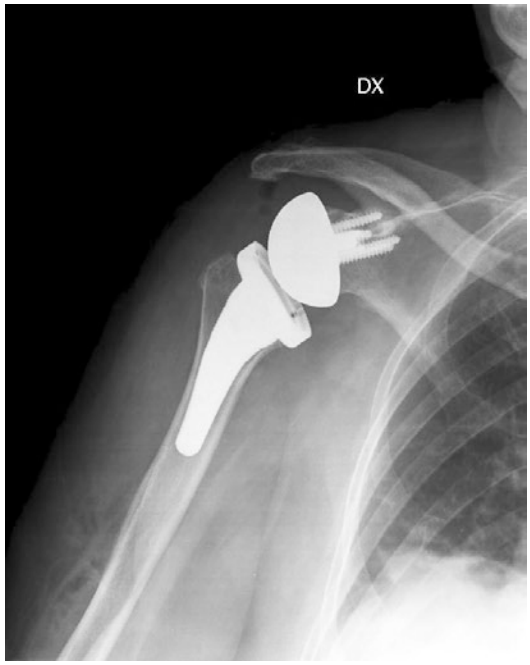

Fig. 26.5 135° stem inclination reduces scapular notching

humeral inclination and reported that the 135° design improved adduction by 28° if compared to the traditional 155°. Interestingly, there was no difference between 135°, 145°, and 155° designs in FF, but ER at the side was approximately 15° higher with the 135° if compared to the 155° configuration.

The Grammont RSA was the first clinically successful design; partly due to medializing the center of rotation (COR) from its anatomic location [46]. While the Grammont prosthesis revolutionized RSA by decreasing the shear and tensile forces that caused prior designs to fail, it does have several disadvantages, including decreased prosthetic range of motion, potentially decreased tension on remaining intact rotator cuff muscles, and high scapular notching rates [46–51]. Advancements in metallurgy and design (including locking screws) have allowed for the development of clinically successful prostheses with a lateralized COR (although still medial to anatomic COR) [52]. These lateralized designs have proposed advantages in ROM (leading to greater clinical ROM and a lower notching rate), potentially improved length–tension relationship of the remaining rotator cuff muscles (infraspinatus and teres minor), and improved deltoid "wrapping" effect [53, 54] for a potentially lower dislocation rate [48, 49, 55–58]. Conversely, there are several proposed disadvantages of lateralized COR designs, including concern for glenoid baseplate loosening and glenosphere failure [46, 49, 53, 58].

Few studies have compared medialized and lateralized prostheses postsurgical outcomes. Boileau et al. [59] proposed that in a medialized COR prosthesis, the humerosocket may impinge on the posterior neck of the scapula. Li et al. [60] demonstrated maximal impingement-free rotation occurred with inferior translation, inferior tilt, and lateralization of the glenosphere. We are of the opinion that lateralizing the COR preserves the subscapularis and teres minor muscle rotational moment arms and that, theoretically, the mechanical efficacy of the posterior deltoid fibers to assist in external rotation, internal rotation, or both, is lost when the COR is medialized. We found no clear difference between lateralizing and medializing the COR in relative scientific literature. It is our experience that patients treated with a lateralized COR prosthesis showed greater improvements in external rotation than those treated with a medialized COR prosthesis. Contrarily, forward flexion and abduction were similar in medialized or lateralized COR. Lateralization also appeared to result in decreased scapular notching.

26.6 Complications

A systematic review proposed by Joshua K. Helmkamp [61] in 2018 analyzed the most common complications in reverse shoulder prostheses in two groups of RSA (medialized and lateralized COR). This review reported 4 surgical complications documented in 18 selected papers: dislocations, acromial stress fractures, glenoid baseplate failure, and scapular notching. Dislocation and acromial stress fractures were relatively infrequent complications; dislocation between 2.5% and 3.3%; acromial fractures from

1% to 1.4%. Glenoid baseplate failure and scapular notching, however, evidenced a difference between the lateralized (more glenoid baseplate failure) and medialized (more scapular notching) COR groups. The frequency of reported glenoid baseplate failure was higher in the lateralized group than in the medialized group, in all likelihood due to important shear force on the baseplate during elevation and abduction. By increasing the size of baseplate screws and introducing locking screws, results improved. Interestingly, Frankle's popular lateralized design showed a 12% (7 of 60) glenoid baseplate failure rate in 2005 before the inclusion of peripheral locking screws in prosthesis design [62]. After 5.0 mm peripheral locking screws were added, baseplate failure rate decreased to 1% (1 of 94 shoulders) [52]. The most common RSA complication in all studies was scapular notching, a radiographic sign specific to RSA resulting from erosion of the scapular neck (Fig. 26.4) [63] and thought to occur due to impingement of the humeral component against the scapular neck during adduction [64]. Scapular notching was reported to be present in roughly half of RSA patients with medialized COR, but was reported in only 4% of RSA patients with lateralized COR. The clinical significance of scapular notching is a matter of debate. Several studies [50, 63, 65, 66] have implicated scapular notching in glenoid component loosening and decreased functional outcome scores. However, a comprehensive study by Levigne et al. [67] reported that although 62% had evidence of notching, minimal loosening, and no clinical effect associated with notching were found. Current literature suggests that lateralized COR results in a lower incidence of postoperative scapular notching after RSA.

26.7 Conclusions

RSA can improve function in patients with cuff deficient shoulders, even after failure of previous cuff surgery. However, RSA can also lead to serious complications and disappointing results in patients with cuff deficient shoulders. It can restore only active elevation in patients with a pseudoparalyzed shoulder; active rotation will not change unless lateralization of the prostheses is performed. The identification of appropriate indications relative to shoulder replacement and prior to surgery is fundamental to the achievement of good quality results. Possible complications should be discussed with the patient.

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Lateralized RSP: Glenoid Side, European Experience

27

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27.1 Introduction: Glenoid Lateralization in Reverse Shoulder Arthroplasty (RSP). The American Versus European Experience

The introduction of the Grammont prosthesis (Delta III; DePuy, Warsaw, Indiana) in Europe produced a renewed interest in Reverse total shoulder arthroplasty. The Delta III has demonstrated good clinical outcomes in medium- and long-term follow-up, with improvements in both pain and function compared to traditional treatments of rotator cuff deficient shoulders [1, 2].

Several studies conducted in Europe have reported promising results in short-, medium-, and long-term follow-up with the use of a reversed shoulder implant [3, 4].

One of the first investigation [4], a multicenter study carried out in Europe with 77 patients with glenohumeral osteoarthritis and massive rotator cuff tear treated with the Delta-III prosthesis, described: an improvement of 42 points in the mean Constant score, an increase of 65° in forward elevation, and minimal or no pain in 96% of the patients. However, 49 patients (63.6%) were noted to have medial component encroachment and scapular notching without evidence of loosening. Progressive glenoid component loosening was noted in five patients, two of which had been revised at the time of publication. Seven patients had the glenosphere and baseplate dissociated. This uncoupling was progressive in three patients, with one requiring revision. Despite the good clinical outcome of the reversed implants, the authors found a reduction in the mean postoperative external rotation.

Limited postoperative shoulder rotation after RSA is due to limited excursion of the cup around the medialized glenosphere and to mechanical impingement of the tuberosities against the coracoid process and scapular spine, respectively, in internal and external rotation.

Furthermore, humeral medialization may raise cosmetic concerns, as some patients dislike the loss of their normal shoulder contour after RSA [5, 6].

During the last decades, the most discussed topic in shoulder surgery has been trying to find methods to avoid scapular notching and improve the external rotation. Both glenoid and humeral component lateralization in reverse shoulder prosthesis has been indicated as possible solutions to deal with those complications.

In 2006, Frankle et al. [7] introduced the concept of increased offset RSA, using a metallic

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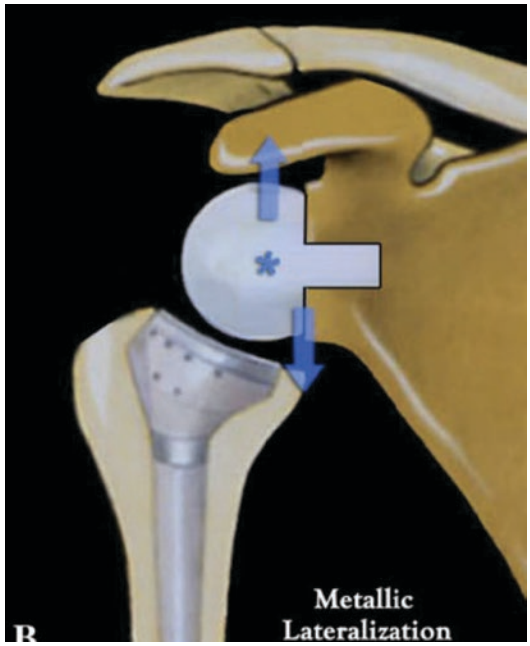

Fig. 27.1 The metallic lateralized RSA (Reproduced from Boileau et al. [8])

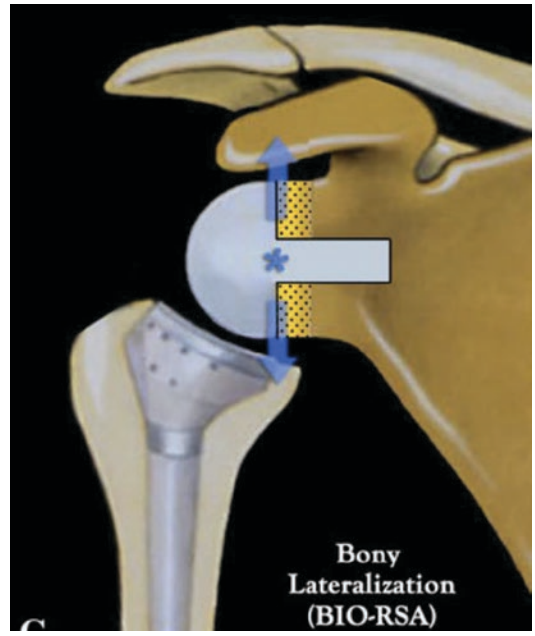

Fig. 27.2 The BIO-RSA. (Reproduced from Boileau et al. [8])

lateralization at the glenoid side (Fig. 27.1). The authors found an improvement in active elevation, which increased from 55° preoperatively to 105° postoperatively. Even though, in this study, the preoperative external rotation data were incomplete, the average postoperative measurement of 35.9° was encouraging, especially compared with the data reported in the study by Sirveaux et al. [4] which showed a mean postoperative external rotation of 11.2°. No patient in the present study showed scapular notching.

Such prosthetic lateralization, achieved by increasing the offset of the glenosphere and/or baseplate (metallic lateralization), has the disadvantage of increasing torque or shear force applied to the glenoid component, potentially increasing the risk of glenoid loosening [9].

In 2011, Boileau et al. [8] proposed an innovative approach to address the problematic issues encountered with standard medialized RSA. They suggested to lateralize the prosthesis by placing an autogenous bone graft harvested from the humeral head on a specifically designed baseplate with a long central peg. This novel surgical procedure, which keeps the center of rotation at the glenoid bone-prosthesis interface once the bone graft has healed, is called the bony increased-offset reversed shoulder arthroplasty (BIO-RSA) (Fig. 27.2).

27.2 Glenoid Lateralization: Definition

Routman et al. [10] classified the glenosphere offset as medialized and lateralized. A glenosphere with a center of rotation (CoR) of 5 mm or less lateral to the glenoid surface is considered as a medialized glenoid (MG) whereas a glenosphere with a CoR located more than 5 mm lateral to the glenoid surface is considered as a lateralized glenoid (LG).

Once more, in a recent paper Werthel et al. [11] on Delta III prosthetic implants, divided the glenoid components offset into two types: medialized (MG) and lateralized glenoid (LG), respectively, with a lateral offset (LO) lower and greater than 5 mm. The Glenoid LO (CE) was defined as the sum of the "perceived radius of the glenosphere" and of the center of rotation offset.

27.3 The European Experience Results

Clinical outcomes related to RSA lateralization should be evaluated in function of scapular notching, impingement-free range of motion, and muscle tension/lengthening.

Lateralization at the glenoid side decreases scapular notching [8, 12, 13] and increases impingement-free motion [14, 15], as the humeral polyethylene bearing is farther from the scapular pillar.

However, since the joint center of rotation gets closer to the deltoid line of pull, the moment arm of the latter decreases in elevation and abduction [16] increases, therefore, force is required to perform those movements [17]. This may also lead to an increase in acromial stress [18, 19]. In addition, the glenoid implant is subjected to substantial shear forces, which could facilitate glenoid loosening [9].

Furthermore, the amount of glenoid lateralization is limited by glenoid bone erosion, inclination, or retroversion [9].

Humeral lateralization (whether the stem or the humeral insert) has several advantages. It restores a more anatomical position of the humerus, lesser and greater tuberosities, improving the length/tension curve of the remaining cuff [20]. Better resting tension of the remaining cuff increases compressive forces on the joint improving stability [21]. A more lateral position of the greater tuberosity increases the abductor lever arm and the wrapping angle of the deltoid [10], which could increase compressive forces [17, 22, 23].

Association of glenoid and humeral lateralization would seem to be the best compromise to achieve a better impingement-free range of motion in abduction, external and internal rotation.

Nevertheless, in a recent biomechanical study, Giles et al. [17] stated that an excessive glenoid lateralization leads to negative effects on joint and muscle loading influencing the long-term success of RTSAs. They [17] suggested that an adequate humeral lateralization, may be a promising method to improve RTSA biomechanics, having positive or neutral effects on deltoid fatigue and acromial fracture, unlike excessive glenoid lateralization. In this paper, humeral lateralization was the only parameter that improved joint and muscle load, whereas lateralization of the glenosphere resulted in increased loads. Therefore, humeral lateralization might be a useful implant method in counteracting some of the negative effects of glenosphere lateralization. However, this should not be considered the only solution for the negative effects of glenosphere lateralization.

Given the results of the double lateralization, which if on the one hand brings advantages in impingement free range of motion, on the other hand, produces controversial results on muscles load; my group recently carried out a clinical study comparing the BIO RSA with 145° curved onlay stem versus Standard RSA with 145° curved onlay stem. At 2 years follow-up, the use of both standard or BIO-RSA in a shoulder implant with an onlay 145° curved stem provided similar outcomes. The humeral lateralization alone is sufficient to decrease scapular notching and improve external rotation [24].

Similar results were also recently found by Werner and Walch [25] in a blueprint software-based study in which the author found that the use of the 135° stem model with 5 mm of glenoid lateralization provided the best results in impingement-free range of motion, except for abduction. A more recent paper from Lädermann and Walch [15] stated that with a 145° onlay humeral stem, a 36 mm inferior eccentric glenosphere theoretically optimizes ROM while limiting scapular notching.

Given the above, the use of glenoid lateralization might be not enough and counterproductive and the direction taken seems to be performing a more advantageous humeral lateralization. Therefore glenoid deficiency and erosion (excessive retroversion/inclination) should be corrected in reverse shoulder arthroplasty (RSA) in order to avoid notching/instability and to maximize function, range of motion, and prosthesis longevity.

In 2017 Boileau and Walch [26] described the results of angled BIO RSA, which predictably corrects glenoid deficiency, including severe (>25°) multiplanar deformity.

In a recent work by Gerber et al. [27], the impossibility of correcting the posterior static

dislocation associated with type B2 glenoids in the setting of primitive arthritis has underlined the role of reverse prostheses also in this type of arthrosis. The correction of the B2 glenoids in this case can be carried out as described by Walch and Boileau using an angled BIO-RSA.

Advantages of using an autograft harvested in situ include: bone stock augmentation, lateralization, low donor-site morbidity, relative low cost, and flexibility needed to simultaneously correct posterior and superior glenoid defects.

27.4 Conclusion

The European contribution to the development and improvement of anatomic and then reverse shoulder arthroplasty has been huge and fundamental. The first prosthetic shoulder arthroplasty performed has widely been ascribed to the French surgeon Jules Emile Pean in 1893.

Currently, the European experience of glenoid lateralization is mainly based on Boileau and Walch's principles. Using of bone allows us to lateralize the center of rotation always, keeping it in the bone–implant interface, thus reducing stress and possible mobilization. However, recently it has been noted that humeral lateralization produces better results than glenoid lateralization regarding impingement free range of motion and scapular notching. Moreover, humeral lateralization favors the deltoid loads and reduces stress on the prosthetic implant. The use of a BIO is to be understood not to excessively lateralize, 5 mm seems to be enough according to Walch, but mainly to correct the deformities occurring in osteoarthritic glenoids. This goal might be reached using an angled BIO RSA.

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28 Lateralized RSA: The US Experience

Prashant Meshram, Edward McFarland, Yingjie Zhou, and Stephen C. Weber

28.1 Introduction

Arthroplasty of the shoulder joint has become established as a predictable, reliable, and reproducible treatment to provide pain relief and improved function for rotator cuff tear arthropathy and numerous other end-stage shoulder diseases. The reverse total shoulder arthroplasty (RTSA) was approved in the United States by the Food and Drug Administration in 2004 for the sole indication in patients with cuff tear arthropathy [1]. The indications for RTSA have now expanded over the years to include not only painful rotator cuff arthropathy but also glenohumeral arthritis with bone loss, rheumatoid arthritis, post-traumatic arthritis, instability, revision arthroplasty, infection, proximal humerus fractures in the elderly, osteonecrosis, and tumors [2]. Accordingly, the number of RTSA in the United States has been increasing every year [3, 4]. RTSA implantation in 2011 was 21,916 procedures and was 24,465 in 2012, which was a 41% increase [3]. In 2013, 30,850 RTSA procedures were performed in the United States, which is close to 34,155 procedures reported for anatomical TSA and nearly three times the 11,180 procedures reported for hemiarthroplasty. The projected RTSA to be performed in 2020 is more than 80,000 [4].

The results of the earliest constrained reverse shoulder arthroplasty systems for cuff tear arthropathy were not encouraging with high complication and implant failure rates [5]. The major cause of failure in these early RTSA designs was glenoid component failure and displacement due to the high shear forces between the glenoid sphere and the surface of the glenoid. One of the key reasons for the success of RTSA was the improvement in the prosthesis design which largely eliminated that problem with baseplate failures. With these changes, RTSA not only was found to successfully treat cuff tear arthropathy but could also successfully treat many other conditions with either abnormal or deficient rotator cuffs by providing patients with pain relief and increased function.

The first major evolutionary change was introduced by Dr. Grammont who improved the success of RTSA by moving the center of rotation (COR) of the glenoid component to more medial COR than that of the normal shoulder (Fig. 28.1). The crucial concept of this design by Dr. Grammont was the medialization of the COR of the glenoid sphere to utilize the deltoid as a lever for elevation. This medialization was intended to convert shear forces across the implant on the

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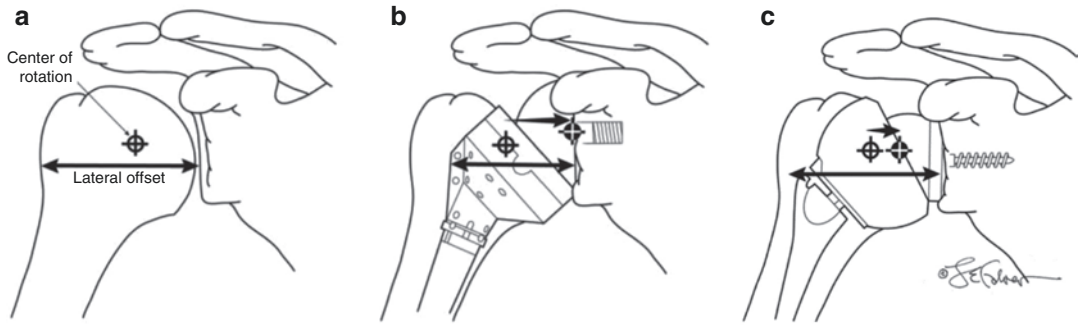

Fig. 28.1 Diagram depicting the change of center of rotation due to different RTSA designs (**a**) Anatomic drawing of a shoulder, depicting the center of rotation (COR) with the bull's-eye and the lateral offset with the *bold arrow*. (**b**) Drawing of a Grammont style RTSA design implanted in a shoulder with demonstrating the medialization of COR, (**c**) A drawing of the lateralized COR 135° neck-shaft angle RTSA design implanted in a shoulder demonstrating the center of rotation and lateral offset to shift medially with respect to the anatomic shoulder still lateral to Grammont's medialized RTSA design. (Reprinted here with permission from Frankle et al. [8])

glenoid surfaces into compressive forces [6]. This change was found to have also resulted in improvements in the postoperative range of motion, and consequently, the functional outcomes. Moving the COR also provided improved stability of the construct and reduced glenoid loosening compared to earlier models [6, 7].

A subsequent significant modification of the design of the RTSA on the glenoid side was initiated in the United States [8]. The change was to move the COR of the glenoid sphere to a less medial position than that of the initial successful designs by Grammont (Fig. 28.1) [8, 9]. This type of prosthesis was called a "lateralized" COR although it actually was just a less medial COR than the successful component design used initially in Europe [8]. As a result, the term "lateralized" COR type of prosthesis is a misnomer as the COR is just "less medial" than the other successful designs. This type of prosthesis with a more lateral COR became the more popular design in the United States over time.

However, the design of the glenoid component is only half of the prosthetic construct of RTSA and from the beginning, the controversy over glenoid COR was simultaneously accompanied by the realization that humeral side design could also significantly affect clinical results. The more medialized COR prosthesis also typically had a humeral component with a more horizontal neck-shaft angle (NSA) of 155° (Fig. 28.2). The prosthesis with a more lateral COR on the glenoid side was accompanied by a humeral component design with a more vertical NSA of 135°. Consequently, the two major competing designs came in two different configurations: one with a more medial COR and an NSA of 155° and another with a less medial or lateralized COR and an NSA of 135°.

The goal of this chapter is to discuss the experience in the United States with RTSA prosthesis with a more lateralized COR. The rationale for the use of a more lateralized RTSA design will be discussed, and the clinical implication and results will be reviewed and compared to RTSA with more medial COR. This chapter will also address the biomechanical rationale and clinical results with inlay versus onlay humeral components as they relate to the more medial or more lateral COR RTSA designs.

28.2 Rationale of Lateralized RTSA

The initial high complication rates of a prosthesis with a medialized COR and NSA of 155° were concerning for patients and clinicians alike. Early studies of the complication rates of medial COR prosthesis varied from 0% to 80% [6, 10]. The major complications included notching of the scapular neck inferior to the baseplate, base-

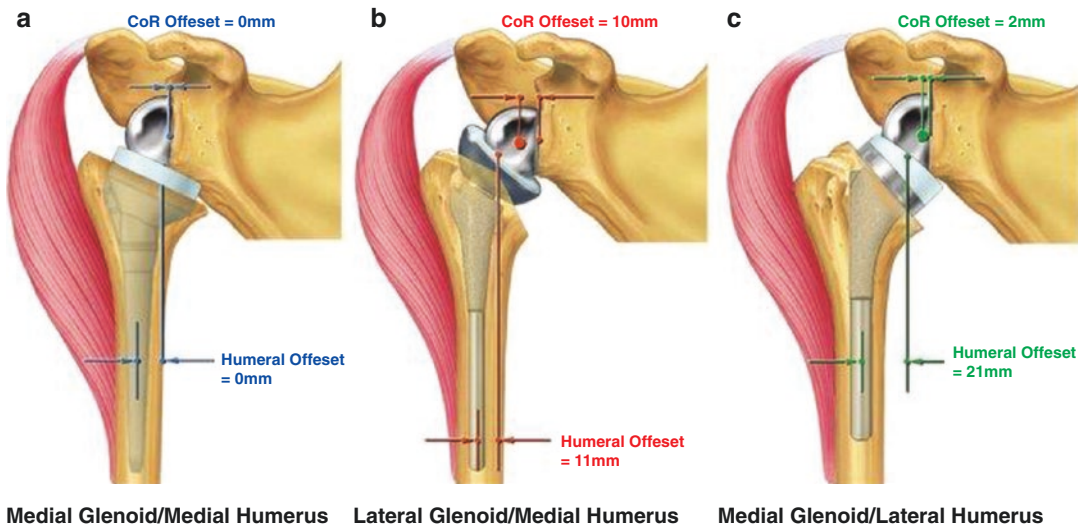

Fig. 28.2 The difference in the center of rotation and humeral offset associated with different prosthesis designs. Medialized glenosphere and 155° neck-shaft angle in Grammont's prosthesis (**a**), lateralized glenosphere with 135° neck-shaft angle and an inlay prosthesis popularized in the United States (**b**), and medialized glenoid with increased humeral offset using onlay prosthesis (**c**). (Reprinted with permission from Routman et al. [3])

plate failure, dislocation of the prosthesis, nerve injury, loss of range of motion, acromial or scapula fractures, and long-term loosening of the components [6, 11]. Despite the overwhelming number and frequency of complications, patients often had significant pain relief and improvement in function [6, 7]. Long-term studies of more medial COR prosthesis and 155° NSA have reflected the relationship of this design combination on long-term clinical results. Gerber et al. in their series of 22 patients with a minimum follow-up of 15 years in patients with a Grammont prosthesis with a more medial COR, and 155°NSA showed an overall complication rate of 59%, reoperation in 55% of patients due to any cause, and a failure requiring revision in 27% of the original cohort [12].

The rationale of advocating the use of lateralized RTSA to avoid scapular notching is rather controversial [13]. Some studies suggested that scapula notching is an incidental finding that does not affect clinical outcomes and occasionally represents osteophyte formation rather than true erosion [7, 14–17]. In contrast, there are indications that scapular notching after RTSA can lead to osteolysis, chronic inflammation, and, ultimately, and implant loosening [18]. There are few studies that suggest inferior clinical outcomes with a higher grade of scapular notching [19–22]. For this reason, there was increased interest in the concept of lateralized RTSA with the aim of decreasing notching and baseplate loosening. This was postulated to lead to improvements in range of motion, functional outcomes, and implant survival [9].

Subsequently, modifications in surgical technique and design changes in RTSA were made to address notching and instability of RTSA constructs. There are three options for lateralization of the COR of RTSA on the glenoid side. The first is bone graft between the baseplate and native glenoid using Grammont prosthesis (BIO-RSA) and the second is by using augmented glenoid components. The third is to utilize a glenosphere with more lateral offset compared to the more medialized components. On the humeral side, the options for lateralization of the construct by increasing humeral offset include using a more anatomical 135° NSA stem or using an onlay humeral tray.

The lateralization of the glenoid component using bone graft (Bio RTSA) has shown similar functional outcomes and rate of scapular notching as the medialized RTSA [23, 24]. However,

concerns with Bio-RTSA include failure of bone graft incorporation, a high rate of a scapular stress fracture, and technical challenges of performing this procedure, especially when facing variable glenoid deformations [25–27]. Another way to lateralize the RTSA on the glenoid side has been to use glenoid baseplates which have metal augments to make up for the glenoid bone loss. Thus, far at short-term follow-up, the use of these augmented glenoid trays has shown similar or better clinical outcomes and less notching than constructs using BIO-RSA [28, 29]. However, concerns of the use of these augmented glenoid trays include lack of long-term clinical outcomes, higher implant cost, ease of prosthesis availability, and failure at articulations of the modular components [30].

Another way proposed to lateralize RTSA is the use of lateral offset glenosphere, which has been popularized in the United States (Fig. 28.2). This design modification was accompanied by a decrease in humeral NSA to 135° instead of the conventional 155° found in Grammont prosthesis. The first aim of these changes was to prevent impingement of the prosthesis on the scapula with the arm in adduction and thereby prevent scapular notching [31]. The second goal was to restore the anatomic placement of the humerus to improve the tensioning of the deltoid and remaining rotator cuff muscles and hence provide for the restoration of strength and improve shoulder motion, especially external rotation [9]. The third was to create a compressive force by the deltoid upon the construct to decrease the dislocation issue with the Grammont type of RTSA [32]. Finally, a more vertical NSA was proposed to provide a better range of motion by preventing contact of the humeral side upon the glenoid rim or other portions of the scapula and further reduce scapular notching [31, 33].

There were several studies that evaluated the effect of lateralization of the sphere COR on biomechanical performance of RTSA. Gutiérrez et al. using saw bone models reported that the greatest impingement-free abduction was found with a lateralized glenosphere with 10 mm offset [33]. They also found a positive linear correlation between abduction range of motion and a more lateral center of rotation offset relative to the glenoid. Another biomechanical study using computer-simulated bone models found that the largest average increase in the range of impingement-free abduction resulted when changing from a medialized glenosphere (0 mm offset) to a lateralized one (10 mm offset) [31]. Berhouet et al. in a cadaveric study reported inferior scapular notching can be most effectively prevented by using large-diameter glenosphere with lateralized COR [34]. They also found that internal and external range of motion were maximized with a 42-size glenosphere and 10 mm lateral offset when compared to a smaller size glenosphere with less than 10-mm lateral offset less. Similarly, Virani et al. found that that a lateralized COR using a glenosphere with a 10 mm offset provided the greatest degree of motion in all planes compared to a medialized COR provided by 0 mm offset [35].

The method of increasing the humeral offset in the prosthesis design to improve range of motion and avoid adduction impingement has been controversial. To increase humeral offset, proponents of lateralized RTSA in the United States proposed using a 135° varus angle, whereas European counterparts proposed an onlay humeral cup position design and a less varus 145° NSA prosthesis.

Biomechanical studies have evaluated the combined effect of increasing the humeral offset with a varus humeral NSA which was a more common design in the United States. Among the five factors studied by Gutiérrez et al., which decreased impingement of the component in adduction, the largest effect was provided by changing the humeral NSA from 155° to 130° [31]. The next most important factor found was inferior placement of the glenoid baseplate so that the sphere covered the inferior glenoid. The next most important factor was using a 10-mm lateralized glenosphere instead of a medialized one. The final factors included inferiorly tilting the glenosphere and lastly by using a larger glenosphere size [31]. Another biomechanical study by Virani et al. using computer modeling found that a valgus humeral component would maximize the motion in abduction, whereas a varus

humeral component provided more motion in flexion/extension. De Wilde et al. in another computer modeling study showed that a reduction in the humeral NSA from 155° to 145° resulted in a gain of 10° in impingement-free adduction [36]. Werner et al. studying various component configurations in computer model study reported that changing the humeral NSA demonstrated the most important influence on impingement-free adduction, extension, and internal and external rotation, They also found that glenoid COR lateralization had more effect on abduction and forward flexion [37].

The position of the humeral tray has also been suggested in biomechanical studies to influence the range of motion of RTSA in vitro. The position of the humeral tray has been described as "inlay," where it is recessed somewhat in the proximal humerus, or "onlay," where the tray rests more prominently on the humeral stem (Fig. 28.2). The position of humeral tray in traditional Grammont design was an inlay where in metaphyseal bone was reamed to allow the metal humeral cup to have more bone contact and bony in growth. The lateralized RTSA design popularized in the United States continued to use the inlay humeral insert design in favor of improved humeral stem fixation (Fig. 28.2). In contrast, the proponents of medialized COR design introduced an onlay humeral tray design that would increase the humeral offset and thereby improve range of motion. With onlay humeral tray design, the humeral metal cup would sit on the humeral metaphysis without reaming (Fig. 28.2).

However, biomechanical studies have not demonstrated improvement in the range of motion only with the use of onlay humeral tray position. Virani et al. using a computer simulation model did not find any difference in range of motion and adduction deficit between onlay and inlay humeral side designs [35]. Ladermann et al. in a biomechanical study using computer modeling reported that compared to the inlay design, the onlay humeral design with the same humeral NSA increased humeral offset by 7 mm [38]. Using onlay design with 155° NSA, they found that abduction decreased by 10° with minimal improvement in other range of motions (5° increase in adduction, 3° increase in flexion, 4° increase in external rotation) when compared to an inlay design. They also reported that with an onlay humerus tray, changing the humeral inclination from 145° to 135° improved adduction by 15°; however, abduction was reduced by 6° due to contact either between the superior polyethylene and the glenoid or between the acromion and the greater tuberosity [38]. Consequently, the authors proposed using an onlay 145° NSA with a curved stem design instead of 135° for optimal range of motion currently popularized in Europe. These modeling studies suggest that RTSA designs with an onlay humeral tray position have advantages which include (1) preserving tuberosity bone stock, (2) decrease the risk of greater tuberosity fracture, (3) preservation of the remaining rotator cuff insertion, (4) optimizing the ease of insertion of the components, and (5) preserved metaphyseal stability. Despite these proposed advantages, these modeling studies do not account for soft-tissue tension or the mechanical advantage of the deltoid with different degrees of arm lengthening. As a result, these suggested advantages have not been established by clinical studies.

28.3 Issues with Early Lateralized RTSA Designs

The first published report upon an RTSA design with a lateralized glenoid COR RTSA with an accompanying 135° NSA was by Frankle et al. in 2005 [8]. They reported upon 60 patients with glenohumeral arthritis associated with rotator cuff deficiency at minimum 2-year follow-up. They reported that this cohort had excellent clinical outcomes with RTSA, and there were no cases of scapular notching [8]. However, of the 60 patients, they reported 7 (12%) patients had baseplate failure. Subsequent studies found these early lateralized RTSA designs had concern for complications, such as baseplate failure (12.8%), dissociation of the glenosphere from baseplate (1.3%), humeral socket dissociation from humeral stem (2.1%), and high revision rate (13%) [8, 39]. Due to the high rate of these

complications the lateralized COR design subsequently underwent several modifications aimed at decreasing these complications [40].

The first modification was to change the peripheral baseplate screws from non-locking to locking to increase the rigidity of the baseplate fixation and to reduce baseplate failure. This change was based on a previous biomechanical study, which showed that the addition of locking screws reduces baseplate micromotion [41]. The incidence of baseplate failure of 12.8% with non-locking screws was reduced to 0.3% after introducing locking screws [39, 42]. A second change in the lateralized RTSA design was the replacement of humeral sockets previously made entirely of polyethylene to a metal metaphyseal shell with a polyethylene insert. This change was made as metal metaphyseal shells were felt to be able to withstand increasing stress. The rate of humeral socket dissociation subsequently was reduced from 2.1% to 0.2% at a minimum follow-up of 2 years [39]. Another modification was the use of a monoblock humeral stem to reduce the humeral stem mechanical failure in patients with a lack of bone support in the proximal humerus. The addition of the monoblock stem option was based on a biomechanical study, which showed that non-modular cemented humeral components can withstand greater loads before failure when compared to modular humeral components [43]. The third change in prosthesis design was to introduce a central hole in the glenosphere for an inserter device. This would allow the surgeon to confirm the glenoid to baseplate taper engagement intraoperatively. This design also used this hole to place a screw to lock the glenosphere to the baseplate. As a result, the glenosphere dissociation was reduced from 1.3% with earlier designs to 0.3% after the glenosphere modifications [39].

28.4 Clinical Results

Since the first decade of the twenty-first century, there has been a significant increase in publications on the use of RTSA not only for cuff tear arthropathy but also for a variety of conditions that previously could not be successfully addressed. Similarly, the clinical results of the various designs of RTSA have been extensively reported. Unfortunately, there are no prospective, randomized trials comparing a design with a lateral COR to those with a more medial COR. Most of the clinical studies are of one RTSA design or another and none comparing the two designs are prospective (Table 28.1). There are also a myriad of design differences in the glenoid side and the humeral side among different systems that make a direct comparison of results difficult. The most important variables that will be discussed here include the COR of the glenoid component, the NSA of the humeral component, and whether the metaphyseal component on the humeral side is inlay or onlay.

Subsequent studies of the results of a prosthesis with a more lateral COR and an NSA of 135° showed considerable improvement over the initial designs (Table 28.1). In 2008, Cuff et al. reported upon the clinical results of lateralized RTSA with 135° NSA in 96 shoulders with cuff tear arthropathy (CTA) at a minimum 2 years follow-up [44]. The clinical outcome scores were favorable in 86 (94%) patients with a prosthesis survival rate of 97% at short-term follow-up. There were no complications related to mechanical failure of the implants, and none of the patients had scapula notching at 2-year follow-up. A subsequent study of 76 patients of the same cohort at a minimum of 5-year follow-up showed that the good clinical outcomes were maintained with a 94% prosthesis survival rate [45]. At a minimum of 5-year follow-up, seven (9%) patients showed grade 1 scapular notching according to the criteria of Sirveaux et al. [20]. There were no reports of baseplate failure but two (3%) patients had humeral loosening. Finally, follow-up of the original cohort at a minimum of 10 years in 42 patients maintained good clinical outcome scores with a 91% survival rate of the prosthesis [46]. Of the total reoperations done over a period of 10 years in the original 96 shoulders of this series, four were done for dislocation, one was for humeral loosening, one for resorption of proximal humeral allograft in a patient of failed previous arthroplasty, and one for

Table 28.1 Outcomes of lateralized RTSA prosthesis for cuff tear arthropathy

Study	Prosthesis	Number of patients	Indication	Mean follow up in months (range)	Mean values of clinical outcomes				Complications	Survival rate
Cuff et al. 2017 [46]	Reverse shoulder prosthesis (DJO)	40 patients (42 shoulders)	GHOA with RCT: 19 (45.2%), Previous failed rotator cuff operations 13 shoulders (31.0%), Failed arthroplasty and cuff deficiency 10 shoulders (23.8%)	132 (120–147)		Preoperative	Postoperative	*P* value	Scapular notching 6/40 (15%) Instability[a] 4/94 (4%) Resorption of proximal humeral allograft[a]:1/94 Periprosthetic fracture[a]:1/94 Humeral radiolucency[a]: 1/94 Scapula spine fracture[a]: 1/94	91%
					ASES	35	74	<0.001		
					SST	2	7	<0.001		
					FF	70°	126°	<0.001		
					Abduction	65°	117 °	<0.001		
					ER	18 °	40°	<0.001		
Mulieri, et al. 2010 [47]	Reverse shoulder prosthesis (DJO)	58	Irreparable RCT without GHOA	52 (24–101)		Preoperative	Postoperative	*P* value	Scapular notching 7 (12%) Baseplate failure[b]: 4 (7%) Periprosthetic fracture: 4 (7%) Deep infection: 1 (1.7%) Instability: 1 (1.7%) Broken center screw: 1 (1.7%) Hematoma: 1 (1.7%)	91%
					Pain VAS	6.3	1.9	<0.001		
					ASES	33	75	<0.001		
					SST	1.6	6.5	<0.001		
					FF	53°	134°	<0.001		
					Abduction	49°	125°	<0.001		
					ER	27°	51°	<0.001		
Sanchez-Sotelo, et al. [48]	ReUnion RSA (Stryker)	90	CTA: 13, irreparable RCT: 39, GHOA: 32, Dislocation arthropathy: 1, Proximal humerus nonunion: 2, AVN: 1, RA: 2	Minimum 2 years		Preoperative	Postoperative	*P* value	Scapular notching 0 Total complications: 8 (8.8%) Deep infection: 2 Periprosthetic humeral fracture: 1 Glenoid erosion:1 Acromion fracture: 1 Scapula spine fracture: 1 Hematoma:2	96%
					ASES	Not mentioned	77	Not mentioned		
					Elevation	98	131	Not mentioned		
					FF	78	132	Not mentioned		
					ER	34	46	Not mentioned		

(continued)

Table 28.1 (continued)

Study	Prosthesis	Number of patients	Indication	Mean follow up in months (range)	Mean values of clinical outcomes				Complications	Survival rate
Gobezie et al. 2019 [52]	Univers revers (135° vs. 155° neck shaft angle)	135° group: 37 155° group: 31	CTA	38 (29–45)		135° group	155° group	*P* value	135° group: Scapula notching: 77% Polyethylene disassociation: 1.7% Symptomatic acromial fracture: 1.7% Recurrent instability: 1.7% 155° group: Scapula notching: 47% Recurrent dislocation: 1.7% Glenosphere disassociation: 1.7% Deep infection: 1.7%	135° group: 96.6% 155° group: 87% (*P* = N.S.)
					VAS	2	1	NS		
					ASES	74	78	NS		
					SANE	74	76	NS		
					SST	8	7	NS		
					FF	132°	135°	NS		
					ER	29°	30°	NS		
Huri et al. 2016 [49]	Lateralized RTSA: Encore/ DJO prosthesis Medialized RTSA: Grammont-type prosthesis.	Lateralized RTSA: 56 Medialized RTSA: 44	CTA, GHOA with RCT, or GHOA with glenoid bone loss	35 (24–66)	NA				Lateralized RTSA: Scapula notching: 23% Dislocation: 0% Medialized RTSA: Scapula notching: 72% Dislocation: 17%	NA
Kempton et al. 2011 [50]	Lateralized RTSA: Zimmer trabecular metal reverse prosthesis Medialized RTSA: Grammont type prosthesis	Lateralized RTSA: 28, Medialized RTSA: 37	CTA 29, irreparable RCT 15, failed humeral head resurfacing arthroplasties 11, GHOS with RCT: 6, RA 3, and proximal humerus fracture malunion 1	20 (12–35)	NA				Scapular notching: Lateralized RTSA (16%), medialized RTSA (61%), *P* = 0.003	Both groups 100%

Kennon et al. 2020 [51]	Lateralized RTSA: Encore/ DJO prosthesis. Medialized RTSA: Delta III prosthesis	Lateralized RTSA: 47 Medialized RTSA: 18	CTA, sequalae of proximal humeral fractures, post-traumatic arthritis, AVN	87 (25–161)		Lateralized RTSA	Medialized RTSA		Lateralized RTSA: Scapula notching: 47% Dislocation: 1.7% Glenosphere disassociation: 1.7% Deep infection: 1.7% Medialized RTSA: Scapula notching: 77% Polyethylene disassociation: 1.7% Symptomatic acromial fracture: 1.7% Recurrent instability: 1.7	Lateralized RTSA: 8%, M group 5%
					ASES	69	73	NS		
					FF	115°	144°	0.002		
					ER	39°	50°	NS		
Merolla et al. 2018 [53]	Onlay RTSA: Ascend flex. Inlay RTSA: Aequalis II	Onlay RTSA: 38 Inlay RTSA: 36	Cuff tear arthropathy	68 patients (74 shoulders)		Onlay RTSA	Inlay RTSA		Onlay RTSA: Scapula notching: 5% Acromial fracture: 2.6% Scapula spine fracture: 5% Dislocation: 2.6% Inlay RTSA: Scapula notching: 39% Dislocation/instability:8%	Onlay RTSA: 5%, Inlay RTSA: 0%
					Pain VAS	0.8	0.9	NS		
					Constant score	71.2	69.6	NS		
					FF	142	142	NS		
					Abduction	131	131	NS		
					ER	32	30	NS		

GHOA glenohumeral osteoarthritis, *CTA* cuff tear arthropathy, *RCT* rotator cuff tear, *RTSA* reverse total shoulder arthroplasty, *AVN* avascular necrosis, *ASES* American Shoulder and Elbow Surgeons, *ER* external rotation, *FF* forward flexion, *SST* Simple Shoulder Test, *SANE* single assessment numeric evaluation, *VAS* visual analog scale, *NS* Not significant

[a]Indicates the incidence of instability in the whole initial cohort of 94 patients of this longitudinal study reported at 2, 5, and 10 years.

[b]All four baseplate failures were seen in patients with early prosthesis design before the screws were replaced from non-locking to locking.

periprosthetic fracture [46]. The overall incidence of notching at the last follow-up was 15% (6 of 40 patients). The authors retrospectively evaluated when notching began after the initial implantation and found that the average onset radiographically was 49 months (range, 25.7–115.3 months). Interestingly, between the 5- and 10-year studies, the authors noticed a decrease in shoulder motion in all planes which they attributed to advancing age of the patients.

Mulieri et al. reported the results of lateralized COR RTSA done for irreparable rotator cuff tear without glenohumeral arthritis in 58 patients and also found improvements in functional outcomes and range of motion at a mean follow-up of 52 months [47]. In this cohort, there were 12 (20%) complications with survivorship of 90.7% at a mean of 52 months. There was baseplate loosening in four (7%) patients which they attributed to the use of an older design with non-locking screws. Scapular notching was found in only 7 (13.5%) patients.

Sanchez-Sotelo et al. reported the clinical results of a newer RTSA design with features of lateralized COR with 135° NSA and onlay design humeral tray position at a minimum follow-up of 2 years [48]. Of 90 reported patients, the indication for surgery was cuff tear arthropathy in 13 (14%), massive irreparable cuff tear in 39 (43%), primary osteoarthritis with severe bone loss in 32 (36%), and other diagnoses in 6 (7%). The clinical outcomes and range of motion improved in all patients. There was no scapular notching or dislocation. Four patients needed revision surgery with two (2%) for infection, one for periprosthetic fracture (1%), and one for glenoid loosening (1%).

There are several retrospective studies that compare a more medial COR with 155° NSA RTSA with RTSA having a more lateral COR, and an NSA of 135° demonstrated the difference in complication rates. Huri et al. reported a retrospective comparative study between lateralized COR RTSA with 135° NSA against medialized COR Grammont prosthesis with 155° NSA [49]. Of 65 RTSA studied, the incidence of scapular notching in lateralized RTSA (11 of 47 RTSA; 23%) was significantly lower than medialized RTSA (13 of 18 RTSA; 72%). The incidence of instability was less in lateralized RTSA (0 of 47 RTSA; 0%) when compared to the medialized group (3 of 18 RTSA; 17%). Kempton et al. compared 65 patients with either a 2.5-mm lateralized COR or 143° NSA RTSA with conventional Grammont prosthesis at a minimum of 1-year follow-up [50]. The rate of scapula notching was lower in the lateralized group (16%) compared to the medialized Grammont prosthesis (61%). None of the patients in the study had instability or dislocations. Kennon et al. reported a retrospective comparative study of medialized 155° prosthesis to a lateralized 135° prosthesis in one institute [51]. In a subgroup of patients with a minimum 7-year follow-up (mean 10.2 years), they found similar functional outcomes in the two different RTSA designs. While the medialized RTSA group had better mean active elevation (157° vs. 119°) and external rotation (50° vs. 39°) compared to lateralized RTSA group, these differences were not statistically significant. The rate of notching at a minimum of 2-years follow-up was higher in the medialized RTSA group (77%) compared to lateralized group prosthesis (47%; $P = 0.013$). They also found that there was a clinically relevant higher rate of severe notching (grades 3 and 4) between the two groups with 23% in the 155° NSA and medial COR group compared to 9% in the 135° NSA and more lateral COR group, but this difference did not reach statistical significance. The 10-year cumulative incidence of reoperation was 5% in the medialized COR prosthesis and 8% in lateralized COR group. The incidence of glenoid component loosening in lateralized COR prosthesis was 3.1% and medialized COR RTSA was 2.3% with no statistically significant difference between the two groups ($P = 0.82$). The 10-year cumulative incidence of complications of 14% in the 155° prosthesis and 20% in lateralized group, but this was not found to be statistically different.

The only randomized controlled study published to date was by Gobezie et al. who prospectively compared using an RTSA system that allowed for using either a 155° or a 135° humeral NSA [52]. The glenoid side COR was kept constant, and the patients were randomized to one of

the two available NSAs. At a follow-up of 29–45 months, they found that in the 37 patients with a 135° NSA and the 31 patients with a 155° NSA, the functional outcomes and the final range of motion were not statistically different. There were no cases of baseplate loosening in either group. There was a statistically significantly ($p = 0.009$) increased rate of scapular notching in the 155° group (58%) than in the 135° group (21%). Of 37 patients in the 135° group, 1 (2.7%) patient had dislocation whereas 2 (6.4%) of the 31patients had a dislocation in the 155° group.

The clinical studies comparing onlay versus inlay humeral designs as far as they influence results of RTSA, and other design characteristics are limited. Merolla et al. compared the clinical and radiographic outcomes of 68 patients who had undergone RTSA with either a 155° inlay Grammont prosthesis design or a curved stem onlay with a 145° NSA at a minimum 2-year follow-up [53]. Twenty of the 38 patients in the onlay group had a lateralized glenoid with BIO-RSA. The functional improvements were similar to both designs, but patients with the onlay design had statistically significantly greater improvements in external rotation. The rate of scapular notching was 5% in onlay design group compared to 39% in the inlay design group, and this difference was statistically significant. The clinical outcomes in subgroup comparison of patients with onlay prosthesis with or without glenoid bone grafting did not show any statistically significant difference whether there was lateralization of the baseplate with bone grafting or not. A prospective study of 42 patients compared patients with inlay Grammont design with a 155° NSA to a group to an onlay prosthesis with 145° NSA [54]. At 1-year follow-up, the onlay-145° group had statistically significant functional and clinical results than the inlay-155° group at 1-year follow-up. Another retrospective review of 109 patients reported a trend toward a higher rate of acromial fractures among patients with an onlay (12%) as opposed to inlay (4%) system [55]. It was hypothesized that the increased acromiohumeral distance with onlay design might cause fractures due to acromial impingement during abduction [38]. In summary, onlay prosthesis have shown good clinical outcomes including range of motion compared to inlay-type prosthesis. The relationship of inlay and onlay with a prosthesis with more medial or lateral COR needs longer term follow-up to determine the effect of these designs upon the performance of RTSA.

Systematic reviews have supported the lower rate of notching in RTSA systems with a lateral COR and a 135° NSA design as compared to a medialized RTSA design with 155° NSA. Despite these studies, comparing the other complications and clinical outcomes for the two different designs has produced conflicting results [56–59]. A systematic review and meta-analysis of 32 studies published between 1985 to June 2012 included 2,049 patients with a minimum 2-year follow-up and compared clinical outcomes between lateralized and medialized COR RTSA designs [57]. Notably, the indication for RTSA included patients with cuff tear arthropathy, massive cuff tear, primary osteoarthritis with degenerative cuff tear, failed rotator cuff repair, fracture sequelae, rheumatoid arthritis, posttraumatic osteoarthritis, revision of TSA, and revision of RTSA. This study found that lateralized COR design (22.9°) when compared to medialized COR design (5°) had a statistically significant improvement in mean external rotation. They also found a statistically significant difference in the improvement in the American Shoulder and Elbow Surgeons score in lateralized COR design (37.7 points) when compared to medialized COR design (17 points). The second part of this meta-analysis with 37 studies published between 1985 and June 2012 included 3,150 patients with a minimum 2-year follow-up and compared complications and revision rates between lateralized and medialized COR RTSA designs [58]. They found that lateralized COR design had a statistically significant lower rate of scapula notching (43.8% vs. 4.6%) when compared to medialized COR design. They also found that lateralized COR design had a statistically significant higher rate of glenoid component loosening (4.6% vs. 1.8%) and revision (10.5% vs. 5.6%) when compared to medialized COR design. The authors noted that the difference in glenoid loosening

between the two groups may be due to the inclusion of studies with early lateralized RTSA designs that were associated with high baseplate failure. In contrast, no studies with older designs of medialized RTSA prostheses were included in this meta-analysis.

Lawrence et al. [59] reported a systematic review of 13 studies published between 2005 and July 2014 comparing outcomes and complications of lateralized RTSA with 135° NSA to medialized RTSA with 155° NSA. The indications for RTSA in the patients of included studies were cuff tear arthropathy and massive irreparable rotator cuff tears. They found that the frequency-weighted mean active external rotation was more in lateralized RTSA group (46° vs. 24°, $p = 0.0001$) when compared to the medialized RTSA group. Scapular notching was lower in lateralized RTSA group (5% vs. 45%, $p = 0.0001$) when compared to the medialized RTSA group. Glenoid loosening was higher in lateralized RTSA group (8.8% vs. 1.8%, $p = 0.003$) when compared to the medialized RTSA group. Notably, all the cases of glenoid loosening in the lateralized RTSA group were associated with an earlier design of lateralized RTSA. The dislocation rate was lower in lateralized RTSA group (0.7% vs. 2.6%, $p = 0.26$), but this difference was not statistically significant. The overall reoperation rate was not statistically significant in between the lateralized RTSA group (10.4%) and medialized RTSA group (7.1%) at a mean follow-up of 47 months.

Erickson et al. in a systematic review of 38 studies and 2222 shoulders compared the results of two prosthesis designs of 135° versus 155° NSA. They reported significantly higher rates of scapular notching in the medialized RTSA group (16.8% vs. 2.8%) compared to the lateralized RTSA. However, they found no difference in dislocation rates between the two different RTSA designs [56]. The 135° group demonstrated significantly more postoperative external rotation with the arm at side (33° vs. 23°, $P = 0.0007$) than the 155° group while forward flexion was similar between both the groups (119° vs. 125.5°, $P = 0.22$). Like many systematic reviews, studies included in the review used a variety of different implant systems and only focused on the NSA of the implants. Other design characteristics such as the center of rotation and amount of lateralization of the glenoid and humerus were not specifically addressed in these reviews. Another systematic review by Ernstbrunner et al. focused on longitudinal outcomes of RTSA noted that statistically significant improvement in external rotation at 5- and 10-year follow-up was reported only in those studies that used a lateralized COR RTSA as opposed to no significant improvement in studies which reported long-term outcomes of medialized COR RTSA [60]. However, they did not compare the clinical outcomes, survival rate, or incidence of complications between lateralized COR RTSA and medialized COR RTSA.

28.5 Current Challenges

Over the past 20 years, RTSA has proven to be an amazing advancement in treating cuff tear arthropathy and other conditions, where rotator cuff deficiency could previously not be treated with traditional anatomical TSA. The complication rate after 9 years of experience decreased from 19% to 10.8%, and the revision rate decreased from 7.5% to 5% [61]. Overall revision rate in the early lateralized RTSA designs of 12% at minimum 2-year follow-up has reduced to 3% with more recent designs [8, 44]. Despite advances in lateralized RTSA design, high complication rates and limited clinical improvement still remain concerning [62]. Thus far, the rate of scapula notching with lateralized RTSA is lower than that of medialized RTSA. However, this complication is still reported to be in the range of 21–47% in some clinical studies [51, 52]. Furthermore, conflicting results of improvement in range of motion after medialized and lateralized RTSA in comparative clinical studies needs further study [51, 52, 56]. While long-term studies at 10–15 years show survival rates of 84–91%, longer term follow-up will be necessary for guiding patients and surgeons in their decision-making [12, 46]. Long-term studies comparing medialized and lateralized RTSA designs are

needed to improve our understanding of the clinical results of these prostheses. Apart from center of rotation of prosthesis, other factors such as the surgeon's experience, positioning of glenoid baseplate, and glenoid inclination should be taken into account in clinical practice and research purposes. Additionally, surgeons should be vigilant about patient factors such as osteoporosis, medical comorbidities, and patient expectations which may influence the results of RTSA surgery [63, 64].

28.6 Conclusion

The high complication rates associated with initial lateralized RTSA designs have substantially reduced over time. The decreased complication rates and improved clinical outcomes after lateralized RTSA design may be a result of the COR but also is a result of the 135° NSA. The comparative studies do not establish the superiority of lateralized RTSA over medialized RTSA or for prosthesis with either 155° or 135° NSAs. The prosthesis selection in the treatment of patients should be judged based on benefits and risks associated with the prosthesis along with patient parameters and surgeon's experience.

Conflict of Interest *Disclaimer*: None.

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Part V

Complications

29 Complications of Managing the Failed Rotator Cuff Repair

William N. Levine and Matthew J. J. Anderson

29.1 Complications of Revision Rotator Cuff Repair

The complication rate following revision rotator cuff repair (RCR) varies significantly by study, in large part due to differing definitions of retear and discrepancies in reporting. Many studies only consider rates of symptomatic failure and reoperation, while neglecting important postoperative outcomes such as shoulder stiffness, infection, nerve injury, chondrolysis, venous thromboembolism, and persistent pain [1–4]. Parnes et al. performed revision arthroscopic rotator cuff repair (ARCR) in 94 patients and reported the occurrence of any postoperative event or condition that required additional treatment. The overall complication rate was 20%, which included failure to heal (10.6%), stiffness (7.4%), infection (2.1%), and nerve injury (1.1%) [2]. By comparison, the complication rate after primary ARCR is approximately 11% [2, 5, 6]. Interestingly, Parnes et al. observed a direct correlation between the complication rate and the number of revision ARCR procedures: 14% after one revision, 17% after two, 33% after three, and 50% after four or more [2].

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Failure of RCR can occur via tendon retear, at the tendon-suture interface, or at the bone-implant interface. Although the clinical significance of retear remains controversial [7], Shamsudin et al. found a significantly higher retear rate following revision ARCR compared to primary ARCR at both 6 months and 2 years (28% vs. 16% at 6 months and 40% vs. 21% at 2 years, respectively.) [8]. In terms of reoperation after failed revision RCR, Piasecki et al. observed a reoperation rate of 11.1% at a mean follow-up of 2.6 years after revision ARCR and concluded that a history of more than one prior ipsilateral shoulder surgery was a significant risk factor for failure requiring reoperation [9]. Lädermann et al. compared revision ARCR for non-massive and massive tears and found no difference in reoperation rates (10% vs. 8%, respectively) [3]. Notably, no postoperative infections or instances of hardware failure were noted in either group at a mean follow-up of 5.3 years [3].

Several options exist for augmentation and interposition grafting in the setting of revision RCR, including autograft, allograft, xenograft, and synthetic material. Although the use of grafts does not appear to be associated with increased complication rates [10–12], data are limited. Bailey et al. performed a meta-analysis comparing outcomes of RCR with graft augmentation or interposition versus RCR alone and found a significantly lower retear rate with graft augmentation or interposition. However,

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complications rates were not considered in this study [13]. Among 24 patients who underwent ARCR with fascia lata autograft interposition, Mori et al. observed an 8.3% retear rate and no complications at a mean follow-up of 3 years [11]. Similarly, acellular human dermal matrix allograft has been used for both RCR augmentation and interposition grafting in the setting of primary and revision RCR with no noted complications at a minimum follow-up of 2 years [10, 14].

Despite low overall complication rates, a few specific complications associated with graft augmentation and interposition merit further discussion. Xenografts and synthetic grafts, in particular, may elicit a foreign body response and host intolerance, which can mimic and/or potentially lead to infection [15–17]. In a study of open RCR with porcine small intestine submucosal patch augmentation, three patients (20%) developed infectious symptoms (shoulder swelling, erythema, pain, and/or drainage) 3–6 weeks postoperatively [16]. One patient underwent open irrigation and debridement with no evidence of infection but complete disruption of the rotator cuff repair. Cultures for this patient were negative for bacterial growth, and tissue pathology demonstrated acute inflammation. The patient improved with a week of empiric antibiotics. A second patient had the subacromial space of the affected shoulder aspirated and was started on oral antibiotics, which were later discontinued after final culture results were negative. Symptoms resolved in the third patient without intervention [16]. Similarly, Ranebo et al. reported on 12 patients who underwent open rotator cuff repair with a synthetic interposition graft, ten of whom had undergone previous ipsilateral shoulder surgery. Four patients experienced transient postoperative fevers, two of whom received antibiotics, but none had verified infections [15]. The use of autograft eliminates the potential for a foreign body response but can result in harvest site morbidity. Autograft biceps tendon interposition grafting, for instance, can lead to a Popeye deformity, though the incidence is low (3–6%) [18, 19].

29.2 Complications of Arthroscopic Superior Capsular Reconstruction

The reported complication rate following arthroscopic superior capsular reconstruction (ASCR) is 0–8% and comparable to that of arthroscopic rotator cuff repair alone [20, 21]. In addition to those complications inherent to all arthroscopic shoulder procedures (e.g., infection, shoulder stiffness), common complications after ASCR include suture anchor pullout and graft tear. In a study of 100 patients who underwent ASCR with fascia lata autograft, Mihata et al. observed suture anchor pullout in four patients, all of whom underwent subsequent reoperation for suture anchor removal. Four additional patients required reoperation for infection (two) and shoulder contracture (two), for an overall reoperation rate of 8% at an average follow-up of 48 months [22]. The overall incidence of graft failure varies significantly by study, with a range of 3.4–36.1% [22–26]. Graft failure tends to occur most often at the lateral anchors [21].

29.3 Complications of Subacromial Balloon Spacer Implantation

There is scant literature regarding complications following implantation of a subacromial balloon spacer for massive irreparable rotator cuff tears. Stewart et al. performed a systematic review that included 291 shoulders in 284 patients and found an overall complication rate of 2.1%, which included transient neurapraxia of the lateral antebrachial cutaneous nerve, superficial and deep wound infections, and balloon migration [27]. Notably, two of the three patients who experienced balloon migration required reoperation for balloon removal [28–30]. Balloon migration has been observed in the anterior, posterior, and cranial directions (Fig. 29.1), [31] and maybe the result of overaggressive subacromial bursectomy [32]. The implantation of a subacromial balloon spacer may also lead to a foreign body response

and local inflammatory changes that can be visualized on magnetic resonance imaging, though the clinical significance of such findings remains unknown [31]. Senekovic et al. observed synovitis and impaired shoulder function in two patients after subacromial balloon spacer implantation, though it could not be ascertained if the synovitis was a component of the initial pathology or a device-related complication as baseline imaging was not available [33].

29.4 Complications of Tendon Transfer Procedures

For young active patients without significant glenohumeral arthritis who have failed rotator cuff repair, latissimus dorsi tendon transfer represents a potential salvage procedure that is particularly effective at restoring external rotation. However, when performed as a revision procedure, latissimus dorsi tendon transfer is generally believed to have inferior clinical outcomes and higher complication rates [34–36]. Warner et al. compared latissimus dorsi tendon transfer performed as a primary versus salvage procedure and found rupture rates of 17% and 44%, respectively [35]. Muench et al. observed clinical failure (defined as a change in the American Shoulder and Elbow Surgeons Shoulder Score of less than 17) in 41% of patients who underwent latissimus dorsi tendon transfer following failed previous rotator cuff repair(s) [37].

In addition to mechanical and clinical failure, potential complications following latissimus dorsi tendon transfer include wound dehiscence, infection, hypertrophic scarring in the axilla, neuroma formation at the latissimus harvest site, ulnar nerve neuropathy presumably from prolonged sling utilization, brachial plexus and axillary nerve injuries, shoulder stiffness, development of subscapularis deficiency, and deltoid disruption/avulsion [34, 36–39]. Additionally, progression of glenohumeral osteoarthritis and rotator cuff arthropathy is a relatively frequent occurrence after latissimus dorsi tendon transfer, [34, 37, 39] requiring revision to RTSA in 14% of patients at a mean follow-up of 3.4 years [34, 37, 39].

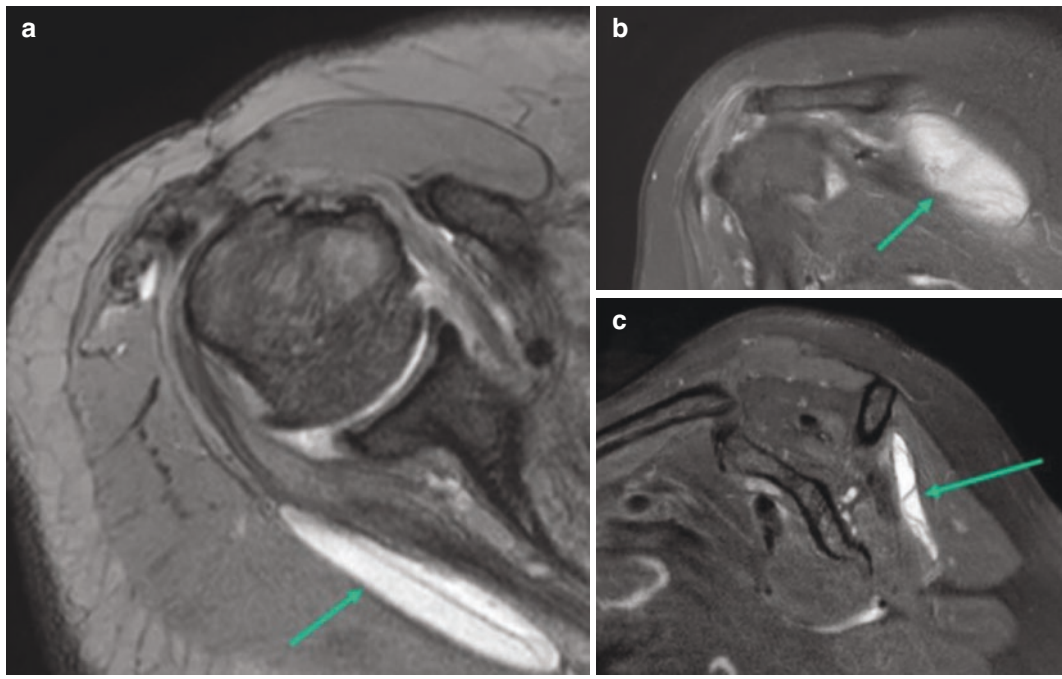

Fig. 29.1 Axial gradient echo (**a**) coronal, (**b**) sagittal oblique, (**c**) proton density fat-suppressed MRI images of a shoulder demonstrating posterior migration of a balloon spacer outside the subacromial space (*green arrows*). (Reproduced from Garcia et al. 2018) [31]

29.5 Complications of Reverse Total Shoulder Arthroplasty

Primarily due to concerns over implant longevity and high complication rates, reverse total shoulder arthroplasty (RTSA) should be used in young active patients with massive irreparable rotator cuff tears only after all other treatment options have been exhausted. In a recent study of patients younger than 60 years of age who underwent RTSA for massive irreparable rotator cuff tears with and without glenohumeral arthritis, 26% of patients required revision surgery, including removal of the prosthesis in 9%, at a mean follow-up of 11.7 years [40]. Similarly, Ek et al. observed an overall reoperation rate of 27.5% and a 15% failure rate at a mean follow-up of 7.8 years in patients younger than 65 years of age [41]. Failure is most often the result of infection or glenoid loosening [40–42].

Interestingly, while prior shoulder surgery does not appear to be associated with increased complications [40–42], 83.3% of patients who required reoperation in the study by Ernstbrunner et al. had a history of ipsilateral shoulder surgery [40]. In a recent systematic review of primary RTSA procedures for cuff tear arthropathy or massive irreparable rotator cuff tears, the survivorship until reoperation for any reason was 85% at 5 years, 74% at 10 years, and 70% at 15 years [43]. The survivorship until reoperation involving prosthesis removal or conversion to hemiarthroplasty was 94% at 5 years, 90% at 10 years, and 85% at 15 years after RTSA [43].

In young patients (<65 years of age) undergoing RTSA for massive irreparable rotator cuff tears, the complication rate is nearly 40% [40, 41]. In a slightly older cohort (mean age 68), 59% of patients experienced at least one complication [42]. The most common complications include dislocation (14–18%), infection (9–27%), and glenoid component loosening or dissociation (4–9%) [40–42]. Other reported complications include shoulder stiffness, persistent pain, avulsion of the greater tuberosity resulting in a mechanical block to motion, soft tissue impingement, dislocation, glenoid component loosening or dissociation, humeral component loosening, polyethylene wear, scapula fracture, periprosthetic humeral fracture, infection, and postoperative nerve palsy [40, 41].

Although the clinical significance of inferior scapular notching is widely debated, both the incidence and degree of notching have been shown to increase over time [40–43]. Ernstbrunner et al. observed at least grade one notching in 95% of patients at greater than 18 years of follow-up [40]. At 10 or more years, nearly half of patients have been shown to exhibit grade III or IV inferior scapular notching [42, 43]. Although some studies have associated scapular notching with impaired shoulder function (lower relative constant score, decreased subjective shoulder value, limited range of motion, and greater pain), the topic requires further investigation [40, 41]. Severe scapular notching, however, can lead to glenoid component loosening and failure (Fig. 29.2).

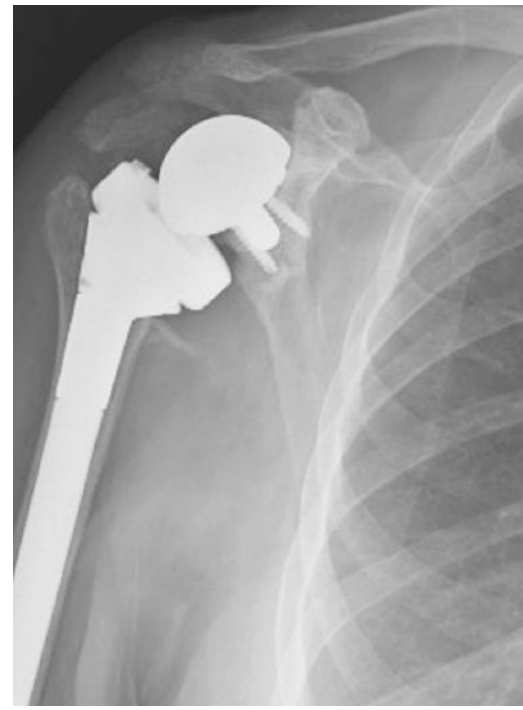

Fig. 29.2 An anteroposterior radiograph of a shoulder after reverse total shoulder arthroplasty with grade four inferior scapular notching and osteolysis resulting in loosening of the glenoid component. (Reproduced from Ackland et al. 2015 [44], published under the Creative Commons Attribution 4.0 http://creativecommons.org/licenses/by/4.0)

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Stiffness after Rotator Cuff Repair

30

Jack W. Weick and Michael T. Freehill

30.1 Introduction

Stiffness after rotator cuff repair can have a significant impact on a patient's functional utility of the shoulder. The limited range of motion (ROM) arises from capsular contraction combined with postsurgical adhesions. Estimates of the rate of stiffness after arthroscopic or open rotator cuff repair vary widely depending on the definition. A subjective sensation of stiffness has been reported in 2.5–6.6% of patients postoperatively, on average ~6.4 months postoperative [1–3]. However, when the objective range of motion measures have been used in the assessment of stiffness (defined as forward flexion <110°, external rotation <25°, or internal rotation below the second sacral vertebral level), up to 12.2% of patients have been found to have decreased motion up to 2 years postoperatively [4]. Though no exact definition of shoulder stiffness exists, it has been described in the postoperative shoulder as one of the following: total passive external rotation with arm at the side less than 10°, total passive external rotation with the arm in 90° abduction of less than 30°, or total passive forward flexion of less than 100° that has persisted for 90 days postoperatively [5]. Multiple factors can play a role in the development of this postoperative complication including patient-specific risk factors, surgical risk factors, and postoperative rehabilitation protocols. This chapter will discuss these risk factors as well as management options for postoperative stiffness after a rotator cuff repair.

30.2 Patient Risk Factors

Certain intrinsic, patient-related characteristics increase the risk of postoperative stiffness after rotator cuff repair. Both patient comorbidities and demographic data have been previously studied.

30.2.1 Age

Age is an independent risk factor for postoperative stiffness, in both older and younger aged cohorts. Chung et al. showed in a retrospective review that patients with postoperative stiffness were, on average, about 3 years older than those who were not stiff (65 vs. 62 years, p value < 0.036) [1]. Vastamäki and Vastamäki in their review of stiff shoulders after rotator cuff repair

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identified age at the time of surgery as an independent risk factor for postoperative stiffness in logistic regression analysis (age at time of surgery OR 1.11, 95% CI 1.01–1.20) [6]. However, a more recent review of nearly 20,000 patients who underwent lysis of adhesions (LOA) or manipulation under anesthesia (MUA) after rotator cuff repair found aged under 50, increased risk of development of postoperative stiffness (OR 1.9, 95% CI 1.47–2.37, p value <0.0001) [7]. These data suggest that age has a bimodal distribution as a risk factor for this postoperative complication with both younger patients (<50 years) and older patients (~65+ years) at increased risk.

30.2.2 Sex and Obesity

Mixed data exist for gender as an independent risk factor for postoperative stiffness after rotator cuff repair. Recent data suggest females are at nearly twice the risk of development of decreased ROM [7]. However, studies prior to this did not show a correlation with gender and postoperative stiffness [3, 6]. Similarly, inconsistent data exist with regard to body mass index (BMI). Though functional outcomes have been found to be inferior in obese patients, ROM was similar between obese (n = 59) and nonobese (n = 90) patients with a slight increase in forward flexion in the nonobese patients (142° vs. 127°) [8]. Burrus et al. did not show a correlation with either obesity or patients underweight in the development of stiffness postsurgically [7], however, it should be noted that obesity has been described as a risk factor for idiopathic adhesive capsulitis [9].

30.2.3 Endocrine

Diabetes mellitus (DM) is a known risk factor for idiopathic adhesive capsulitis [9]. Similarly, both type I and II DM have previously been shown to increase the risk of postoperative stiffness after rotator cuff repair [10]. However, in the review by Burrus et al., only type I DM was an independent risk factor with no significant difference observed in patients with or without type II DM [7]. However, this review was of the Pearl Diver database and, therefore, relies on the accuracy of coding data. Hypothyroidism and systemic lupus erythematosus (SLE) have also been shown to increase the risk of postoperative stiffness [7, 10]. Though there is little in terms of in vivo data, it has been suggested that the pro-inflammatory environment of patients with these diseases can increase inflammation around the capsule with increased scarring leading to stiffness [11].

30.3 Surgical Factors

Surgery-specific details have been shown to play a role in the development of postoperative stiffness after rotator cuff repair. The size of rotator cuff tear has been correlated to the risk of stiffness postoperatively [1, 12]. Chung et al. in their retrospective review reported patients who subsequently developed postoperative stiffness were found to have tears larger in the anterior to posterior (AP) direction (3.91 cm vs. 2.28 cm, $p < 0.001$) compared to patients who did not develop stiffness, as well as significantly greater tendon retraction compared to patients who did not develop stiffness (3.43 cm vs. 2.20 cm, $p < 0.001$) [1]. Patients with stiffness at 1 year postoperatively were also observed to have increased fatty infiltration on preoperative MRI with an average Goutallier grade of 3.05 in the patients who developed stiffness and 2.14 in patients who did not develop stiffness ($p = 0.01$) [1]. Subscapularis tear requiring repair has also been shown to be an independent risk factor for the development of stiffness post-operatively [12]. In their review, Namdari et al. found that in the 345 patients retrospectively reviewed, 20% of these patients had a subscapularis repair performed. Although they did not explicitly define the percentage of these patients who developed stiffness, they noted that subscapularis repair was an independent risk factor for decreased external rotation postoperatively ($p = 0.04$) [12].

Surgical approach for rotator cuff repair (arthroscopic vs. mini-open vs. open) has been studied in terms of development of postoperative

stiffness. One of the benefits of an all-arthroscopic rotator cuff repair is presumed decreased adhesion and scar formation reducing the risk of limited postoperative ROM. Open rotator cuff repair has been shown to increase the risk of stiffness early in recovery, but often recovers without intervention 6–12 months postoperatively [6]. Jensen et al. reported patients who have undergone open rotator cuff repair were at increased risk of requiring subsequent surgical intervention or manipulation under anesthesia for postoperative stiffness [13]. Rates of stiffness after mini-open approach are variable with some reports of similar rates of stiffness to arthroscopic repair and other reports of overall increased risk [1, 14].

Partial-thickness rotator cuff tears can be treated by transtendon repair or formal repair after completion of the partial thickness tear. Partial-thickness transtendon repairs have the theoretical benefit of maintenance of the intact portion of the tendon. However, there is a concern for increased risk of stiffness with transtendon repairs. Shin et al. showed an increased risk of stiffness in a review of 48 patients with partial-thickness tears that were treated with transtendon technique versus completion of the tear (12.5% vs. 8.3% of patients) [15]. In their review, Jordan et al. showed an overall stiffness rate of 0–18% in patients who underwent a transtendon repair as opposed to a stiffness rate of 0–2.8% of patients who underwent completion of the tear and formal repair [16].

Concomitant shoulder procedures during rotator cuff repair have the theoretical potential for increased stiffness postoperatively, given the increased inflammatory environment associated with additional surgical intervention within the shoulder potentially increasing scarring and adhesions. Though not extensively studied, the only associated procedures performed during rotator cuff repair that have been shown to increase the risk of postoperative stiffness were labral repairs and coracoplasty, though data for these are also mixed [1, 3]. Of note, to our knowledge, there is no association at this time with subacromial decompression, distal clavicle excision, biceps tenodesis, or biceps tenotomy Table 30.1.

Table 30.1 Risk factors for stiffness after rotator cuff repair

Patient risk factors
Age (bimodal)—<50 years, >65 years
Female
Obesity
Diabetes
Hypothyroidism
SLE
Surgical risk factors
Larger size tear—anterior to posterior and medial to lateral
Increased fatty infiltration
Subscapularis repair
Open repair
Transtendinous repair

30.4 Post-Operative Rehabilitation

The postoperative rehabilitation program after rotator cuff repair is vital in optimizing outcomes and preventing postoperative stiffness. Tendon to bone healing is a slow process, however, prolonged immobilization can place the patient at risk for stiffness. This becomes a delicate balance secondary to the integrity of the repair and the quality of the tendon tissue and the need for delayed initiation of formal physical therapy. A period of preventing active motion after rotator cuff repair is widely accepted as necessary to allow for bone–tendon healing [17, 18]. Controversy does exist, however, regarding complete immobilization versus early passive motion. Proponents of immobilization cite no long-term difference in ROM [19, 20] with a greater likelihood of tendon healing. However, a prospective randomized trial comparing immobilization and early passive motion after arthroscopic rotator cuff repair showed no difference in healing, stiffness, or functional outcomes [21]. Type of sling used postoperatively (abduction pillow or regular sling) has not been studied in terms of the effect on postoperative stiffness. The abduction pillow is thought to provide less tension on the superior rotator cuff, however, use of the abduction sling has not been shown to affect clinical outcomes and postoperative pain control [18, 22, 23]. Thus, at this time it is unknown if immobilization with an abduction pillow sling increases the risk of stiffness.

30.5 Management of Post-Operative Stiffness

Management of postoperative stiffness after rotator cuff repair can be challenging as the repair of the rotator cuff must not be compromised. Both nonoperative and operative treatment options exist. Nonoperative management includes physical therapy, intra-articular injections, or brisement (injection of fluid between the capsule and tendon) [24–26]. Kim et al. did show success with early corticosteroid injection begun at 6 weeks postoperatively for stiffness after rotator cuff repair without evidence of compromise of the repair after injection with improvement in forward flexion and external rotation, as well as improvement in outcome scores [27]. They performed a series of three intra-articular corticosteroid injections and found improvement in patients' pain and ROM. Corticosteroids have been shown to affect both the cell number of tenocytes and associated collagen synthesis. Thus, there is some debate on the timing of injections after a tendon repair and the potential for delaying or impacting healing [28]. The senior author recommends waiting at least 3 months postoperatively.

Manipulation under anesthesia (MUA) was previously a frontline treatment option for shoulder stiffness in both adhesive capsulitis and postoperative stiffness [29, 30]. However, this approach came in favor prior to advances in shoulder arthroscopy and modern arthroscopic tools and techniques. Aggressive manipulation for shoulder stiffness puts the rotator cuff repair at significant risk for retear. Additionally, a number of non-rotator cuff injuries have been reported with MUAs including fractures, dislocations, and other soft-tissue injuries [31].

Surgical intervention has become the treatment of choice for patients with persistently limited ROM after failed nonoperative intervention for stiffness after rotator cuff repair. Although the role of arthroscopic capsular release has been well documented for adhesive capsulitis and generalized shoulder stiffness, few articles have focused specifically on the role of stiffness after rotator cuff repair. Huberty et al. reviewed their results in a population of 24 patients who underwent arthroscopic capsular release and LOA after rotator cuff repair [3]. They found an increase in forward flexion by an average of 28° and increase in external rotation by 22°. All 24 patients who returned to the operating room for capsular release and LOA were subsequently satisfied with their results.

When addressing postoperative stiffness surgically, it is important to carefully assess the rotator cuff repair for any evidence of retear and to discuss with the patient preoperatively the possibility of need for repeat fixation. Often, significant adhesions may be present in the shoulder, these should be carefully debrided being sure not to violate any normal structures or any component of the prior repair. Typically, in these patients, the anterior capsule, including the rotator interval, can be thickened. Rotator interval release and debridement are performed with an array of instruments including radiofrequency wand, shaver, and arthroscopic scissors. The capsule is then further released through the middle and anterior glenohumeral ligaments. This is then extended inferiorly and posteriorly. It is important to view from anterior looking posterior and assess the need for further release. The senior author has found in this population the radiofrequency wand is advantageous as it both obtains hemostasis and is decisive with its releases (Fig. 30.1). The subacromial space should be entered to assess and address adhesions, inflamed and scarred bursa. Postoperatively, barring the need

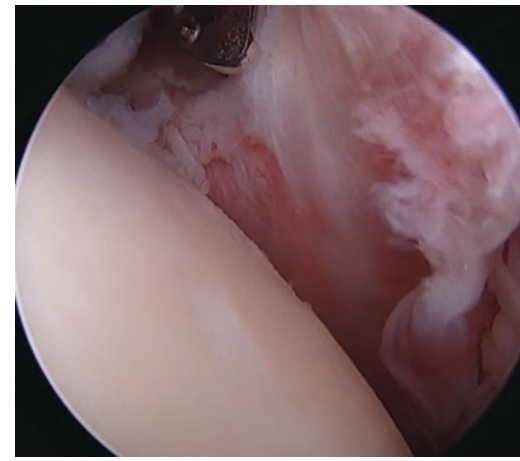

Fig. 30.1 A thickened anterior capsule can be seen with the radiofrequency wand about to perform the release with care to work between the plane of capsule and the posterior surface of the subscapularis

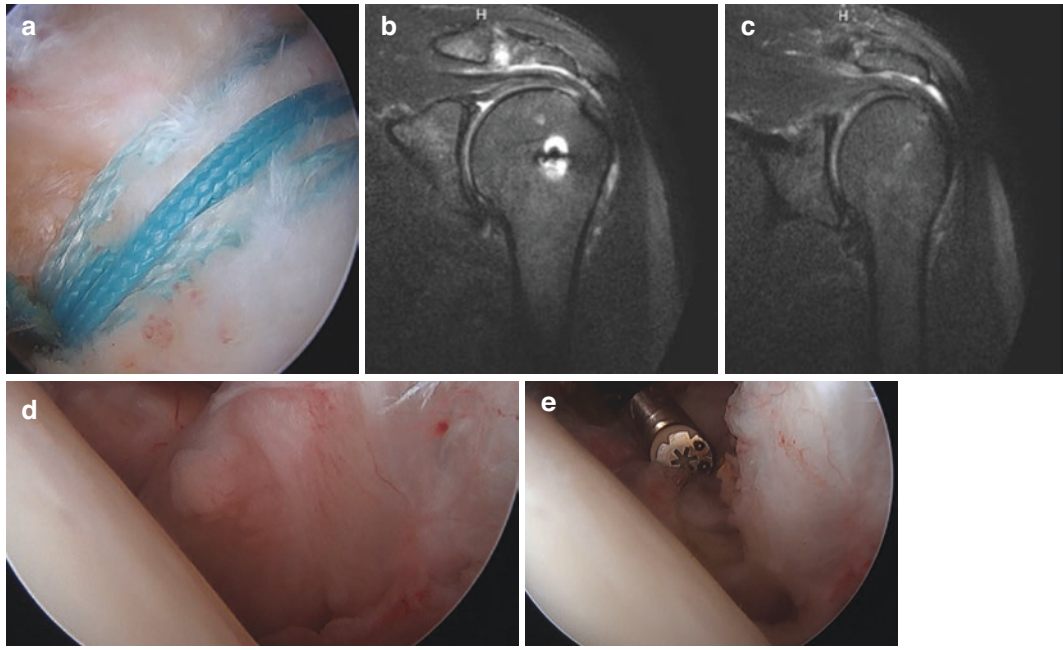

Fig. 30.2 (**a**–**e**) 58 y/o RHD male s/p L RC repair for medium-size crescent-shaped tear. (**a**) Repaired with double-loaded one suture and one tape 5.5 mm PEEK anchor with transosseous equivalent bridging to lateral row 4.75 mm knotless PEEK anchor. Physical therapy started at 3 weeks post-op. Pain and stiffness continued. Injections to subacromial space at 3 months post-op. MRI at 4 months post-op. (**b**) Coronal view demonstrating thickening of the capsule inferiorly. (**c**) Coronal view demonstrating both thickened inferior capsule, as well as increased bursitis in the subacromial space. Injection into the glenohumeral joint with modest improvement. At 7 months post-op, exhausted conservative management and taken for arthroscopic debridement and release. (**d**) Arthroscopic view demonstrating thickened, irritated anterior capsule. (**e**) Release of the thickened capsule with a radiofrequency wand protecting the subscapularis anterior, posterior in this picture

for repeat rotator cuff repair, the goal for the patient should be to achieve immediate ROM. Active-assisted and passive ROM exercises should be started immediately with an aggressive physical therapy program. These patients should be monitored closely postoperatively for progression in their ROM. The senior author prefers an indwelling interscalene nerve catheter, which allows comfort and the ability to perform PT postoperative day number 1. For the first 2 weeks, PT is performed 5 days per week, followed by 3 days per week for weeks 3 and 4, and then returning to 2 times per week (Fig. 30.2a–e).

30.6 Conclusion

Postoperative stiffness after rotator cuff repair can be significantly debilitating and lead to dissatisfaction and poor outcomes. Identifying the preoperative and intra-operative risk factors for postoperative stiffness is important for both preventive steps and patient education of this result. Both nonsurgical (PT, injections, brisement) and surgical management options (arthroscopic LOA and capsular release) exist for these patients.

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31 Infection: Diagnosis and Management of the Failed Infected Rotator Cuff Repair

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31.1 Epidemiology of Shoulder Joint Infections

Infection of the shoulder joint is one of the most common joint infections in the human body. The infection can evolve via hematogenous bacterial scattering or via direct entry into the immune-privileged joint. After shoulder arthroscopy with imbedded implants such as anchors or suture material, germs find excellent conditions for settlement. Significant risk factors for shoulder joint infections were identified in several studies and were also demonstrated in 88% of the patients examined in these studies (Table 31.1) [1–3].

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Direct entry of germs into the shoulder joint can take place through trauma with opening of the protective skin, subcutis, fascia, and muscle barrier as well as opening of the joint capsule. However, most of the times shoulder infections result in iatrogenic through peri- or intra-articular infiltrations as well as through surgical interventions [6]. The likelihood of preoperative shoulder joint infection in open procedures is increased compared to purely arthroscopic procedures in which the postoperative risk of infection is around 1% [6, 7]. Although the probability of infection after periarticular puncture or infiltration is relatively low with an incidence of approx. 1/10,000–1/100,000, the incidence of postoperative infections after shoulder arthroscopy is 0.14–2.25% [8–10]. Due to the improved detection methods an increased infection rate with *Cutibacterium acnes*, the most common cause of

Table 31.1 Risk factors of shoulder infection [1, 4, 5]

• alcohol abuse • COPD • urinary catheter • diabetes mellitus • smoking • hyperuricemia • omarthrosis • cirrhosis • i.v. catheter • tuberculosis • tick bite	• drug abuse • total or hemiarthroplasty • systemic immunosuppression (medicinal, HIV) • systemic diseases (e.g., Hodgkin's lymphoma, chronic lymphocytic leukemia, rheumatoid arthritis, gout) • obesity • renal failure • menstruation, pregnancy: Increased risk of gonorrhea

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Table 31.2 Criteria for differentiation between joint irritation and joint infection

Pro joint irritation	Pro joint infection
• symptoms <12 h after intervention	• symptoms 12 h to 5 days after the intervention
• joint swelling	• general feeling of sickness
• no fever	• fever (but not mandatory)
• only a slight increase of CRP	• significant increase of CRP
• leukocytes < 20,000/µL	• leukocytes > 20,000/µL
• normal procalcitonin	• increased procalcitonin
• no risk factor (see Table 31.1)	• one or more risk factors

Modified according to [12]
CRP C reactive protein

low-grade infections of the shoulder joint after joint surgery could be shown in the last years.

31.2 Diagnosis

The clinical presentation of the shoulder joint infection has a wide range. The classical signs of infection such as joint swelling, reddening, overheating, fever (possibly also chills), pain, and functional impairment (tumor, rubor, dolor, calor, and functio laesa) can lead to diagnose an acute infection. Regarding a low-grade or chronic infection, persistent pain and functional restrictions after shoulder surgery may also be a warning signal.

After an inspection and palpation, the painful restricted function and restricted range of motion can be the leading milestone during the clinical examination [11]. Additionally, it is essential to distinguish between a joint irritation and a joint infection, especially after previous surgery (see Table 31.2) [12].

31.3 Additional Diagnostics

Even if there is little suspicion of an infected shoulder joint, a blood test should be initiated. Particular attention should be paid to the determination of the leukocyte count, the C-reactive protein (CRP), and the procalcitonin (PCT). Additionally, kidney and liver parameters should be determined. This can be helpful to plan a later antibiotic therapy. If there are signs of systemic infection, blood cultures should be taken (at least two pairs, two aerobic and two anaerobic cultures from two different points). However, the informative value of the chemical blood tests itself does only show a low specificity. The sensitivity can be increased by determining interleukin 6 in addition to CRP [12].

Diagnostic imaging should be added if a shoulder infection is suspected. Through an ultrasound examination, a quick and easy-to-use procedure is available, which is suitable for the detection of periarticular fluid accumulation and joint effusions. Furthermore, ultrasonography also allows an overview of common rotator cuff pathologies, such as tendinosis calcarea, changes of the long head of the biceps tendon, and possible degenerative changes in the acromioclavicular (AC) and glenohumeral joint.

A conventional X-ray (a.p. and y-view) of the shoulder should also be carried out, allowing to assess bony changes (e.g., osteolyses, osteophytes, tendinosis calcarean) as well as the joint position.

Extended diagnostic imaging with CT or MRI (with injection of contrast medium) helps to further investigate the involvement of adjacent soft tissue structures and expansion of an abscess, if detected. Positron emission tomography (PET)-CT and leukocyte scintigraphy are indicated to clarify unclear constellations of infection but are not used as a primary tool for shoulder joint infections.

The essential diagnostic tool for a suspected shoulder joint infection is the joint puncture. The puncture is usually performed from the dorsal side but can also be done from the anterior. A sonographically assisted puncture is recommended and allows the controlled puncture of the target area. The procedure should be performed under sterile conditions (disinfection, mouth protection, sterile gloves, and sterile drape). After that, the punctate should be assessed macroscopically (serous, clear, cloudy, and bloody) and then used for further determination of:

1. cell count
2. gram staining
3. microscopy
4. extended microbiological diagnostics.

If an acute infection is suspected (see Table 31.3), cell count, macroscopic assessment, and microscopy after gram staining help to make a quick diagnose and support a quick decision-making process for the further course of treatment. The interpretation of the punctate can be done according to the Chapman et al. [8] and Stutz et al. [13], who proposed the following criteria: The main distinctive feature between reactive and septic arthritis is the number of cells. If this is greater than 20,000/μL, there is a high probability of an infectious event (Table 31.2). However, there are some limitations to these criteria. The cell count must be interpreted in regard to the individual patient, i.e., a leukocyte count of 15,000/μL can already be considered critical if an implant is present (anchor or suture material). Whereas a leukocyte count of 15,000/μL from a native shoulder joint might be from a noninfectious origin. Additionally, in patients with immunosuppression, the leucocyte count may not be elevated and therefore mask a joint infection.

The negative results after cultivation, to assess pathological germs of the punctate, do not necessarily exclude an infection. This also applies to the long-term cultivation (14 days and longer) [14].

31.4 Further Microbiological Diagnostics

In addition to the initially obtained joint punctate, at least five (tissue) samples should be sent in for further microbiological investigation. The sensitivity for germ detection is significantly increased with tissue samples compared to punctate fluid only [15]. It should also be noted that bacterial detection is significantly less frequent with ongoing antibiotic therapy than without prior systemic therapy. Therefore, if a shoulder joint infection is suspected, the main aim is to check for germs before starting an empirical antibiotic therapy. If the situation requires an implant removal during the revision surgery, it is recommended to prepare the implant(s) for an additional microbiological diagnosis using sonication. The sensitivity and specificity of sonication exceed that of tissue biopsies (79% vs. 61% for tissue biopsy) with a high specificity of 99% [16].

Table 31.3 Differentiation between acute infection versus chronic infection

Acute infection	Chronic infection
• symptoms have existed for a few days • often redness, swelling and overheating, possibly fever • early postoperative infection or later hematogenous infection	• developed over months and persistent • often fistula • delayed postoperative infection; often 3–24 months postoperatively

Typical local bacteria are *Cutibacterium acnes*, coagulase-negative staphylococci (e.g., *Staphylococcus epidermidis*), and *Staphylococcus aureus* [4, 17, 18]. Of course, less frequently detected germs such as *Corynebacterium species, Proteus mirabilis, Enterococcus faecalis, Peptostreptococcus magnus, Bacillus species, Streptococcus viridans, and Actinomyces species* or polymicrobial infections can also be seen. However, positive microbiological results should also be interpreted with regard to a possible false-positive result.

In any case, a long-term culture (at least 14 days) of the samples is recommended, because some germs can only be detected after this period of cultivation. This particularly includes the *Cutibacterium acnes*, which is frequently represented in shoulder joint infections [19]. This could be demonstrated in 19.6% postoperative shoulder infections [20]. Furthermore, studies showed no significant reduction in the infection rate despite perioperative antibiotics for *Cutibacterium acnes* [18] or preoperative skin treatment [21]. In modern state of the art microbiological institutes, 16S ribosomal RNA PCR (polymerase chain reaction), which allows detection of a broad range of pathogens or pathogen-specific PCR are available as reliable (high sensitivity) and fast diagnostic method [22].

31.5 Classification of a Joint Infection

The joint infection can be classified according to pathological–anatomical [23], clinical [13], or arthroscopic [9] aspects. The most frequently used and also an indicator for further therapy is

the classification according to Gächter (Tables 31.4 and 31.5).

Critical for the successful therapy of a joint infection is the correct and early diagnosis, initiation of the correct therapy, and the correct timed antibiosis (see Fig. 31.2).

31.6 Therapeutic Approach

If an infection is confirmed or suspected, the indication for an early arthroscopic joint irrigation and joint debridement is given (Fig. 31.3). If a high-grade joint infection is already confirmed at the time of diagnosis (Gächter stage 3 or 4), an open procedure should be considered.

At least five tissue samples should be obtained intraoperatively before starting a calculated antibiotic therapy. In addition, the histological examination is essential to support the diagnosis. Furthermore, the histological investigation is also very critical to differentiate between a gout arthropathy and noninfectious joint pathologies [24].

Table 31.4 Classification of a joint infection according to Gächter [9]

- Cloudy effusion, synovialitis, and possible petechial bleeding
- Clear synovialitis, putrid effusion, and fibrin deposits (Fig. 31.1a, b)
- Villi formation ("bath sponge") and chambering
- Aggressive synovial infiltration with undermining of the cartilage
  - radiological: Osteolysis and cysts

After an initial extensive lavage, debridement with synovectomy and hemostasis should be performed. Necrotic tissue or pannus tissue should be carefully removed. If an additional pathology can be found during arthroscopy, it is very important to evaluate between reconstruction with the use of an implant or to leave the joint as it is. In case of doubt, foreign material should be avoided. For example: If a pathology of the long head of the biceps tendon can be detected, the biceps is treated with tenotomy or loop tenodesis instead of anchor tenodesis [25].

If an infection after rotator cuff repair is confirmed, it is very important to distinguish between an acute and chronic infection (Table 31.3). In the event of an acute infection, the implant material (anchors) can be left with an early and thorough debridement and lavage, independently from the germ that will or will not be detected. In our practice, patients will stay in hospital for the i.v. application of antibiotics until the results from the microbiological testing. Therefore, we can ensure the right and specific treatment. Even though *Cutibacterium acnes* will take more than 48 h to be detected, patients will be in hospital until the final result. It must also be mentioned, that *Cutibacterium acnes* is rarely detected in

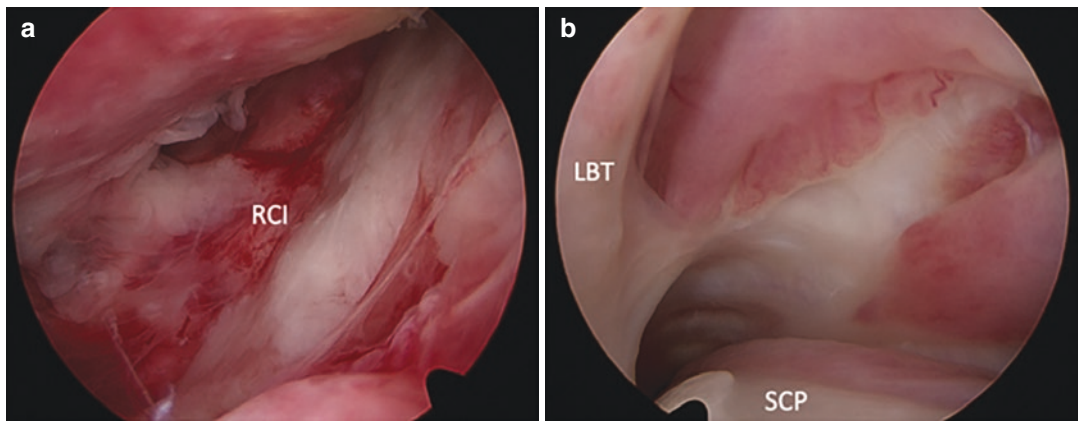

Fig. 31.1 Shoulder joint infection after arthroscopic irrigation, before debridement: (**a**, **b**) left shoulder via a dorsal standard portal—Gächter type II with clear synovialitis in the anterior joint compartment with fibrin deposits. (*RCI* rotator cuff interval, *LBS* long head of biceps tendon, *SCP* subscapularis)

acute cases of infection. Therefore, the type of treatment will mostly follow the surgical approach for chronic infection.

The administration of a biofilm-effective antibiotic (usually rifampicin) is recommended. In order to avoid the development of a bacterial resistance, it seems reasonable to administer rifampicin when wounds are dry and irritable. Furthermore, a second antibiotic should always be administered to avoid resistance development. If the infection is determined to be chronic, we recommend removing the implants, because the probability of a mature biofilm is very high, and only the debridement is not successful.

In addition to the glenohumeral joint, the subacromial space should also be examined for the presence of an infection and addressed using bursectomy and debridement.

The intraoperative lavage should be carried out with a sufficient volume (6 L recommended). Antiseptics such as iodine-containing solutions, chlorhexidine, or hydrogen peroxide have good antimicrobial effects, but have to be seen as critical because of their high chondrotoxicity, which may lead to advanced chondrolysis [26, 27].

Before the revision surgery ends, a drainage (with suction) is recommended to get control of the remaining intra-articular fluid and to have a direct visualization of the fluid itself, which may help to evaluate the postoperative clinical course [28]. The application of a suction-irrigation drainage or the application of a vacuum dressing is not recommended for intra-articular infections.

Table 31.5 Recommendations for basic diagnostical procedures if a shoulder joint infection is suspected, according to Pfeifer et al. [5]

- Medical history and clinical examination
- Blood test (CRP, PCT)
- Ultrasound
- Joint puncture with subsequent diagnosis of cell count, gram staining with microscopy, and microbiology:

Priority	Tube	Volume	Aim
1.	EDTA	2 mL	Synovia analysis
2.	Blood culture (aerob/PED)	1 mL each	Cultivation
3.	Sterile tube	0.5 mL	Crystal analysis
4.	Sterile syringe	1 mL	Cultivation, gram staining

- X-ray
- Consider advanced diagnostics

31.7 Antibiotic Therapy

The administration of intra-articular antibiotics is not indicated because the local effect level with systemic administration is above the minimum inhibitory concentration [29]. Furthermore, there may also be an increased chondrotoxicity when administered locally.

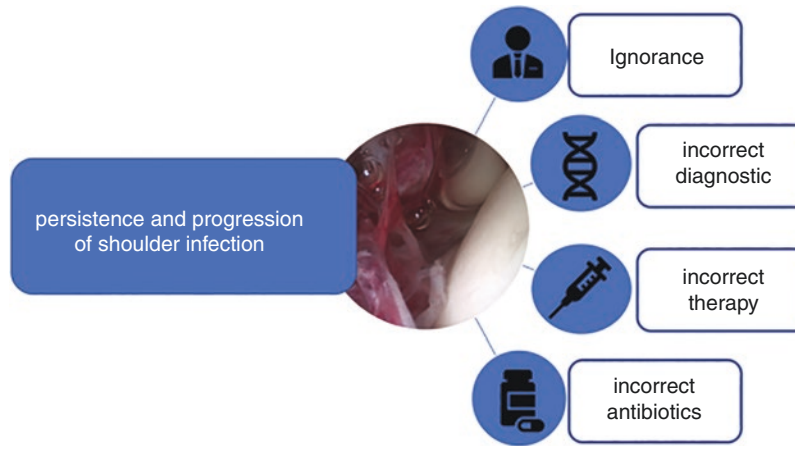

Fig. 31.2 Avoidable pitfalls in case of shoulder joint infection

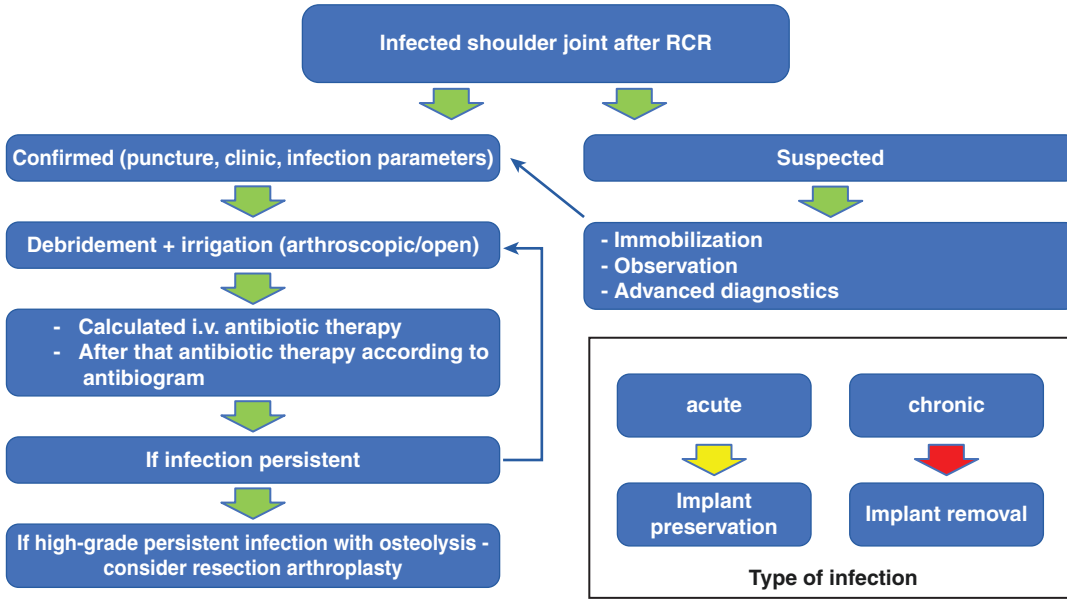

Fig. 31.3 Treatment pathway for infected shoulder joints

After adequate tissue and joint fluid collection, a calculated systemic antibiotic therapy must be started intravenously. In the absence of other risk factors, a second-generation cephalosporin is recommended for a calculated antibiotic therapy of shoulder joint infections. However, newer findings suggest the expansion of the calculated antibiotic therapy and the "hit hard and early" strategy. This will include the i.v. application of piperacillin/ tazobactam (3 g) three times a day or amoxicillin/ clavulanic acid 2.2 g three times a day. Particularly in cases of acute infections with the intention to preserve the implants, a biofilm effective antibiotic, such as rifampicin (dry wounds), in combination with the calculated antibiosis is recommended.

After receiving the antibiogram, specific antibiotic therapy should be performed. The choice of antibiotic, as well as the way of application (i.v. vs. p.o.) and duration of the therapy, always depends on accompanying factors. These can be the duration and severity of the infection as well as accompanying diseases of the patient [30]. Special therapy regimes must be implemented when detecting multiresistant bacteria and special attention is required to Rifampicin and Ciprofloxacin-resistant bacteria because both antibiotics are important to treat biofilms. Therefore, an interdisciplinary cooperation between multiple faculties is recommended for the best of the patient.

31.8 Aftercare

In the postoperative clinical course, the passive mobilization of the shoulder joint is the first way of treatment. After removing the drainage and the dropping of the infection parameters a more passive-assistive therapy can be started. It is sometimes very difficult to find the right way between mobilization and immobilization after revision shoulder surgery for infection. However, the authors do not recommend an immobilization longer than 14 days after surgery. Further rehabilitation treatment is then based on the intraoperative findings and the reconstructive procedures during surgery.

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Instability in Reverse Shoulder Arthroplasty

32

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32.1 Introduction

Reverse shoulder arthroplasty (RSA) is increasing for the treatment of massive irreparable cuff tear in elderly patients. Recent data reporting good long-term outcomes [1, 2] and low-complication rate with new designs [3] may motivate surgeons to use this implant for younger patients. RSA for cuff tear arthropathy seems to achieve the most reliable outcomes, consistently restoring pain-free mobility.

Chae [4] reported a complication rate as high as 68% including prosthetic instability, scapular notching, acromial fracture, deltoid weakness, and non-implant-specific complications including infection, periprosthetic fractures, hematoma, and implant loosening. RSA instability is a complex problem with many contributing factors including implant design features, spacer parameters, as well as soft tissue, and bone considerations. Based on several studies, the rate of dislocation is ranging from 1.5% to 31%. Of the 1699 RSA collected in the Danish shoulder registry, 32% of revisions were performed for unstable RSA [5]. Gauci confirmed in a different cohort that 32% of revisions after RSA are due to instability [6]. Instability is most common after RSA is performed for fracture or other indications involving humeral bone loss.

In the current chapter, we will mostly focus on RSA performed for rotator cuff tear and cuff tear arthropathy. Managing RSA instability requires careful assessment of the shoulder and the prosthetic components. With respect to the shoulder, one must evaluate (1) the deltoid muscle, its innervation, structural integrity, and tension, (2) the humeral bone, particularly its length compared to the other side, and (3) the scapula and glenoid with attention to the status of the acromion and glenoid bone stock for consideration of revision options. In regard to the prosthesis, one should evaluate (1) humeral component height and version; (2) glenoid component position and version; (3) presence of mechanical impingement posteriorly, inferiorly, and anteriorly; and (4) sizes of modular components presently implanted and what additional revision options are available. A change in any one of these elements could impact the stability and mobility of the shoulder.

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In many cases, several elements may contribute to instability and therefore the treatment in most cases will require modification of more than one condition.

32.2 Classical Causes

RSA has a high rate of dislocation after surgery. Many causes are reported in the literature.

32.2.1 Revision Surgery

Revision total shoulder arthroplasty (TSA) or hemiarthroplasty is a challenging procedure with many reports of poor clinical outcomes. RSA can provide reliable clinical outcomes in this scenario. Hernandez [7] reported a higher rate of dislocation after revision surgery for patients who have a BMI greater than 35 kg/m^2 with prior hemiarthroplasty compared to those with prior TSA. They reported that one in seven patients will experience a dislocation, without identifying local associated factors. For Kohan et al., most patients in both groups were men, who were 70 years of age or greater, and had a history of shoulder surgery before the primary RTSA [8].

Abdelfattah in 2017 [9] proposed a classification based on surgeon experience, review of the literature, and description of several cases performed by the senior author, Dr. Frankle. They proposed three groups: (1) loss of compression, (2) loss of containment, and (3) impingement. Loss of compression included an undersized implant, loss of deltoid contour, humeral height loss, subscapularis deficiency, and acromial or scapular fractures. Loss of containment included mechanical failure and alteration of the depth/ratio (humero-socket depth). Impingement referred to soft tissue and bony impingement, prosthetic malalignment, and body habitus. After revision surgery, 14.7% to 37% of patients still have an unstable implant.

32.2.2 Classical

Hematoma or infection should be considered as a cause of acute instability due to massive swelling inside the joint.

32.2.3 Soft Tissue

Soft tissue tension is the key determinant of RSA stability and is difficult to accurately assess at the time of surgery due to anesthetic muscle relaxation and general anesthesia or local nerve blockade. Inadequate deltoid tension may result in an inability to maintain compressive forces at the glenohumeral articulation. Additionally, soft tissue, particularly inferiorly may result in impingement, which is a common cause in our experience. The diagnosis can be difficult, particularly, when there are other contributing factors. In most cases, there is no abnormal positioning of the implant, and CT scans do not identify any bony abnormality.

We attempt dynamic ultrasound assessment with the patient carefully evaluating the apprehensive position. In some cases, we found "abnormal" contact between the tuberosity and the conjoint tendon. In these cases, we recommend performing a release of the impinging tissues and consider increasing the size of the glenosphere. The small size is not necessarily the direct cause of the instability but changing to a bigger glenosphere increases stability and modifies impingement as bone and soft tissue contact are changed.

32.2.3.1 Direct

The involvement of the subscapularis in RSA instability is still debated. Many authors believe it is an important element in the global function of RSA. Edwards et al. found higher dislocation rates in cases with irreparable subscapularis tendons, although those cases had more complex history of proximal humerus trauma, or failed prior arthroplasty [10]. Some authors [9] reported that if during revision surgery it is pos-

sible to repair the subscapularis, then it is worth doing so. In 2018, Roberson reported no clinical difference and no difference in dislocation rates after lateralized RSA, with or without subscapularis repair [11]. However, Matthewson [12] found that instability is higher when there is no subscapularis repair in medialized RSA designs. The deltoid can directly affect the result and the stability of RSA. In revision surgery, a weakened or fibrous deltoid can limit the compressive force at the glenohumeral articulation as well as limit the wraparound effect. Clearly, the type of RSA design plays a role or determines to what extent subscapularis repair influences instability.

32.2.3.2 Indirect

Kohan [8] reports that 68% of unstable RSA cases were related to inadequate soft-tissue tensioning (10% due to partial axillary nerve injury). To date, even with preoperative planning using 3D patient-specific instrumentation, it is difficult to assess soft-tissue tensioning as this technology is largely based on bony anatomy alone. Some companies are providing temporary spacers to evaluate mobility and tension (Fig. 32.1). It is reported by Chae [4] that high levels of tension can result in acromial stress fractures, decreased ROM, neurologic damage, and deltoid pain. To date, soft-tissue balancing in RSA is based on surgeon's experiences and nonvalidated operative evaluation of the conjoined tendon, triceps, and ability to reduce the joint and maintain stability during range of motion. These are empiric techniques used during surgery but not validated. Postoperative acromial fractures are also related to traction of the deltoid on the acromion and result in poor results and sometimes dislocation.

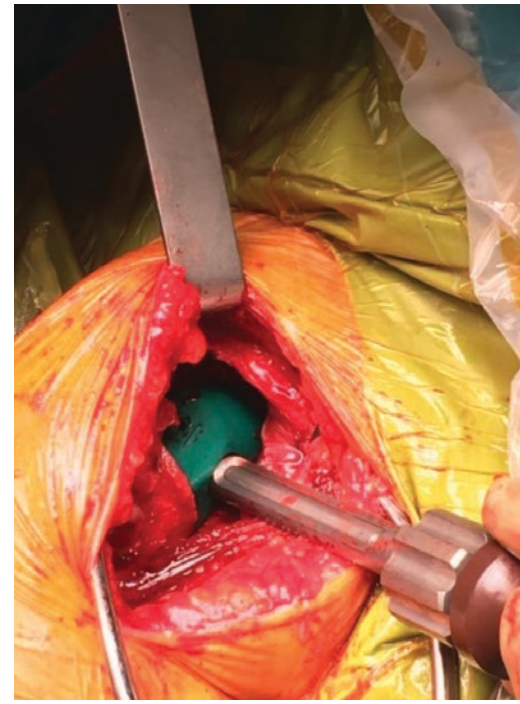

Fig. 32.1 Use of a trial spacer after baseplate and glenoid preparation, to try to evaluate good soft-tissue tension during RSA procedure (Fx Shoulder)

32.2.3.3 Bone

Glenoid

Many studies report the importance of the lateralization of the center of rotation to improve the stability of the reverse. A glenoid defect that is not initially corrected by a partial or total graft (bio RSA or lateralized glenosphere or metal buildup) could be one of the reasons for shoulder instability. Aggressive glenoid bone removal, shortening of the scapular neck, or superior tilt of the baseplate and glenosphere could also be responsible for instability [13, 14]). E3 favard classification glenoid or high-RSA angle of Boileau that are not recognized can lead to superior tilt of the implant [15].

Superior positioning of the glenosphere can also result in inferior impingement between the scapular neck and the humeral polyethylene component resulting in potential instability. When medialization is less than 1.5 cm, Chae et al. [4] recommend increasing the size of the glenosphere, and for medialization more than 1.5 cm, it may be necessary to modify the baseplate by grafting the glenoid or using an augmented baseplate.

Humerus

Philippe Valenti [16] reported that humeral shortening was the most likely cause of revision in a multicenter study of 25 unstable reverse shoulder arthroplasties. Diagnosis was confirmed using bilateral full-length humerus radiographs [17]. In those cases, treatment varies depending on the defect and on the local accessibility to allograft. For Chae [4], a shortening less than 1.5 cm should be treated by increasing the size of the polyethylene component. If the defect is greater than 1.5 cm, stem revision is likely necessary, with or without allograft.

32.2.4 Implant

32.2.4.1 Implant Design

Lateralized center of rotation: Helmkamp [18] reported in a systematic review the advantages and limits of implants with a lateralized Center of Rotation (COR). In his study, RSA demonstrated significant improvements in outcome scores post-surgery regardless of prosthesis type. Overall, this study found no clear difference in outcome scores between the lateralized and medialized COR groups. Although there was a higher reported incidence of scapular notching with medial COR prostheses, there were no clear differences in the rate of instability between the two groups. For Matthewson [12], instability is more likely when there is no subscapularis repair in a medialized RSA design. This element is not significant in lateralized RSA designs [11].

Because humeral shortening is one of the main causes of RSA instability, proximal humerus bone stock is important. Lateralization is mostly performed by the combination between the humeral and glenoid design. Werthel [16] reported the high variability of the center of rotation between all implants designs. Implants are working with a cervico-diaphyseal angle ranking from 155 to 135°. The proximal humeral implant can be inserted in an inlay or onlay fashion, requiring a variable amount of bone removal. Decreasing the cervico-diaphyseal angle biomechanically decreases the impingement in adduction and abduction, and is responsible for a lower notching rate. From a biomechanical perspective, decreasing the cervico-diaphyseal angle decreases the rate of dislocation in internal rotation.

32.2.4.2 Thickness or Design of the PE

Increasing the thickness of the PE is the simplest way to revise the reverse shoulder arthroplasty. It must be done when the surgeon is certain that there is no other cause responsible for instability. Having said that, review of a literature reports that in more than 50% of cases this approach does not provide long-term stability [19]. Biomechanical studies reported that increasing the PE increases the deltoid tension, decreases adduction, but does not increase stability. Retentive PE options may increase stability but are associated with a decreased mobility, particularly in adduction. Retentive PE may also have a higher rate of polyethylene wear that can increase glenoid notching. Based on the literature, PE exchange is indicated in PE wear in chronic cases, but not in acute cases. Kohan et al. [8] found asymmetric liner wear accounted for 60% of late dislocations. Of the late dislocations, 80% had evidence of adduction impingement, via either heterotopic ossification or asymmetric PE wear.

32.2.4.3 Glenosphere

Many biomechanical studies demonstrate that increasing the size of the glenosphere can improve the stability of the RSA [16]. However, this can limit mobility. No clinical study demonstrates that putting a bigger glenosphere decreases the risk of instability. Abdelfattah [9] and other studies confirm the general concept that even when it is unclear if the glenosphere is involved

in the instability, most surgeons will frequently increase the size of the glenosphere when possible. This has proven to be a reliable option in our experience.

32.3 Management of RSA Dislocation

In 2006, Guery [20] reported the midterm survivorship of 80 RSA reporting only two cases of dislocation with Grammont design implants. These cases were treated with closed reduction, and no further revision surgery. Chalmers [21] recommends closed reduction followed by up to 6 weeks of sling immobilization and avoidance of extension, adduction, and internal rotation. The most common associated factors for RSA dislocation were a BMI >30 kg/m^2, male gender, subscapularis deficiency, and previous surgery. Closed reduction alone was successful in only 44% of cases with all others requiring surgical revision. Teusing [22] also reported the rate of successful stabilization after closed reduction of RSA is approximately 50%. Because revision is very complex, many authors propose to try closed reduction prior to revision.

Cheung [19] reported that most RSA dislocations happen in the short postoperative period (8 weeks, from 3 days to 5 months). In her study, postoperative instability was associated with male gender, history of prior open shoulder surgery, and preoperative diagnoses of fracture sequelae, particularly proximal humeral or tuberosity nonunion. Absence of subscapularis repair was an independent predictor of instability. Patients had revision by placement of a thicker polyethylene component but 5 of the 11 patients (45%) in the instability cohort sustained a second dislocation and needed revision with a bigger glenosphere and thicker PE.

It is important to remember that infection can be a contributing factor to instability. Gerber suggests early dislocations are related to surgical errors and thus are less likely to be successfully treated with closed reduction.

Kohan [8] reported that the most common procedure of revision was to increase the thickness of the PE (5 mm for early dislocation and 7.5 for late dislocation) with a retentive PE in almost 50% of cases. The failure rate was around 30% with this particular approach.

32.4 Salvage Procedures

The global rate of new dislocation after revision of any kind of arthroplasty by RSA is between 3% and 11% [7]. Kohan reports [8] recurrent instability after revision of RSA is 29% of early and 40% of late dislocators.

In case of recurrent dislocation after surgical treatment of unstable RSA, several procedures have been proposed with very limited numbers. Conversion to hemiarthroplasty decreases pain and improves function. Hardware removal with resection arthroplasty can be also a solution to prevent new dislocation but with limited function and persistent pain [23]. For revision, RSA is useful but the two major complications are glenoid loosening and instability [24]. Bois [25] recently confirmed in cases of revision RSA, instability is the most frequent complication, especially when the revision is for a failed reverse. Some authors have reported the use of tendon transfer to treat deltoid palsy or insufficiency but harvesting the pectoralis major can further add to RSA instability.

32.5 Conclusion

One of the most frequent complications of RSA is instability, most commonly occurring after revision surgery. For early instability, closed reduction and immobilization for 6 weeks can be effective in approximately 50% of cases. When surgical revision is necessary, a careful assess-

ment is necessary of the soft tissues, bony parameters, and component position. A step-by-step analysis and revision must be planned with an understanding of revision options for a particular system. Even with revision, almost 30% of cases will dislocate again, demonstrating the importance of a well-executed primary surgery (Figs. 32.2 and 32.3).

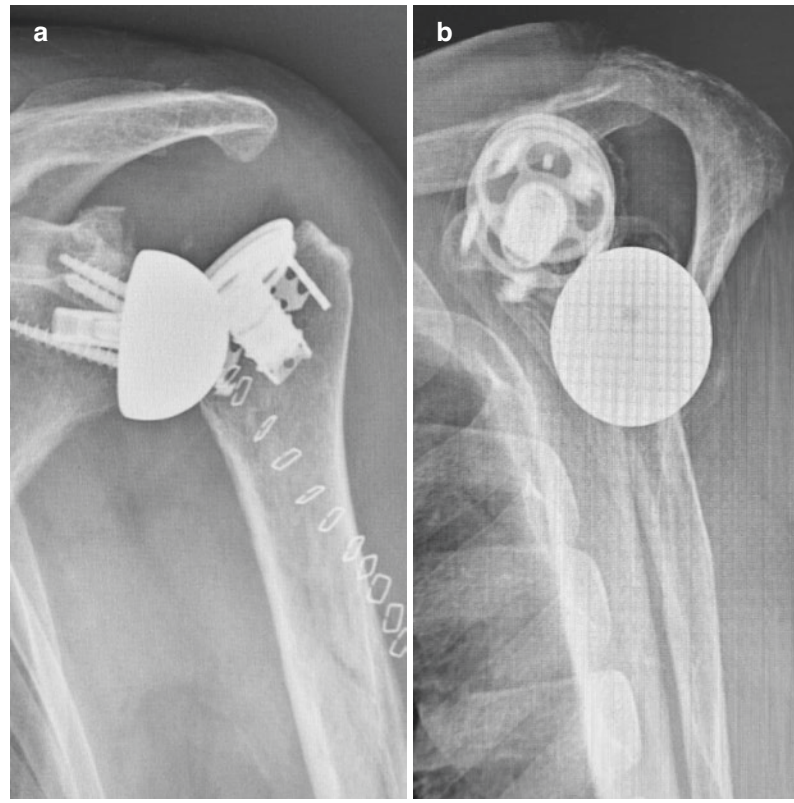

Fig. 32.2 (**a**, **b**) Postoperative AP and profile view of RSA dislocation

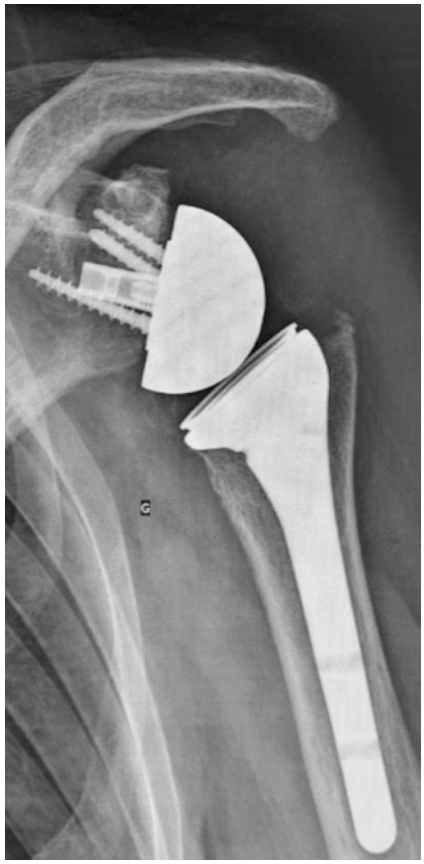

Fig. 32.3 Revision with increased size of glenosphere, keeping in place the baseplate, and no proximal bone loss allowing revision with uncemented stem

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Options for the Catastrophic Failed Reverse Shoulder Prosthetic

33

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33.1 Introduction

Originally approved in 2004 with a single indication of cuff tear arthropathy, the reverse total shoulder arthroplasty's (RTSA) utility has grown exponentially [1, 2]. Indications have since expanded to cover conditions such as end-stage glenohumeral arthritis with bone loss, rheumatoid arthritis, post-traumatic arthritis, osteonecrosis, revision arthroplasty, proximal humeral fractures of the elderly, infection, instability, and tumors. With the indications of the procedure growing, so has the annual incidence of the procedure across the nation [3–5]. While rotator cuff tear arthropathy in the setting of end-stage arthritis remains the most common indication for the procedure [6, 7], RTSA is now being performed on patients with an irreparable cuff tear without glenohumeral arthritis [8].

Management of patients with severe cuff dysfunction is challenging even more, so they happen to be young and active. For a period of time, it was generally accepted that patients younger than 65 years of age were not recommended for an RTSA procedure. Therefore joint sparing treatment options were used such as physical therapy, steroid injection, debridement, and tendon transfers but often failed to provide pain-free function [9, 10]. There are multiple variables when accessing a cuff tear including size/shape of tear, age of patient, acuteness of injury, and strength of secondary muscles, all of these factors are compounded in a patient who has previously failed cuff repair surgery [8, 11, 12]. The main factors after this point are the age of the patient, degenerative changes in glenohumeral joint, and the functionality of the shoulder [8].

Proper indication and patient selection are very important with RTSA as the complication rate has been reported to be approximately 15% but has been reported to be as high as 68% in revision surgery with an estimated longevity of the prosthesis to be around 10 years [13–17]. For these reasons, surgeons must take great care when deciding to operate on young and highly functional patients. New studies are now showing promising results when RTSA is utilized in younger patients with a substantial gain in overall function and reduction of pain if done with minimal complications, however, the literature continues to illustrate a high rate of complications with this procedure [9, 18]. Importantly for future management, these studies have demonstrated that outcomes are significantly inferior in patients who have previous cuff repairs or debridement surgery prior to their definitive arthroplasty procedure.

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The most common complications associated with an RTSA are dislocation, infection, notching, and scapular spine fractures. Additional complications can include glenoid fractures, humeral fractures, glenoid sphere and base loosening, nerve palsies, and symptomatic hardware [16, 17]. Additionally, there is a significant increase in complications with revision surgery compared to primary [16]. Surgeons must take careful consideration to implant design, soft tissue management, areas of impingement, and proper technique to reduce the probability of these issues arising.

The goal of this chapter is to discuss the options available to surgeons in the situation of a failed RTSA. Expand on the current literature available on treatment options for these patients will be reviewed. Different case studies will be used to demonstrate available options for treatment. Finally, the author will discuss their preferred technique when handling a catastrophic failed RTSA.

33.2 Literature Review

33.2.1 Instability

In 2011, Zumstein et al. performed a systematic review, and during that review, they defined a complication as an intraoperative or postoperative event that it was likely to have a negative influence on the final outcome (infection, dislocation, nerve palsies, aseptic loosening, and disassociation of components) and used the term "problem" for events perceived as adverse but unlikely to affect final outcome (notching, hematoma, heterotopic ossification, algodystrophy, intraoperative fractures, cement extravasation, or glenoid lucent lines) [19]. Their systematic review of 21 different cohort studies looked at 782 different cases. A problem rate of 44% was reported with radiographic scapular notching being the most prevalent. The complication rate was noted to be 24% with instability (4.7%) and infection (4%). It is important to point out that both problems and complications were shown to be twice as high in patients undergoing revision surgery compared to the primary arthroplasty patients (33.3% vs. 13.4% and 12.5% vs. 6.0%). Patients with an etiology of cuff tear arthropathy or rheumatoid arthritis had the highest rate of reoperations at 11.9% and 26.1%, respectively [17, 19].

Dislocation or instability is often the most commonly reported complication after an RTSA and represents a major concern for surgeons. It has been proposed that dislocation often occurs in abduction and extension. Additionally, a reverse shoulder prosthetic relies on the deltoid muscle to compensate for the absent rotator cuff. The deltoid is used effectively as a lever arm and proper tension is necessary or the risk of instability increase [17, 20]. The prothesis center of rotation (COR) plays an important role as well. It is thought that with a medial COR, the pull of the deltoid muscle is skewed resulting in a potential dislocating effect [21], thus leading surgeons to try more lateralized COR. Edwards et al. noted that when using a medial COR and a deltopectoral approach, instability doubled when the subscapularis repair was not obtained compared to when it was obtained [22].

Teusink et al. looked at 21 patients treated with closed reduction for dislocation after reverse arthroplasty. They noted nearly 50% of these patients had prior surgery with over 50% of them having a previous arthroplasty highlighting the previously mentioned increase in risk with revision surgery. Average time to first dislocation was 200 days but 62% of them dislocated within the first 90 days. With closed reduction and temporary immobilization 62% of these dislocations were stable at 28 months, 29% required revision surgery, and 9% remained unstable indicating closed reduction can be successful [20]. For the cases that are not successful with closed reduction, revision surgery is often required which exposes the patient to further complications and increasing the risk of infection.

33.2.2 Infections

While infections happen at a lower rate than instability, the infection rate for RTSA is higher

than that of anatomic shoulder arthroplasty, this is thought to be related to larger dead space, increased implant surface area, and complexity of indications for RTSA [15]. Anatomical shoulder arthroplasty has infections rates reported as low as 0.7% for primary and 3.15% for revision [23]. Infection rates for RTSA have been reported anywhere from 1% to 15% [17]. A prospective study done by Trappey et al. looked at 284 patients receiving RTSA, an infection rate of 1% for primary and 7% for revision procedures was the result [24]. Richards et al. looked at 3,906 patients receiving total shoulder arthroplasty and found that younger patients and being male were at a higher risk of infection [25]. Interestingly additional studies found that smoking, rheumatoid arthritis, and obesity did not significantly increase the risk of infection [24–26].

Similar to other joint arthroplasty procedures, appropriate preoperative antibiotic prophylaxis administered within 1 h of incision is mandatory. Once a postoperative infection is identified, antibiotics should be continued until cultures can confirm the bacteria present. One popular species of bacteria is *Propionibacterium acnes* which can take up to 14 days to grow and identity through culture [15, 27]. Acute infection (<6 weeks) should initially be managed with irrigation, debridement, and polyethylene exchange. Chronic infection (>6 weeks) requires more invasive management with a two-stage revision: Stage 1: hardware removal, irrigation and debridement, and placement of antibiotic spacer with a minimum of 6 weeks of IV antibiotics. Stage 2 consists of prosthesis reimplantation after all cultures and blood tests are negative. New evidence is showing that a one-stage exchange with irrigation and debridement, reimplantation, and IV antibiotics can also be effective for chronic infections [15, 28].

Scapular spine fractures have been associated with less medialization of the glenoid baseplate. It has been postulated that the dependence of the prosthesis on the Deltoid muscle may be the cause of the stress type fracture. Most respond to rest, but occasionally fixation may be required.

Scapular notching is a common radiographic finding after reverse shoulder arthroplasty of unknown significance. It refers to erosion of the lateral scapular neck due to impingement of the humeral component on the scapula in adduction. The incidence and severity are thought to be associated with surgical technique and prosthetic design. The Nerot–Sirveaux radiographic classification system is the most widely used. The more severe grade 3 and 4 may indicate polyethylene wear and potential baseplate loosening (Ref. Friedman 2019).

33.3 Treatment Options: Authors Preferred Technique

33.3.1 Instability

Dislocation of an RSP is unfortunately not uncommon, occurring more than 10% of the time in some studies. Faucet, a simple closed reduction with local anesthesia or sedation may be possible. Infection must be ruled out as well but in some cases, a simple closed reduction followed by a period of immobilization may be effective. Most cases will require open reduction and a change in some part of the construct, either diameter of the glenosphere, a change in version of the humeral or glenoid component or liner change to improve both the biomechanics of the construct and the Deltoid tension and function.

In a classic Gramont prosthesis (medial center of rotation and inlay humeral component), subscapularis repair or reconstruction may be useful to prevent dislocation. In the more lateral designs, instability may occur more due to bone impingement. Soft tissue repair in these systems may also improve stability.

In evaluating the unstable RSP, one should evaluate the baseplate inclination, version, and size of the glenosphere. The axillary view may help to evaluate bone impingement. CT scan with 3D reconstruction may help in further assessing areas of impingement and version mismatch. Once the evaluation is complete, a surgical plan can be developed. Any superior tilt, anteversion, or retroversion may require a complete revision of this part of the shoulder. In revision cases in

which the humeral stem requires revision, the Deltoid attachment must be preserved.

The dislocation may be readily apparent on examination in most cases except for the mobidly obese patients but all should have radiographs (Fig. 33.1a, b). The surgical plan is developed, and the revision surgery should improve balance and biomechanics, leading to a successful result (Fig. 33.1c–e).

In more severe cases of recurrent instability cases, Tachidan has pioneered a technique using suture tape under the glenoid baseplate or glenosphere and wrapped around the humeral stem to provide additional stability. This cannot make up for the biomechanical deficiency but is useful in revision situations to provide temporary stability while the soft tissue envelope heals.

33.4 Infection

Infection after RSP can be devastating and unfortunately not uncommon. The large amount of dead space that is present, the patient age, nutritional and immunological status often make them at higher risk for infection. Preventative measures may include bathing in antibiotic soap (Hibiclens), double prepping prior to beginning the procedure and frequent irrigation, and glove change may also be beneficial.

Infection should be suspected in the painful arthroplasty. Comparing the skin temperature of both shoulders by placing one hand on each shoulder at the same time can provide the clinician evidence of slight increase in warmth of the infected shoulder. In addition, redness or blotches on the skin may be noticeable. Radiographs may eventu-

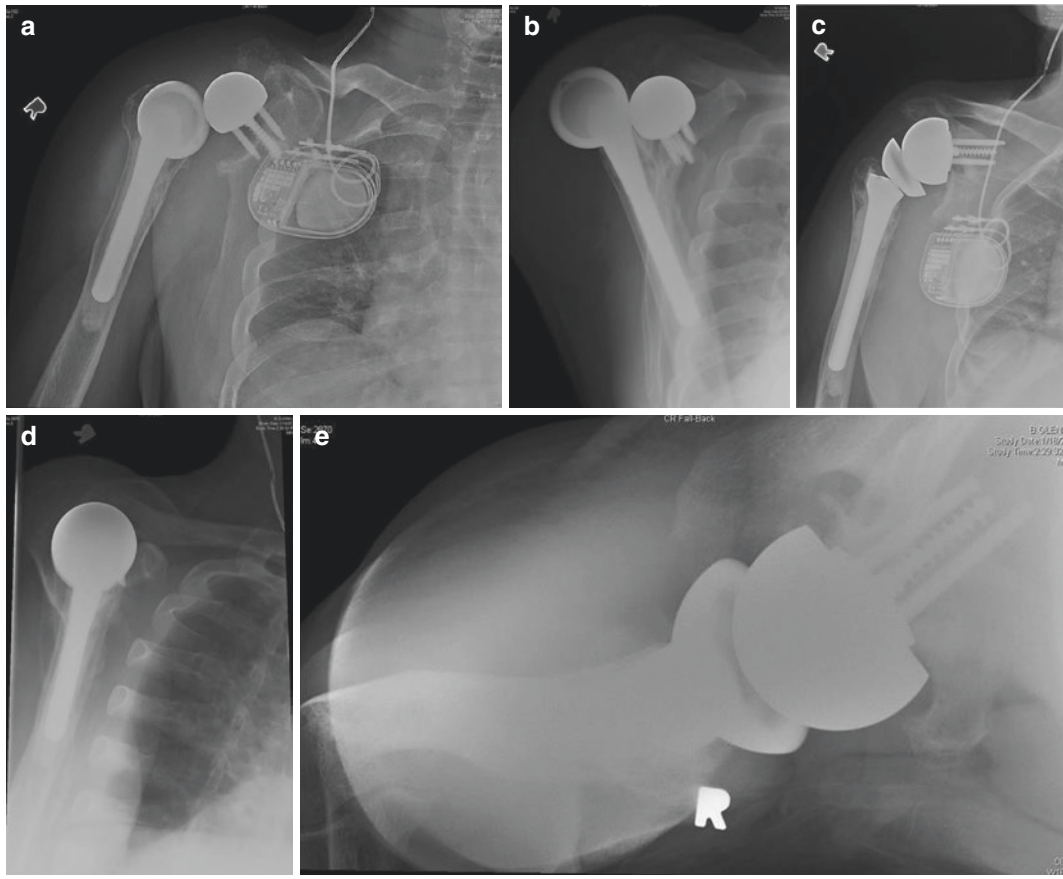

Fig. 33.1 (**a**, **b**) AP and Scpaular "y" view radiographs showing dislocation of right reverese shoulder prosthesis with displacement of the glenosphere aftet a traumatic fall. Figure 33-1 (**c**, **d**, **e**) AP, Y and Axillary views after complete revision of the traumatic dislocation showing improved placement of the prosthesis

ally show lucent lines around various parts of the prosthetic components but often they are completely normal. Initial lab work should include CBC, erythrocyte sedimentation rate, and C reactive protein levels. These may be normal, but we also obtain an interleukin 6 level which is usually elevated, even in *Cutibacterium acnes* infection. Aspiration and testing of the aspirate may be beneficial. In some cases (Fig. 33.2), the infection may be readily apparent on inspection of the wound.

Once the infection has been diagnosed, a decision on one- or two-stage treatment needs to be made. In Chap. 31 by Voss et al. in this textbook, infection after rotator cuff surgery is discussed in excellent detail. The infected reverse shoulder replacement is often more problematic. Frankle has had success with one-stage revision in certain circumstances, but this has rarely worked in our practice. Similarly, the standard shoulder prostalac has often proven to be ineffective in maintaining length and stability (Fig. 33.3a–c).

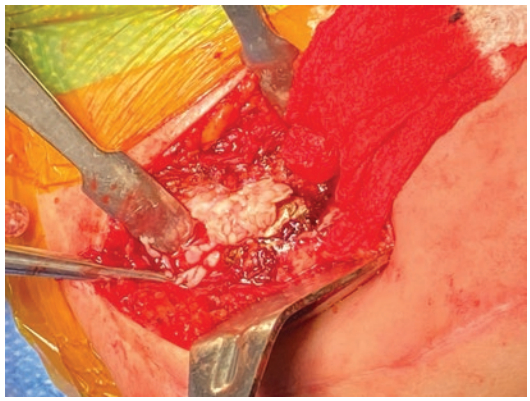

Fig. 33.2 Intra-operative view of purulence and tissue reaction from a severely infected reverse shoulder prosthesis

We have found two-stage revision utilizing a hip prostalac to fill the void created by prosthesis removal and maintain lateralization of the deltoid to be the most effective in managing the infection and preserving anatomy for later revision.

In Fig. 33.4a, b, radiographs of an elderly female with a painful reverse shoulder placed for rotator cuff tear arthropathy are shown. During the surgery, she sustained a non-displaced fracture of the humeral shaft treated with a cerclage wire. Although she had pain after the surgery, it was initially thought it was due to the fracture. However, the pain continued to worsen and motion declined. Initial lab work was negative and she was referred for more extensive evaluation. Repeat routine lab work was again negative but Interleukin 6 was extremely positive. CT scan showed lysis around the stem and the baseplate. Stage 1 surgery involved extensive debridement and removal of the prosthesis with multiple tissue biopsies and cultures with the placement of a hip prostalac spacer to full the soft tissues. Fig. 33.4c Tissue biopsies were + and cultures grew

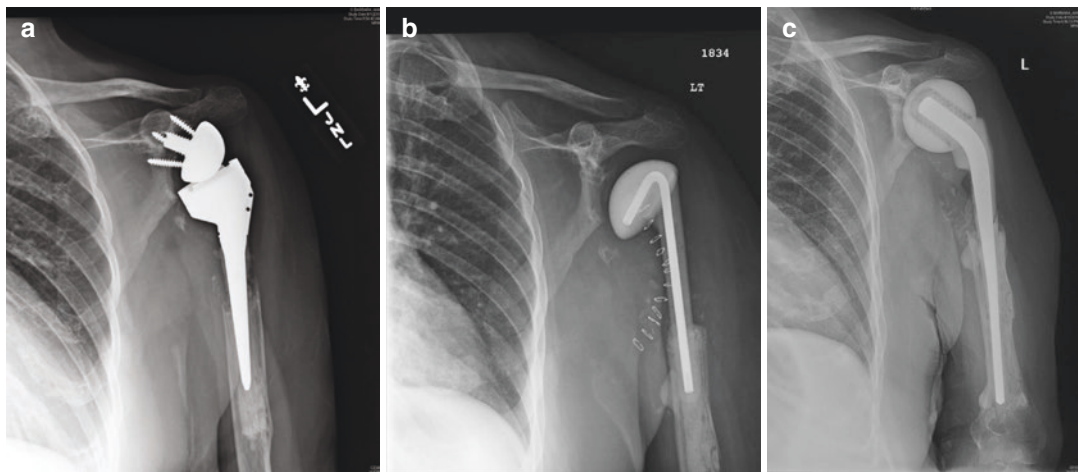

Fig. 33.3 (**a**) An infected prosthesis with loss of humeral bone is identifed in the radiograph. (**b**) Ap shoulder and removal of the prosthesis and placement of preformed humeral prostalac, wiht inadequate filling of the glenohumeral space and minimal humeral canal fill. (**c**) Example of a preformed hip prostalac with excellent filling of both the humeral canal and the glenohumeral joint

C. Acnes. Six weeks of IV antibiotics were followed by oral antibiotics for the next 6 months with the prostalac in place. Her pain resolved within 2 weeks of the removal and her function improved from a Sane of 20 to 1 of 50. Six months postoperatively her interleukin 6 level finally returned to normal and we were able to reimplant a new RSP with satisfactory results, improving her SANE rating to 65 (Fig. 33.4d).

Another issue that can occur is acromial fracture. In most cases, this can be managed by a brief period of rest with resolution of symptoms. In more severe cases, fixation may be needed but this can be problematic due to thin skin and risk of infection. In severe cases, one may have to remove the baseplate and temporarily convert to a hemiarthroplasty to take pressure off the scapular spine/acromion area until the fracture heals. In the featured case this 84-year-old lady sustained an acromial fracture that underwent fixation. It became infected, eventually resulting in the removal of the acromion and the Deltoid origin with complete loss of function (Fig. 33.5).

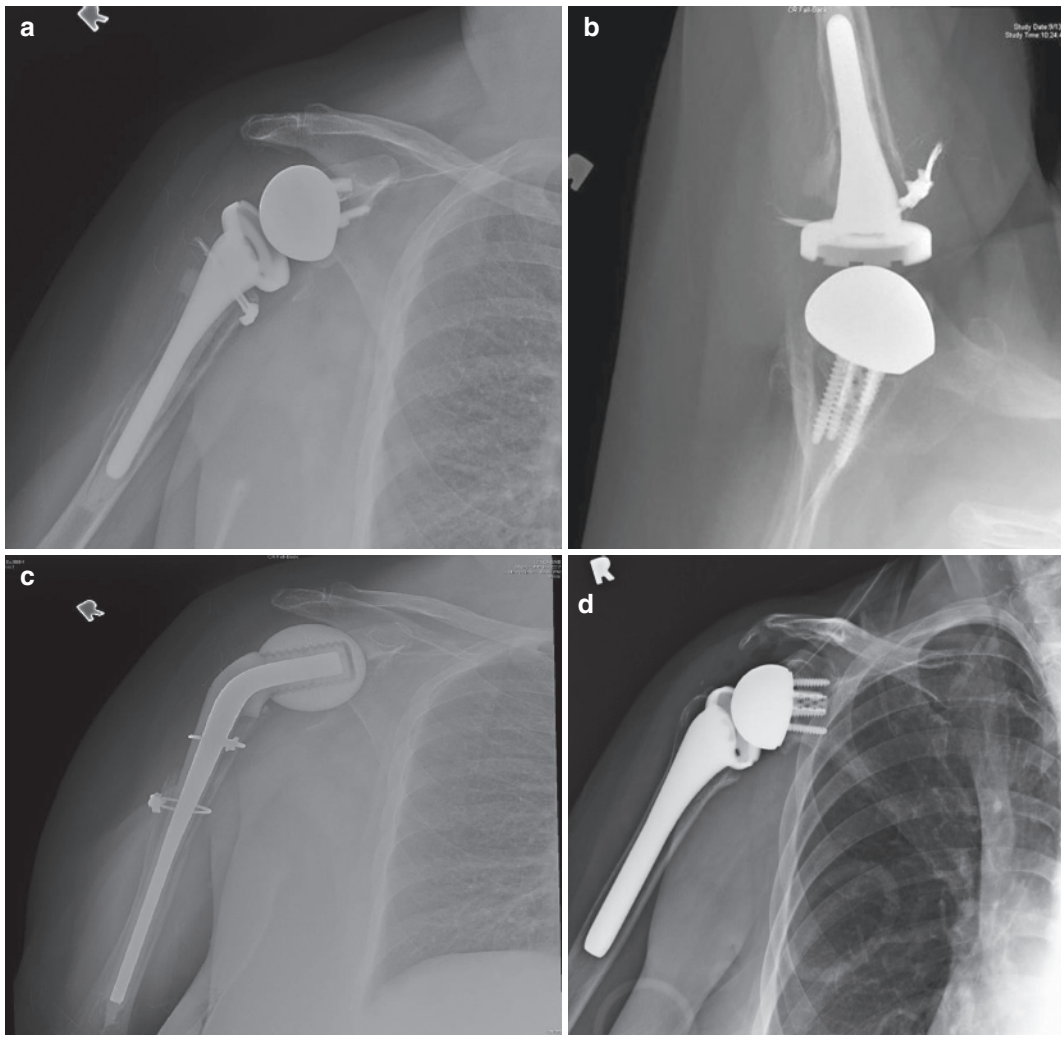

Fig. 33.4 (**a**) AP view of a reverse shoulder prosthesis with cirlage wire fixation of humeral fracture. (**b**) Axillary view of the same shoulder demonstrating the broken circlage wire and radiolucencies around both the humeral and glenoid components. (**c**) Stage 1 revision with removal of the implant and placement of a preformed hip prostalac to fill both the glenohumeral joint and the humeral canal . (**d**) Stage 2 revision showing a radiograph of the revision of the prostalac to a new Reverese shoulder 6 months post stage 1 and after the infection resolved, resulting in approximately 60% of normal function and minimal pain

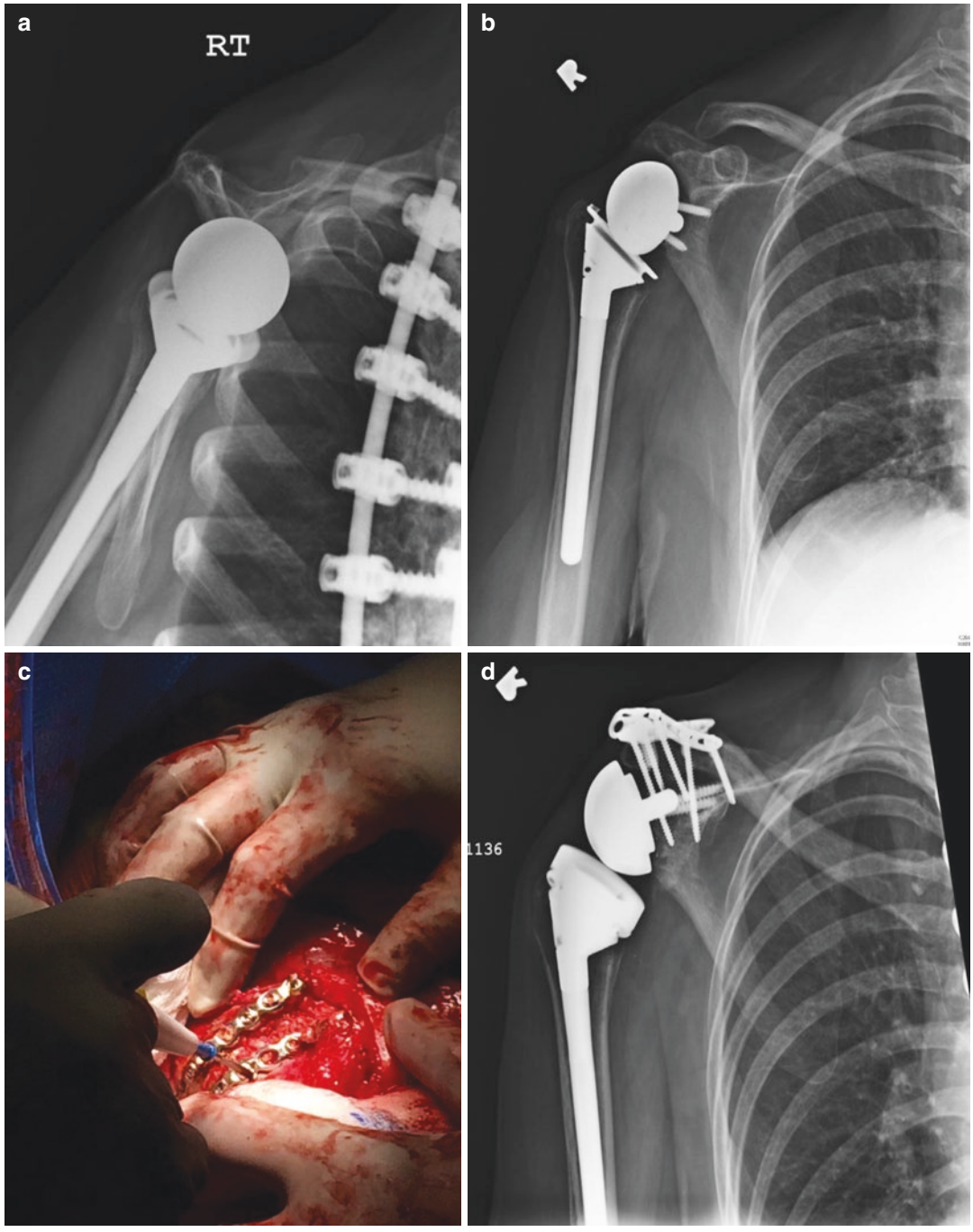

Fig. 33.5 (**a**, **b**) Scapular "y" and AP views of an acromial and scapular spine fracture with displacement and deltoid insufficiency. (**c**) open view of the fractures being plated for stabilization and the Deltoid origin being reconstructed. (**d**) radiograph showing healed fractures and stability of the prosthesis resulting in a functional SANE score of 75

33.5 Conclusion

The failed RSP is unfortunately becoming more common. Replacement after failed rotator cuff surgery may not have a good outcome as primary RSP and risks an increased rate of complications. Dealing with failed reverse shoulder replacement requires an advanced understanding of the shoulder and the prosthesis in order to achieve a good result. In cases of significant bone loss and infection, a two-stage revision utilizing a hip prostalac may provide the best chance for limb preservation.

Conflict of Interest

Disclaimer: None.

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34 Resection Arthroplasty Versus Arthrodesis Versus Amputation

Benno Ejnisman, Bernardo Barcellos Terra, Gyoguevara Patriota, Carlos Vicente Andreoli, and Paulo Santoro Belangero

34.1 Introduction

Resection arthroplasty, arthrodesis, and amputation are salvage procedures in severe shoulder pathologies.

Basically, the indications for resection arthroplasty or arthrodesis are similar, and used in cases of deep periprosthetic infections, following a failed prosthetic replacement or as a treatment for non-reducible fractures. Amputations resulting from unsuccessful procedures in shoulder procedures are rare and absolutely considered an exception.

The optimal therapeutic option should be taken based on the characteristics and the clinical history of the patient.

34.2 Resection Arthoplasty

Resection arthroplasty was historically performed as a treatment for non-reducible fractures [1]. Nove-Josserand concluded in 1916 that function shoulder severely reduced after resection [2, 3]. Total shoulder arthroplasty and hemiarthroplasty are relatively common procedures for the treatment of various disorders of the shoulder. Outcomes of the procedures continue to improve, but infection remains a devastating complication. The rate of infection ranges from 0.7% to 2.7% after total shoulder arthroplasty and 1.3% for hemiarthroplasty [4, 5]. One salvage procedure for treating deep periprosthetic infections is shoulder resection arthroplasty. Authors have previously reported the clinically relevant limitations of resection arthroplasty, including limited range of motion and poor outcomes in scoring methods.

In 1985, Cofield [2] reported pain relief in 50–66% of patients submitted to this procedure, but also reported poor functional outcomes, especially as limited strength and abduction <90.

In 2001, Sperling et al. [6, 7] compared resection arthroplasty, debridement and prosthesis retention, direct exchange, and delayed reimplantation. After 2 years of follow-up, the resection arthroplasty group presented pain reduction in 10 of 11 patients. Strength was poor in 5 patients, fair in 3, and good in 2. They concluded that three shoulders were successful and eight unsuccessful.

Braman et al. in 2006 [1] reviewed outcomes at 20 months follow-up for seven patients with resection arthroplasty. All patients could reach their opposite axilla, their back pocket, and their mouth, but no patient had satisfactory results based on Neer's criteria. They concluded that resection arthroplasty is a reasonable option for patients who are poor candidates for reimplantation techniques.

In 2006, Debeer et al. [3] described outcomes after seven resection arthroplasties using pain

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relief, Constant score, and DASH. All patients had excellent pain relief, but functional outcomes were poor, with a mean Constant score of 25.7 and mean DASH of 69.3. Nevertheless, they also concluded that resection arthroplasty is a reasonable option for infection of the shoulder, especially in elderly patients and in those with intolerable pain.

In 2007, Rispoli et al. [4] corroborated Cofield's previous observation that pain relief was achieved in 50–66% of resection arthroplasties. In 2011, Weber et al. [8] compared two-stage exchange procedures with resection arthroplasty. They determined that exchange procedures had only slightly improved functional outcomes compared with resection arthroplasty and concluded that resection arthroplasty is a reasonable option for the treatment of infected shoulder prostheses.

Our unpublished experience with resection arthroplasty comprises 19 patients of persistent shoulder infection after arthroplasty. After minimum 22 months of follow-up and average age of 68 years, we obtained an improvement in VAS (Visual Analog Scale of Pain) from 7.6 to 1.8, an average elevation of 35°, external rotation of 15°, and internal rotation with hand at the waist. We believe that shoulder resection arthroplasty (Jones surgery) is an option as a salvage procedure for patients with infected shoulder arthroplasty and when revision options are not applicable, especially in patients with severe comorbidities. The procedure aims pain relief, but there is no gain in range of motion.

34.2.1 Technique

The procedure is performed through a deltopectoral approach, with the patient in the beach chair position. Multiple cultures are taken during the procedure. Humeral resection is proximal to the deltoid insertion. The wound is extensively debrided and irrigated before closure. If infection is present, there is an option to use antibiotic spacers placed in the humeral shaft. If possible after resection, the remaining of the cuff is sutured to the humerus to act like an interposition. Patient wears a sling for 6 weeks postoperatively and then is allowed to start self-guided active-assisted and then active range of motion (Fig. 34.1a–e).

34.3 Shoulder Arthrodesis

Shoulder arthrodesis may relieve pain and instability in a variety of patients. Although typically an end-stage procedure, common indications for shoulder arthrodesis include reconstruction after tumor resection, failed arthroplasty, brachial plexus injury, chronic infection, and refractory shoulder instability [9–11].

Glenohumeral arthrodesis following a failed prosthetic replacement is a technically demanding procedure. The need of bone graft is determined preoperatively. The volume of bulk structural graft that is typically needed is difficult to obtain from the patient's iliac crest, and thus a femoral head allograft is preferentially used. When the tuberosities are missing or not attached to the humeral shaft and a large portion of the proximal part of the humerus is deficient, a vascularized fibular autograft can be used to provide a reconstructive solution.

34.3.1 Technique

Patient is placed in lateral decubitus position and the forequarter shoulder area is sterilely prepped and draped, with special attention to maintaining the ability to check the final positioning of the shoulder.

The optimal position of the fused shoulder is controversial [12, 13]. In a fusion following a failed arthroplasty, the position that will allow proper function needs to be balanced with the position of the remaining humeral and glenoid bone that will optimize bone-to-bone contact, stability, and ultimately osseous union. The position of fusion that we regularly chose is 10–20° of abduction, 10–20 of flexion, and 3545 of internal rotation. This position generally allows the patient to reach the mouth, waist, back pocket, and contralateral shoulder, thus facilitating activities of daily living. When the tuberosities are

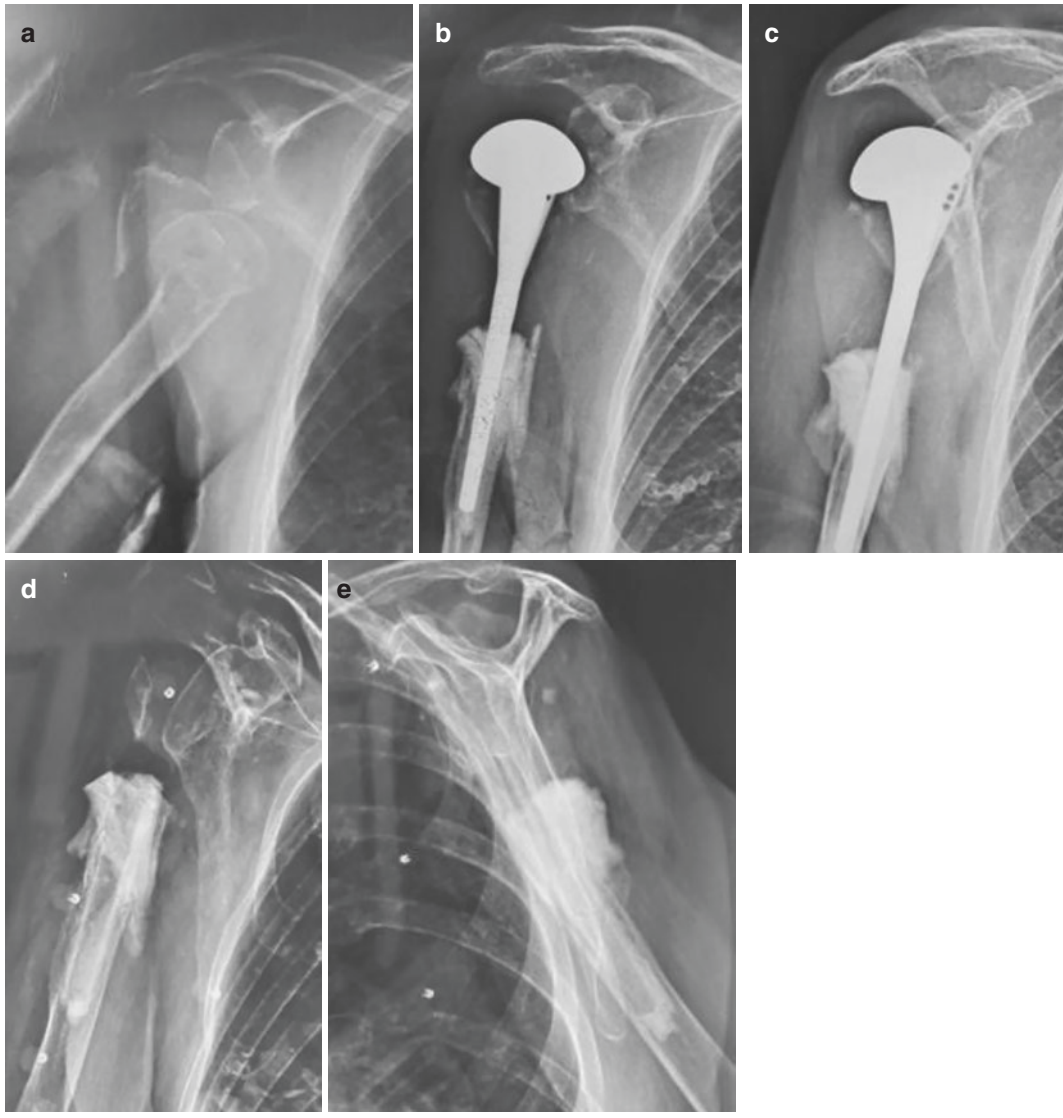

Fig. 34.1 (**a**–**e**) The patient initially had a proximal humeral fracture, submitted to a partial humeral arthroplasty. Evolved to infection and loosening of the humeral component. Opted to perform a shoulder resection arthroplasty

intact, they should be shaped with minimal bone removal and fit around the glenoid. Given that the tuberosities have a significant blood supply, the potential for fusion is enhanced.

A posterolateral approach to the shoulder is used, extending proximally over the scapular spine and distally over the posterolateral aspect of the humerus. An incision is made, and once dissected to the scapular spine proximally, the bone is followed distally to the attachment of the posterior portion of the deltoid. The axillary nerve is identified with its associated vessels. Ligation clips are applied and the nerve is transected with its vessels because the deltoid will no longer be functional with the shoulder joint being fused, although some advocate preserving the nerve to maintain the deltoid for shoulder contour. At this point, the lateral aspect of the acromion is osteotomized and reflected anteriorly to facilitate exposure. The posterior capsule is opened and the humeral head is subsequently dislocated posteriorly. Once the shoulder is dislocated, the suprascapular nerve and

associated vessels may be identified crossing the spinoglenoid notch. They are similarly ligated and transected, allowing for the mobilization of the rotator cuff muscles from the scapula for identification of bony anatomy, specifically the inferior aspect of the neck and glenoid. An oscillating saw is used to create the bony cuts. The goal is to obtain both glenohumeral and subacromial fusion. First, a cut is made on the glenoid surface perpendicular to the axis of the glenoid, removing just enough to expose the bleeding subchondral bone. Next, the proximal humerus is cut to form a bony block. These humeral cuts are important in determining the final position of the shoulder. The superior cut is paramount to determining flexion and abduction position, whereas the medial cut has a major role in determining the rotational position of the joint. The greater tuberosity may be cut as well to allow for better lying of the plate on the bone. Once these cuts are made, the inferior aspect of the acromion is decorticated using a variety of instruments. A pre-contoured 4.5-mm dynamic compression plate lies over the crimson and humerus for fixation.

The goal is to provide adequate fixation and screw purchase so that only a sling is necessary postoperatively and no shoulder spica cast is needed. Typically, four screws in the scapular spine and four bicortical screws in the humerus are sufficient. Additional screws aid in compression and fusion. The first screw is placed from the plate through the scapular spine and glenoid, and the second is placed from the plate through the humeral head and glenoid. Remaining screws are placed, with the bicortical humeral screws being placed in compression (Fig. 34.2). Once fixation is achieved, the glenohumeral and subchondral regions have been compressed, and any gaps may be filled with autologous bone from the previous cuts. The lateral aspect of the acromion maintains its vascularization, as it was reflected forward previously, so it is then repaired to the plate using nonabsorbable suture to provide further bony coverage. The tissues are closed in layers, with attention to providing soft-tissue coverage to the hardware.

Functional motion is assessed by ranging the patient's elbow to ensure the possibility to reach the mouth with ease.

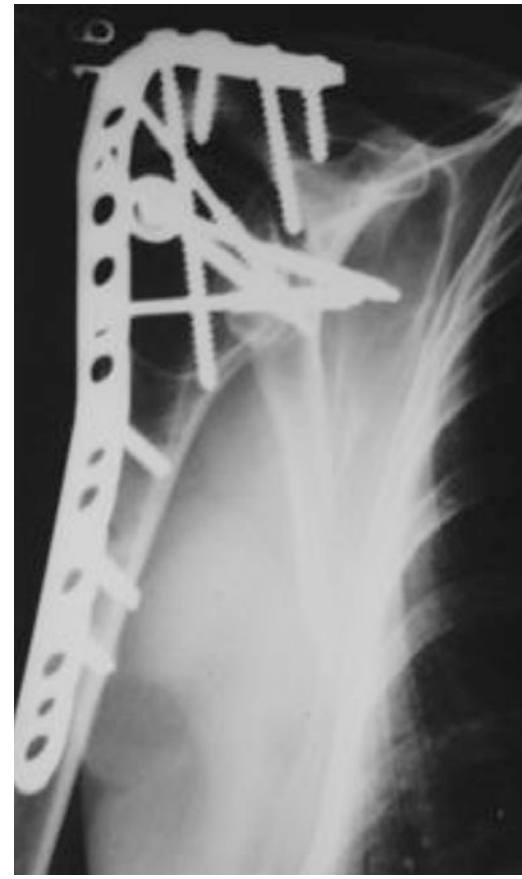

Fig. 34.2 Radiography of a patient who submitted a shoulder arthrodesis due to a failure of primary synthesis after fracture of the proximal humerus

Glenohumeral arthrodesis following a failed prosthetic arthroplasty is a salvage procedure requiring realistic expectations from both the patient and the surgeon. The indications should be appropriately narrow to include only patients in whom additional reconstructive options would not be likely to provide a benefit. Also, some patients with remaining deltoid muscle function may preferentially be candidates for revision arthroplasty.

34.4 Upper Limb Amputation

The prevalence of amputations was 1.6 million in 2005, with projections that the prevalence may double by the year 2050 [14]. Part of this increase,

after years of decline, might be related to the diabetes epidemic that will eventually force amputation in some patients. The risk of limb loss increases with age (greatest risk is age 65 and above).

Amputation for upper limb, is mainly due to trauma, accounting for 80% of cases usually in men aged 15 to 45 years. The second most prevalent cause is cancer/tumors and vascular complications of diseases.

Amputations resulting from unsuccessful procedures in shoulder arthroplasties are rare and absolutely considered an exception. Scientific literature is poorly on this topic [15]. We believe that this option should be the last therapeutic option to do for the patient, as a case in which the patient is at risk of life or wishes to have his limb amputated due to a limb that is painful and nonfunctional.

34.4.1 Anatomy

In shoulders, there are three main types of amputations. The forequarter amputation involves the resection of the clavicle and all structures distally. Shoulder disarticulation, involves complete removal of the humerus from the glenoid, when possible, the scapula is retained to prevent disfigurement of the back. Rotator cuff tendons are sutured together over the glenoid wing and deltoid is attached to the inferior glenoid and lateral scapular border to fill the subacromial space. Finally, transhumeral amputations can occur at any length of the humerus.

34.4.2 Forequarter (Inter scapulothoracic) Amputation

This amputation involves removing the full upper limb and shoulder joint from the scapula and thoracic wall. This extensive procedure is indicated mostly in patients with malignant tumors that infiltrate the shoulder muscles or severe trauma. There are two approaches, anterior and posterior. The anterior approach starts with an incision from the lateral border of the sternocleidomastoid, extending laterally across the clavicle, crossing the acromioclavicular joint, and the superior scapular spine.

The incision then goes inferiorly along the vertical border of the scapula to the scapular angle. The lower part of the incision begins at the middle third of the clavicle and progresses along the deltopectoral groove and connects to the upper part of the incision at the angle of the scapula. The clavicular portion of the pectoralis major is reflected to expose the clavicle, and the external jugular vein is retracted from the field. The clavicle is resected at the lateral sternocleidomastoid to preserve the contour of the neck. Disarticulation occurs at the acromioclavicular joint. Further muscles and soft tissue that hold the shoulder joint to the chest wall are separated, and the limb is removed. The closure is done by suturing the remaining muscles, including the pectoralis major and trapezius over the lateral chest wall for additional padding.

Each type of amputation has clinical significance in functional ability, aesthetics, and prostheses management [14, 16–18].

34.5 Summary

Resection arthroplasty, arthrodesis, and amputations are salvage procedures and require the cooperation of an interprofessional health care team that includes physicians, surgeons, specially trained nurses, and physical and occupational therapists, all working and communicating together to bring about optimal patient care and outcomes.

Basically, the indications for resection arthroplasty or arthrodesis are similar, and used in cases of deep periprosthetic infections, following a failed prosthetic replacement or as a treatment for non-reducible fractures. Amputations resulting from unsuccessful procedures in shoulder procedures are rare and absolutely considered an exception. This option should be the last therapeutic option restricted to threatening situations. These three surgical procedures can relieve pain, however they limit shoulder function. The optimal therapeutic option should be taken based on

the characteristics and the clinical history of the patient.

Mesh Terms:

- Arthrodesis
- Amputation
- Arthroplasty replacement
- shoulder
- infection

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35 Rehabilitation of the Patient with a Failed Rotator Cuff

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35.1 Conservative Treated Rotator Cuff Retears

As the incidence of retears after a rotator cuff repair remain high [1, 2], a comprehensive treatment and rehabilitation protocol must be chosen depending on the circumstances of the injury [3]. When choosing between an operative versus a nonoperative approach, surgeons must consider multiple factors including patient presentation and goals of the patient. Rotator cuff revision surgery should be explored in younger and active patients presenting with a traumatic tear [4, 5]. Whereas, in older patients, a nonoperative rehabilitation approach might be indicated, especially for atraumatic failed rotator cuff repairs [4, 5]. However, the surgeon must raise patients' awareness that an operative approach has an increased risk of retear [6] or that a nonoperative approach requires compliance with a long-term rehabilitation program [3–5]. To this, nonoperative rehabilitation has been moderately successful in the treatment of initial rotator cuff ruptures, thus, might be translated in the rehabilitation of rotator cuff retears. The goals of rehabilitation are as follows [3, 5]:

1. Pain relief.
2. Improve shoulder range of motion.
3. Strengthen rotator cuff, deltoid, and periscapular musculature.

As rotator cuff tears can present with excruciating pain, they can significantly worsen a patient's quality of life. Thus, current literature has shown that physical therapy can improve pain after a full-thickness rotator cuff tear [7], with NSAIDs being used as an adjunct. Subacromial corticoid steroid injections are commonly used in practice, yet systematic reviews have been unable to elucidate any clear benefits and their benefits are comparable to that of NSAIDs [8, 9].

Glenohumeral joint mobility, active/passive range of motion, and muscular flexibility should be normalized prior to advancing with a strengthening program. Advanced strengthening of a shoulder with capsular limitations not only takes the focus off the primary concern of stiffness but also can result in rotator cuff tendonitis or tendinosis due to aberrant moved caused by capsular

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restrictions and/or muscular imbalances. A physical therapist can restore these deficits through joint mobilizations, passive range of motion, manual stretching, and by creating an individualized home exercise program.

Great attention must be placed on the scapula to reduce the risk of abnormal positioning and control of the scapula or scapular dyskinesis. Restrictions associated with scapular dyskinesis include pectoralis minor tightness, posterior capsule tightness, weak lower trapezius, and weak serratus anterior [10]. Rehabilitation should emphasize exercises that stretch the pectoralis minor, posterior capsule, and decrease upper trapezius activation in order to provide an ideal setting for scapular motion [5].

After reestablishing shoulder range of motion, capsular mobility, and scapular control, a strengthening program can be initiated. It is of great importance to restore the scapulohumeral rhythm by strengthening the serratus anterior, lower, and middle trapezius while limiting the activity of the upper trapezius. This is done to optimize the movement and dynamic positioning of the scapula, which will allow for the rotator cuff to function optimally. Thus, and stabilize the humeral head within the glenoid as the deltoid elevates the humerus. Strengthening exercises for the remaining rotator cuff musculature should be started at a low load with progressive increases. Furthermore, strengthening of the anterior deltoid is necessary to improve functional elevation of the shoulder [5].

35.2 Revision Repair with our without Biologic Augmentation

Depending on the initial injury, the surgeons, and patient's preference, revision of the failed rotator cuff with or without biologic augmentation might be indicated. As there is a lack of evidence in current literature to select an evidence-based rehabilitation protocol for refixation after failed rotator cuff surgery, rehabilitation is comparable to that of a primary rotator cuff refixation.

A moderate or conservative approach might be of the surgeon's preference when initiating rehabilitation. The conservative approach consists of an immobilization period of 2–4 weeks before initiating passive range of motion exercises [11]. Whereas, a moderate approach begins passive range of motion exercises on postoperative day 1 [11]. It has to be considered that a delay in shoulder mobilization may lead to postoperative stiffness and decreased shoulder function as time progress. On the contrary, early mobilization may result in early failure of the repaired construct, as the time for tendon-to-bone healing might be increased compared to a primary rotator cuff fixation. Thus, it is imperative to find a balance between immobilization and early passive range of motion. A conservative approach may lead to better outcomes in older patients with full-thickness tears, while a moderate approach is indicated in younger patients with smaller tears [4]. Later stage of rehabilitation focuses on active range of motion and strengthening of the rotator cuff, deltoid, and periscapular musculature [11, 12].

A standard rehabilitation program should progress as follows [11, 12]:

1. Phase 1 (0–6 weeks): Immobilization with Passive Range of Motion.
2. Phase 2 (6–12 weeks): Assisted Active Range of Motion and Active Range of Motion.
3. Phase 3 (12–20 weeks): Initial Strengthening.
4. Phase 4 (20–26 weeks): Advanced Strengthening.

Phase 1 (0–6 weeks): Immobilization with Passive Range of Motion.

The primary aim of rehabilitation in phase 1 is to protect the repair through immobilization while initiating a safe passive range of motion exercises. The repaired tendon is most susceptible to rupture at this time and must be protected from excessive loads through the use of a neutral rotation sling. Communication is of utmost importance and the patient must understand his/her restrictions in this phase to limit complications.

In most cases, early passive range of motion exercises has shown to reduce postoperative range of motion loss while providing a protective effect on the repaired construct [13]. More cau-

tion should be placed if the injury was a full tear. In this stage, passive range of motion exercises should be limited to an elevation of the arm in the scapular plane; as well as slight external rotation and abduction til 20–30°. Slow progression is important in the setting of rotator cuff revisions due to an even weaker suture tendon interface [12]. Continuous passive motion machines may be used; however, there is insufficient evidence to support its use [14]. Cryotherapy can be used as an adjunct to decrease pain and inflammation postoperatively [15]. However, its long-term impacts on outcomes and healing are not fully understood.

Phase 2 (6–12 weeks): Assisted Active Range of Motion and Active Range of Motion.

The aim of phase 2 is to achieve a full, pain-free passive range of motion while introducing assisted active range of motion and active range of motion exercises. At around week 9, passive range of motion exercises should begin to incorporate external rotation in greater angles of abduction and functional internal rotation. These exercises are avoided early on in rehabilitation because they place direct tension on the repaired construct and can potentially result in a retear, especially in the case of revision surgery. If there is increased stiffness in the joint, then earlier initiation of functional internal rotation and external rotation in greater angles of abduction should be considered [11, 12].

Before starting strengthening exercises, sufficient passive range of motion should be achieved with minimal pain. Muscle activation exercises should begin with assisted active range of motion (Fig. 35.1) and active range of motion exercises (Figs. 35.2, 35.3 and 35.4). These should be performed in low-gravity positions such as supine or side-lying and eventually progress into an upright position. If well tolerated, active loading exercises in an upright position can be initiated. Exercise should be performed at low resistance (0–1 lbs.) and should emphasize the rotator cuff, deltoid, and periscapular musculature. At the end

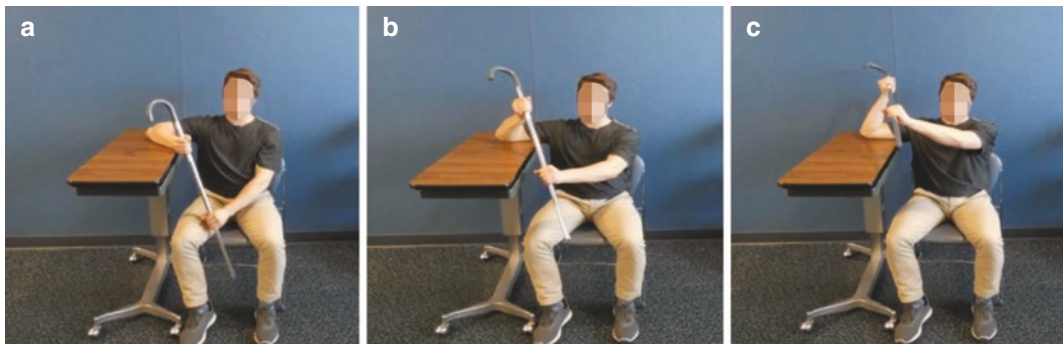

Fig. 35.1 Photographs of external rotation active-assisted range of motion in the (**a**) resting, (**b**) mid-position, and (**c**) end-position

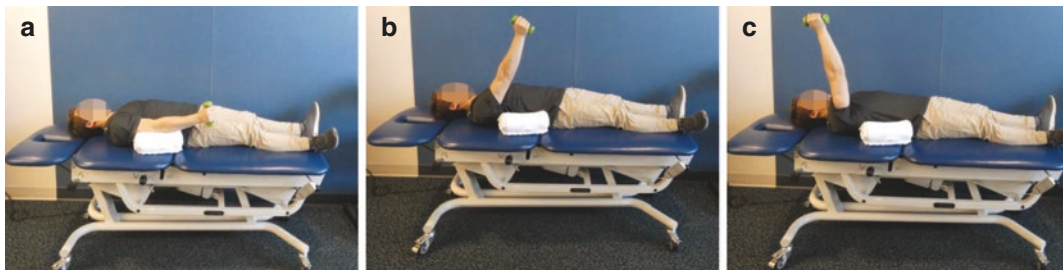

Fig. 35.2 Photographs of supine shoulder flexion active range of motion exercise in the (**a**) resting, (**b**) mid-position, and (**c**) end-position

Fig. 35.3 Photographs of side-lying shoulder flexion active range of motion exercise in the (**a**) resting, (**b**) mid-position, and (**c**) end-position

Fig. 35.4 Photographs of prone horizontal abduction active range of motion exercise in the (**a**) resting position, (**b**) mid-position, and (**c**) end-position

of phase 2, patients should have a full active range of motion without signs of scapular dyskinesis [11, 12].

Phase 3 (12–20 weeks): Initial Strengthening.

Once the patient has achieved sufficient passive and active range of motion, they can progress to phase 3. At this point, the tendon healing has progressed to the point that patients may now begin a more extensive strengthening program. Exercises should incorporate below chest-level strengthening, and increased resistance on phase 2 exercises (Fig. 35.5). If the patient is comfortable with full can exercises, then overhead strengthening can be initiated. If needed, passive range of motion and active range of motion exercises can be continued. At the end of this phase, most patients regain functionality and further rehabilitation may not be necessary [11, 12].

Phase 4 (20–26 weeks): Advanced Strengthening.

Although patients may believe that their shoulder function has been restored in phase 3, all patients should be encouraged to progress to phase 4. Especially patients with lifestyles that involve frequent overhead arm movement such as athletes and manual laborers. At this point, the tendon is almost complete with remodeling. Patients should slowly increase their load from the phase 3 exercises, while incorporating exercises that mimic their daily movements [11, 12]. Plyometric exercises can be explored toward the end of this phase if the patient is an athlete [11]. It is still important not to put excessive load at this time because the tendon is still prone to retears, with most occurring 6 months after surgery [16].

35.3 Superior Capsular Reconstruction Using Allograft or Autografts

Superior capsular reconstruction (SCR) using allografts or autografts is a technically challenging procedure that is often associated with a long rehabilitation period. The literature currently suggests a postoperative rehabilitation protocol that includes an extended immobilization period

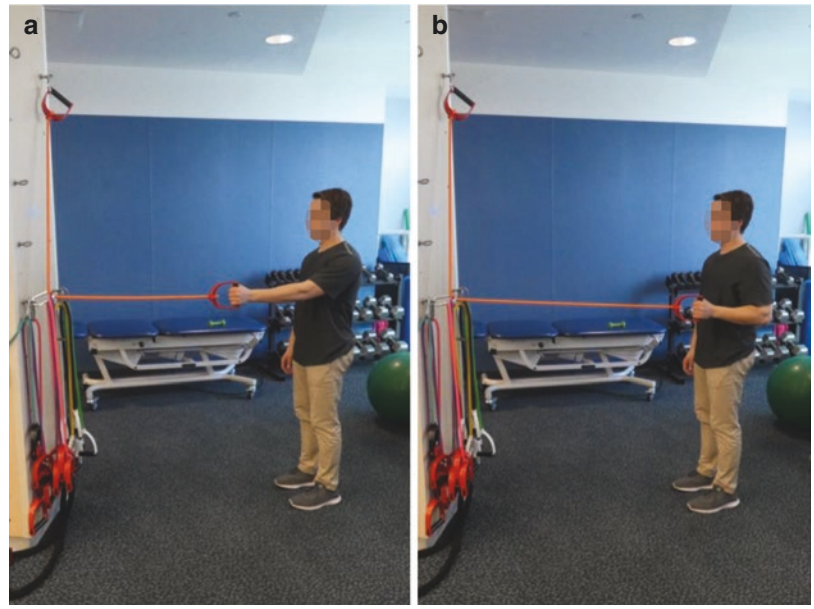

Fig. 35.5 Photographs of resistance band rows used for strengthening in the (**a**) resting and (**b**) end-position

for 6 weeks. However, Gupta et al. still found favorable outcomes with unrestricted passive range of motion exercises with scapular stabilization during the first 8 weeks [17]. Due to the novelty of this procedure, more research is needed to fully establish an evidence-based postoperative protocol. The current protocol that most providers recommend includes 4 phases:

1. Phase 1 (0–6 weeks): Immobilization.
2. Phase 2 (6–10 weeks): Range of Motion and Muscular Endurance.
3. Phase 3 (10–20 weeks): Muscular strength.
4. Phase 4 (20–26 weeks): Advanced strength and return to activity.

Phase 1: Immobilization *(0–6 weeks).*

The main goal of the immobilization period is to protect the repaired construct while reducing inflammation and pain. For 6 weeks, the shoulder is placed in a sling that maintains the shoulder joint in the scapular plane. It is imperative to communicate with the patient to ensure that he understands his postoperative restrictions to prevent accidental injuries. The patient is not allowed to perform passive range of motion with the glenohumeral joint. However, the patient should be encouraged to perform active range of motion exercises of the cervical spine, elbow, and hand. Scapular depression and retraction exercises should also be initiated to assist with limiting postoperative postural/scapular dysfunction. Cryotherapy may be used as an adjunct to provide analgesia and limit inflammation of the joint [17].

Phase 2 (6–10 weeks): Range of Motion and Muscular Endurance.

After 6 weeks of immobilization, the main goals of phase 2 are to improve range of motion, endurance of the rotator cuff musculature, and restore normal scapulohumeral rhythm. This is accomplished by an initial period of pain-free passive range of motion in the supine position followed by the slow incorporation of active range of motion exercises. Exercises should focus on improving scapulothoracic rhythm, forward elevation, and internal/external rotation (Fig. 35.1). Submaximal isometric exercises that focus on the deltoid, subscapularis, infraspinatus, teres minor, biceps, and triceps should also be performed to assist with the restoration of scapulohumeral rhythm. Once the patient is exhibiting pain-free progress (2–3 weeks), active range of motion is incorporated (Figs. 35.2, 35.3 and 35.4). They should begin in low-gravity positions such as supine and eventually advance to a seated and standing position [17].

Phase 3 (10–20 weeks): Muscular Strength.

The aim of phase three is to enhance strength, regain functional range of motion, and return to daily life activities. This is initiated around 10 weeks with resisted range of motion exercises and closed chain stabilization exercises. Exercises should be performed with resistance bands and light dumbbells. Emphasis should be placed on the rotator cuff, deltoid, and periscapular musculature while maintaining proper posture and scapular control. Resisted rows (Fig. 35.5), bicep, and triceps exercises are progressively introduced in this phase. Active range of motion and passive range of motion exercises should be continued if needed [17].

Phase 4 (20–26 weeks): Advanced Strength and Return to Activity.

Phase 4 can be beneficial for most patients especially those who utilize excessive overhead movements such as athletes and manual laborers. This phase works on overhead strengthening, advanced closed chain, proprioceptive, and plyometric exercises [17]. Postoperative operative restriction is lifted around 5–6 months [18]. Mihata et al. utilized a similar rehabilitation for protocol for patients with a superior capsular reconstruction and found that athletes and manual laborers displayed a high rate of return to their respective sport or activity [18].

35.4 Subacromial Balloon Spacer

As the subacromial balloon spacer does not repair the torn rotator cuff, it aims to reduce subacromial friction and improve shoulder function. By inserting the biodegradable balloon into the shoulder joint, it places the humeral head in a more anatomic and biomechanically favorable position. Thus, the rehabilitation is much shorter than more invasive surgeries such as superior capsular reconstruction, reverse total shoulder arthroplasty, or tendon transfer. An immobilization period of 1–3 weeks with a shoulder sling might be recommended. Active range of motion exercises are usually started between postoperative weeks 1–3; followed by full strengthening and the incorporation of a home exercise program for 4 weeks. Barring any complications, restrictions are lifted after 12 weeks [19] [20]. However, more research needs to be conducted to establish an evidence-based rehabilitation protocol for this procedure.

35.5 Tendon Transfer

Tendon transfers that involve the latissimus dorsi and the lower trapezius have shown promising results in the setting of a massive irreparable posterosuperior rotator cuff tears involving the supraspinatus and infraspinatus. This procedure should be considered in younger patients that are highly active and motivated to complete an extensive rehabilitation protocol that can last up to a year [21, 22]. More research must be conducted to suggest an evidence-based rehabilitation protocol for both of these procedures.

35.5.1 Latissimus Dorsi Tendon Transfer

In this procedure, the latissimus dorsi tendon is transferred from its original insertion into the greater tuberosity. Thus, converting the latissimus dorsi into a shoulder flexor and external rotator, for optimal results, the subscapularis tendon must be healthy and with the patient having at least 90° of flexion of abduction of the shoulder joint [23]. Initial rehabilitation involves a 6 week immobilization period in an SCOI brace (45° of abduction, flexion, and external rotation) to optimally protect the tendon transfer.

Passive range of motion exercises is initiated at 1–3 weeks postoperatively with the exception of internal rotation and free external rotation. Furthermore, at this time, the patient should also be performing active range of motion exercises involving the cervical spine, elbow, and hand. At postoperative week 4, active-assisted adduction/abduction limited to 90°, and passive rotational motion is initiated. This should be intensified at 6 weeks with the incorporation of active assisted external/internal rotation (Fig. 35.1). At 8 weeks, the patient can start unlimited active assisted

motion and at 10 weeks they may begin unlimited active motion (Figs. 35.2, 35.3 and 35.4). This is the most important step in rehabilitation because it aids in recruiting the tendon transfer and developing neuromuscular control. The latissimus dorsi must be taught to act as an external rotator and stabilizer of the humeral head instead of an adductor and internal rotator. Once this is achieved, the patient can then begin a strengthening program to further stabilize the construct (Fig. 35.5) [21, 24]. The patient can resume unrestricted activity in 6 months postoperative if progressing appropriately. Every patient is different and the rehabilitation program should be adjusted depending on how the patient is progressing.

35.5.2 Lower Trapezius Tendon Transfer

Another tendon transfer option for an irreparable posterosuperior cuff tear is a lower trapezius tendon transfer. This procedure has been growing in popularity and is recommended for high activity younger patients [22]. It is a less invasive procedure with a shorter recovery time. A recent study has shown that it produces a better moment arm for external rotation compared to a latissimus dorsi tendon transfer [25]. Furthermore, the surgery does not require an intact subscapularis tendon. Rehabilitation is less intense than that for a latissimus dorsi tendon transfer, with an aim of teaching the lower trapezius to function as an external rotator while protecting the repaired construct.

It begins with an immobilization period of 6–8 weeks in a shoulder spica brace with 30° of abduction and 50° of external rotation. Afterward, active-assisted range of motion exercises in all planes except for internal rotation is allowed for 4 weeks (Fig. 35.1). The patient may then progress toward full range of motion and gentle external rotation strengthening exercises with resistance bands (Figs. 35.2, 35.3 and 35.4). The rest of the cuff musculature should also be strengthening to enhance stability (Fig. 35.5). If progressing appropriately, the patient may resume unrestricted activity in 6 months after surgery [22, 26].

35.6 Reverse Shoulder Prosthesis

A reverse shoulder prosthesis is another common procedure that is used in the setting of an irreparable rotator cuff tear. In this operation, the articular surfaces of the glenohumeral joint are reversed so that the glenoid serves as the convex articular surface and the humerus serves as the concave articular surface. Thus, the deltoid is in a biomechanically favorable position to be the dominant arm elevator and abductor [27]. Reverse shoulder prosthesis is usually as a last resort to improve pain and range of motion in low activity patients over the age of 65 with an irreparable rotator cuff tear [27]. Unlike latissimus dorsi tendon transfers, a reverse shoulder prosthesis may be performed if the patient has an arthritic glenohumeral joint or with a compromised subscapularis. Typically, this is not the first surgical option for active younger patients because surgeons seek to conserve the shoulder joint. However, Ek et al. [28] and Sershon et al. [29] still found favorable long-term outcomes. Predictors of surgical success include intraoperative range of motion and preoperative range of motion, male sex to a lesser extent [30].

There is no doubt that rehabilitation plays an important role in the recovery of reverse shoulder prosthesis. However, currently, there is a lack of literature to suggest an evidence-based approach for rehabilitation of a reverse shoulder prosthesis. Most of the current evidence comes from biomechanical plausibility and should be viewed with caution. There is a lot of variation with rehabilitation protocols in the literature, but most of them tend to follow a similar principle. Most of the disagreement stems from the duration of the immobilization period. Most experts advocate for a moderate immobilization period of 4–6 weeks [31]. However, there is contrasting literature that advocates for no formal postoperative immobilization period [32] or an extended immobilization period with delayed range of motion exercises. Currently, the most accepted protocol is as follows [27].

Rehabilitation should begin with an immobilization period of about 4–6 weeks in an abduction type sling, to ensure appropriate healing maximal

protection of the construct. Concurrently, passive range of motion exercises in the scapular plane and external rotation with low-intensity deltoid/scapular isometrics are recommended. At this time, internal rotation is restricted. Once full passive range of motion is obtained, the patient can then begin active-assisted range of motion exercises (Fig. 35.1) that progress to active range of motion (Figs. 35.2, 35.3 and 35.4) for 6–12 weeks. This is followed by strengthening of the deltoid and periscapular musculature via progressive resistance exercises to ensure stability of the new construct. The rehabilitation is complete once the patient has achieved pain-free active range of motion with appropriate shoulder dynamics. Nevertheless, the patient should be encouraged to continue strengthening exercises through a home exercise program to ensure maximum recovery [33].

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