Andreas B. Imhoff
Felix H. Savoie III
Editors

Rotator Cuff Across the Life Span

ISAKOS Consensus Book

Springer

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Part I

Basic

1 Diagnosis and Classification of Rotator Cuff Tears

Emilio Calvo, Carlos Rebollón Guardado, Diana Morcillo, and Guillermo Arce

1.1 Introduction

Rotator cuff pathology is the most common condition affecting the shoulder. The clinical results of rotator cuff repair in symptomatic patients are good to excellent in a high percentage of cases. These observations underline the weight of diagnosing this pathology correctly. Several classification systems have been used to describe rotator cuff tears in the orthopedic literature, but there is not a current standard classification that includes all the types and characteristics of rotator cuff tears. Possible factors contributing to this situation could be a poor interobserver agreement, inaccuracy, incompleteness, or complexity. An improved evaluation of the rotator cuff tears, the advances in imaging methods, and the advent of arthroscopy, in particular, have provided better opportunities to understand and treat these lesions. This paper describes (1) a comprehensive review of diagnostic methods for rotator cuff tears and (2) the ISAKOS rotator cuff tear classification system.

1.2 Diagnosis of Rotator Cuff Tears

A complete medical history of the patient and a full physical exam with an adequate imaging study are mandatory in any patient with shoulder pain to identify a potential rotator cuff tear, especially in those over 40 years of age.

1.2.1 Physical Exam

The examination starts with the inspection of the skin looking for previous surgical scars and muscle periscapular atrophy that could indicate chronicity of the tear or nerve injury. Deltoid atrophy is directly related to axillary nerve injury, and muscle atrophy at the supra- or infraspinatus fossae indicates a potential suprascapular nerve injury. A Popeye's sign indicates rupture of the long head of the biceps, a common finding in rotator cuff tears. A thorough assessment of the active and passive range of motion comparing with the contralateral healthy side is mandatory. Stiffness is a common finding in patients with long-standing rotator cuff tear and must be recognized before planning any surgical repair. Massive tears involving the infraspinatus will typically present with an external rotation lag

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sign. The hornblower's test performed in abduction and external rotation assesses the integrity of the teres minor.

Similarly, large tears involving the subscapularis will often present an increased passive external rotation, internal rotation lag sign, and weakness with the classics tests for subscapularis tendon such as lift-off, bear hug, and belly-press tests. Massive supraspinatus and infraspinatus tears may demonstrate a drop arm sign and positive Jobe test complemented with weakness in abduction and external rotation. Location of the pain can be indicative, over the bicipital groove anteriorly or the acromioclavicular joint superiorly. Crepitation over the greater tuberosity is also indicative of supraspinatus tear.

1.2.2 Imaging Studies for Rotator Cuff Tears

Despite the initiation of new imaging methods, the value of conventional radiology is critical, for all patients with suspected rotator cuff pathology. Three radiographic views of the shoulder are still recommended: true anteroposterior (Grashey), axillary lateral, and outlet (scapular Y). Some indirect radiographic signs, like bone sclerosis at the level of the greater or lesser tuberosity and the inferior acromion, often indicate the presence of rotator cuff disease. Humeral head migration and adaptive changes are indicative of rotator cuff arthropathy. A humeral head anteriorly displaced in the outlet view can be indicative of full-thickness subscapularis tendon rupture. Glenohumeral arthritis is often more clearly identified on the axillary view, demonstrating narrowing of the joint line and sclerosis. Radiographs are also essential to rule out other causes of pain (e.g., tumors, fractures and dislocations, calcium deposits, chondrolysis, loose anchors, acromial fracture).

Ultrasonography (US) is cost-effective and has less postoperative hardware artifact than does MRI, which makes it especially suitable to evaluate re-tears. However, ultrasonography is operator dependent, unfamiliar to most orthopedic surgeons, and does not provide a thorough evaluation of the glenohumeral joint. Due to these limitations in our practice, we reserve US for those patients with rotator cuff disease in whom surgery might not be indicated, while magnetic resonance imaging (MRI) or even computed tomography (CT) is preferred for those patients scheduled for reconstructive surgery. Our preference for preoperative imaging evaluation is high-field MRI, at least at 1.5 T. Coronal MRI views are best used to assess the size, location, geographic pattern of the supra- and infraspinatus tendon tears, the quality of the tendon, and chronicity. Sagittal T1 images may also show atrophy or fatty infiltration of the involved musculature, which can provide prognostic information. Axial views are better to evaluate the integrity of the subscapularis and teres minor tendons and to detect the long head of the biceps tendon pathology as tendinosis, synovitis, tears, or instability. Arthro-CT may be considered as an alternative to MRI to diagnose rotator cuff pathology in those patients in whom MRI is contraindicated. CT scan should be performed to evaluate the glenohumeral joint morphology when a shoulder replacement is deemed indicated.

1.3 Classification of Rotator Cuff Tears

Any classification system for rotator cuff tears should meet several criteria. First of all, the classification should have the capacity to describe the location and pattern of the tear, helping all surgeons to understand precisely its characteristics. Second, the classification system should be already in use and, if possible, reproducible and validated for reliability and encourage communication between physicians and researchers. We are aware in the orthopedic literature of failed attempts of new classifications aimed to overcome the limitations of their classic counterparts directly because the orthopedic community is used to the "classical language" (i.e., new classifications of proximal humeral fractures to substitute the classical Neer-Codman classification). Third, the classification should be able to dictate an appropriate treatment in each specific case. Fourth, it should also have a predictive value to guide physicians and to transmit to the patients the realistic expectations of the postoperative outcome. The classification for rotator cuff must be not only arranged to be understood but also easy to remember and follow. An acronym can be helpful in this sense.

After reviewing the available rotator cuff scoring's systems, the ISAKOS Shoulder Committee has developed a new system that is described in this chapter. The ISAKOS grading system is a complete and straightforward method to describe all rotator cuff tears. It relies on the fact that a good system should allow the surgeon to predict difficulties during the procedure and advise about prognostics. It is comprehensive and user-friendly. The five essential characteristics of the rotator cuff tears included in this system, pattern (P), extension (E), fatty atrophy (A), retraction (R), and location (L), establishing the acronym "PEARL" are explained below (Table 1.1).

1.3.1 Pattern

The recognition of the tear patterns is critical for anatomical repair during the arthroscopic procedure. Traditional classification systems of rotator cuff tears have been based exclusively on the extension of the tear or the number of tendons involved, and do not differentiate between specific tear patterns or methods of repair.

The characteristic of the partial-thickness rotator cuff tears is not considered in most classification systems. The classification of partial thickness rotator cuff tears proposed by Ellman included specific considerations of the site of the tear along the tendon thickness (articular surface, bursal surface, or intra-tendinous) is suggested [1].

Davidson and Burkhart described a three-dimensional geometric classification obtained either from preoperative magnetic resonance imaging (MRI) or at arthroscopy that helps orthopedic surgeons communicate about tears of the supraspinatus, infraspinatus, and teres minor based on tear pattern recognition. The advantage of this system is that it can be used pre- and intraoperatively. This classification provides essential guidance on the treatment technique and prognosis for each tear pattern [2]. This geometric classification defines four different patterns: crescent-shaped tears, U-shaped tears, L-shaped tears, and reverse L-shaped tears. Crescent-shaped tears are relatively short in the coronal image and wide on the sagittal image and are the most common type (Fig. 1.1). They

Table 1.1 ISAKOS rotator cuff tear classification system

Location (L)	Extension (E)[a]	Pattern (P)[b]	Fatty atrophy (A)[c]		Retraction (R)[d]
Partial thickness posterosuperior	>50% thickness <50% thickness	A (articular) B (bursal) I (interstitial)	SS0 SS1 SS2	IS0 IS1 IS2	
Full thickness posterosuperior	C1 C2 C3 C4 (massive)	C U L rL (reverse L)	SS3 SS4	IS3 IS4	1 2 3
Anterior	1 2 3 4 5		SC0 SC1 SC2 SC3 SC4		

[a]Extension in partial-thickness tears is based on the percentage of footprint coverage. Extension in posterosuperior full-thickness cuff tears refers to the size of the tear as measured medial to lateral (C1 = <1 cm, C2 = 1–2 cm, C3 = 3–4 cm, C4 = >4 cm). Extension in anterior (subscapularis) full-thickness tears is based on Lafosse et al. classification system: 1 = Partial lesion of *superior* one-third, 2 = Complete lesion of *superior* one-third, 3 = Complete lesion of *superior* two-thirds, 4 = Complete lesion of *tendon* but head centered and fatty degeneration classified as less than or equal to Goutallier stage III, 5 = Complete lesion of *tendon* but eccentric head with coracoid impingement and fatty degeneration classified as more than or equal to Goutallier stage III (Lafosse et al., JBJS Am 2007 [10])

[b]Full-thickness posterosuperior rotator cuff tear pattern is described as Ellman and Garstman

[c]Fatty atrophy is defined using CT or MRI based on the systems by Goutallier et al. (CT) (Goutallier et al., Clin Orthop 1994 [12]) or Fuchs et al. (MRI) (Fuchs et al., JSES 1999 [13]): 0 = Normal muscle, 1 = Some fatty streaks, 2 = Less than 50% fatty muscle atrophy (more muscle than fat), 3 = 50% fatty muscle atrophy (equal muscle and fat), 4 = More than 50% muscle atrophy (more fat than muscle). *SS* supraspinatus, *IS* infraspinatus, *SC* subscapularis

[d]Retraction is assessed following the Patte et al. classification system (1 = Proximal stump close to bony insertion, 2 = Proximal stump at level of humeral head, 3 = Proximal stump at glenoid level) (Patte, Clin Orthop 1990 [21])

are commonly mobile from medial to lateral and can usually be repaired by fixing the tendon end directly to the footprint on the greater humeral tuberosity. U-shaped and L-shaped tears are relatively long on the coronal and short on the sagittal images and typically require extensive release and mobilization (Figs. 1.2 and 1.3). These tears are generally mobile in an anteroposterior direction and frequently must be repaired by a side-to-side or margin convergence technique.

1.3.2 Extension

Traditionally, rotator cuff tears have been described as partial or full thickness. The classification systems for full-thickness posterosuperior tears have been based on the size of the tear or the number of tendons involved [3–5]. The information on the extension of the tear, either given as area or number of tendons involved, is essential to predict the extent of the surgical procedure and the need of soft tissue releases for repairing. In addition, to recognize the tear size allows to predict the clinical outcome of the repair.

However, the classifications based on the size of the tear must be bidimensional since a unidimensional description can be misleading because it measures the tear size only anterior to posterior, as suggested by DeOrio and Cofield. The behavior of the tear can be unpredictable, and it depends on different factors. A complete cuff avulsion described as massive, implying a problematic repair and unfavorable prognosis, may, in fact, lie directly over the bed of the insertion site, be easy to repair, and have a predictably good result [3]. For these reasons, we propose the use of the classification system of posterosuperior rotator cuff tears suggested by Snyder [6]. This system provides information not only on the size but also on the number of tendons involved and the degree of scarring. The full-thickness tears are classified as C1 (small complete tear, pinhole-sized), C2 (moderate tear less than 2 cm of only one tendon without retraction), C3 (large complete tear with an entire tendon with minimal retraction usually 3–4 cm), or C4 (massive rotator cuff tear involving two or more

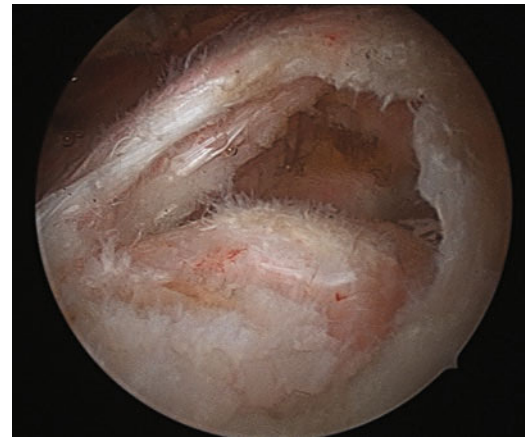

Fig. 1.1 Crescent type, extension grade 2 supraspinatus tear

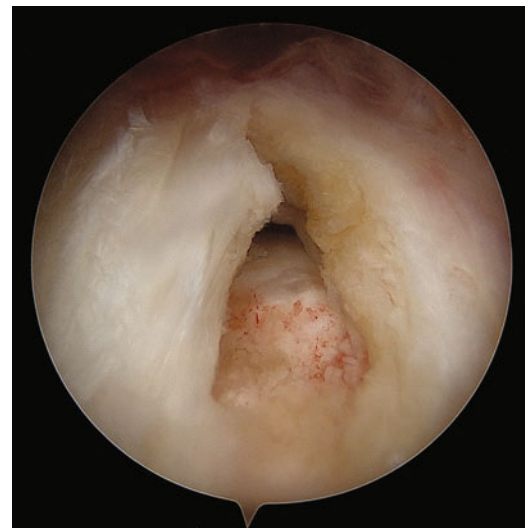

Fig. 1.2 Small pinhole U-pattern tear

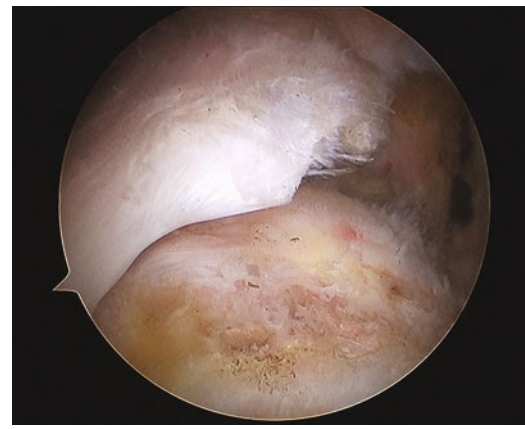

Fig. 1.3 Reverse L-pattern supraspinatus tear

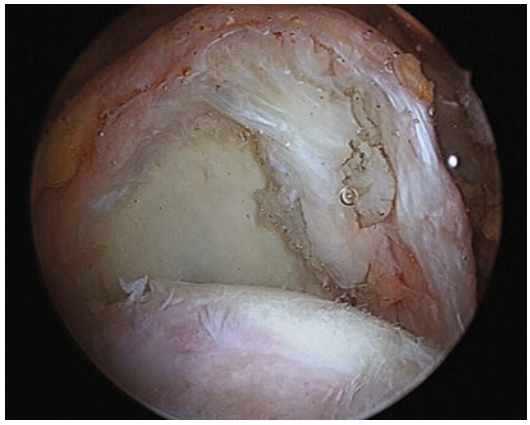

Fig. 1.4 Massive C4 rotator cuff tear

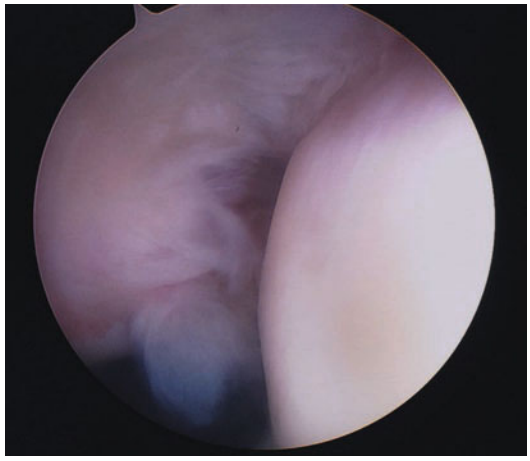

Fig. 1.5 Partial-thickness articular side supraspinatus tear

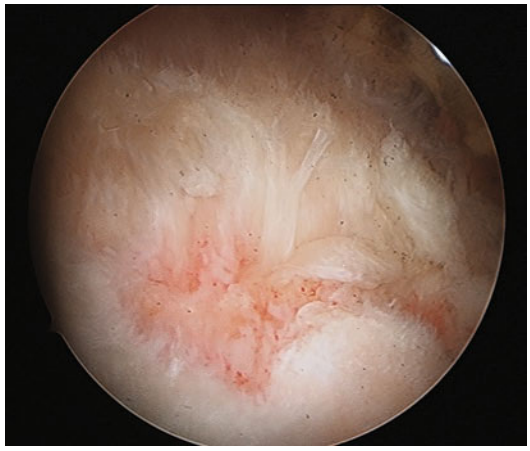

Fig. 1.6 Partial-thickness bursal supraspinatus tear involving less than 50% of tendon thickness

rotator cuff tendons with associated retraction and scarring of the remaining tendon) (Fig. 1.4). With regard to partial-thickness rotator cuff tears, experimental and clinical studies have demonstrated that tears involving more than half of the tendon thickness are a significant threat to tendon integrity and that they outperform better if treated surgically [7, 8]. Based on these observations, we recommend in partial-thickness rotator cuff tears to define the site and tendon tissue involvement as over or fewer than 50% of tendon thickness (Figs. 1.5 and 1.6).

Whereas tears of the subscapularis were previously believed to be rare, now it is recognized that tears of the subscapularis are very common [9]. The etiology, pattern, and surgical approach of subscapularis tear are different from those of posterosuperior rotator cuff tears. Lafosse et al. created a classification system of subscapularis tears that shows the pattern and the size of five different stages based on anatomic observations with arthroscopy and also showed the surgical approach for its reconstruction [10]. Type 1 lesions are simple erosions of the superior third, without bone avulsion. Type 2 consists of detachment restricted to the superior third. Type 3 involves the entire height of the tendon insertion but without muscular detachment of the inferior third, with limited tendon retraction. Type 4 is complete subscapularis detachment from the lesser tuberosity of the humerus but with the humeral head remaining well centered, without contact with the coracoid on internal rotation on CT scan (Fig. 1.7). Type 5 also represents a com-

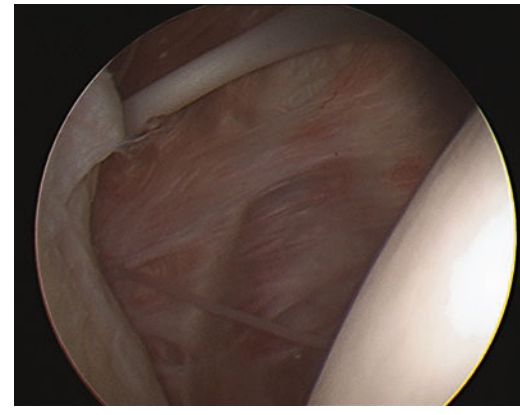

Fig. 1.7 Complete Lafosse type 4 subscapularis tear

plete rupture, but with the anterosuperior migration of the humeral head, which comes into contact with the coracoid, with associated fatty infiltration.

1.3.3 Atrophy and Fatty Infiltration

Tear size and tendon retraction, fatty infiltration, and muscle atrophy are significant prognostic factors of the structural and functional outcomes after rotator cuff tear repair [11]. Rotator cuff tendon failure is associated with progressive and probably irreversible degenerative changes of the rotator cuff muscles.

Thus, a complete rotator cuff classification system should include information about the preoperative muscle status. Goutallier et al. first described a classification of fatty infiltration of the supraspinatus based on the presence of fatty streaks within the muscle belly using CT images, and later Fuchs et al. validated the same system based on MRI images [12, 13]. Fatty degeneration is estimated on coronal and sagittal MRI views as a percentage of fatty tissue in relation to healthy muscle tissue in the subscapularis, supraspinatus, infraspinatus, and teres minor. Additionally, these authors demonstrated that multiple muscles could develop fatty degeneration, even when they are not affected directly by the rotator cuff tear [12]. Melis et al. demonstrated that the mean time to observe a stage 2 supraspinatus fatty infiltration is 3 years and a severe fatty infiltration an average of 5 years after the tendon rupture, respectively. For the infraspinatus and subscapularis, the mean time is two and a half years [14].

The Goutallier classification defines five degrees of muscle fatty infiltration that can be ascribed to all the four rotator cuff muscles. (Grade 0 = normal muscle; grade 1 = some fatty streaks; grade 2 = less than 50% fatty muscle atrophy, i.e., more muscle than fat; grade 3 = 50% fatty muscle atrophy, i.e., equal muscle and fat; and grade 4 = more than 50% muscle atrophy, i.e., more fat than muscle.) The mean time to observe a grade 3 and 4 fatty infiltration is 5, 4, and 3 years for the supraspinatus, the infraspinatus, and the subscapularis, respectively. It has also been demonstrated that musculotendinous retraction can be observed in the Goutallier stage 3 occurs more musculotendinous retraction [15].

1.3.4 Retraction

The musculotendinous retraction is a common phenomenon in rotator cuff tears. It is the most critical pathophysiological consequence of chronic tendon tearing and is a significant limitation for successful operative tendon-to-bone repair [16]. The retraction occurred because of the shortening of the tendon and muscle that is not synchronous after the tendon tear [15]. Along with the retraction, the muscle undergoes atrophy and fatty degeneration [12], with the consequences of decreased muscle elasticity [17], strength, and consequently loss of range of movement and loss of work capacity of the joint [18]. It has been demonstrated that formation of a recurrent tendon defect correlates with the timing of tendon retraction and clinical outcome correlates with its magnitude [19, 20].

The classification most commonly used to describe tendon retraction is that suggested by Patte. This classification uses the distance between the retracted tendon and its original insertion on the greater tuberosity in the coronal plane. Stage 1 is a tear with minimal retraction, in stage 2 the tendon is retracted medial to the humeral head footprint but not to the glenoid, and stage 3 represents a tear retracted to the level of the glenoid. In addition imaging study in preoperative planning is very important to evaluate the tendon retraction intraoperatively to establish a surgical strategy defining the soft tissue releases and to assist in the prediction of the final outcome of the repair [21].

1.3.5 Location

Most classifications reported in the literature have been suggested to describe posterosuperior rotator cuff tears involving the supraspinatus,

Table 1.2 Intra- and interobserver agreement of the ISAKOS rotator cuff tear classification system

Intrarater agreement						
Item	Expected agreement (%)		Observed agreement (%)		κ	
	Observer 1	Observer 2	Observer 1	Observer 2	Observer 1	Observer 2
Extension	19.7	22.8	74.5	94	0.68	0.92
Pattern	30	26	93.5	87.5	0.90	0.83
Location	88.7	92.3	100	100	1	1
Retraction	36.7	39.3	88	92.7	0.81	0.88
Overall					0.88	0.93

infraspinatus, and teres minor, but only more recently, subscapularis tears have drawn some attention. Since the characteristics, as well as therapeutic and prognostic implications of posterosuperior and anterior rotator cuff tears, are often different, we suggest defining first the anatomic location of the rotator cuff tear, posterosuperior or anterior.

While the acronym "PEARL" is helpful to remember this classification, the sequence to classify each specific tear should start with the location of the tear, followed by extension, atrophy, retraction, and finally pattern. Tear location should be first established since the natural history, prognosis and repair techniques are different in anterior and posterosuperior tears are different. The extension, the degree of fatty infiltration and muscular atrophy, and the retraction provide critical information and the reparability of the tear. The tear pattern is only useful for planning the reconstruction.

1.3.6 Preliminary Study

The ISAKOS Shoulder Committee underwent a preliminary study aimed to assess the reliability and reproducibility of the ISAKOS rotator cuff tear classification system. We hypothesized that the classification system is as reliable and reproducible to be used to communicate as well as for multicenter studies involving multiple surgeons and investigators. Sixty videos including a variety of rotator cuff tendon tears were collected and edited. Five were discarded and 55 finally assessed by two blinded surgeons experienced in arthroscopic shoulder surgery and previously trained for the classification system. Duplicate blinded evaluation of the videos was performed at random and separated for 7 days. Multirater kappa statistics were used to measure agreement among the surgeons. As shown in Table 1.2, statistical analysis of measurements showed excellent inter- and intra-observer agreement of the classification system.

1.4 Conclusions

Rotator cuff injury is the most common cause of shoulder pain. Inspection, palpation, active and passive range of movement, and tests aimed to identify the specific tendon involved in the tear should be performed on physical exam. Ultrasound is efficient in diagnosing the tear, but MRI is the preferred imaging method for those potential candidates for surgical reconstruction.

The ISAKOS Shoulder Committee presents a classification system for rotator cuff tears that combines the crucial factors from those classifications in current use into a unified evaluation system easy to remember and that fulfills the needs of the surgeons to classify the rotator cuff tears better. Compared to the previous classifications, this new system has advantages: it (1) is fitted for both posterosuperior and subscapularis tears, (2) also addresses partial- or full-thickness tears, (3) gives details on the size and geographic patterns of the tears useful to establish an appropriate treatment, (4) and provides relevant information on the prognosis of the repair based not only on the size but also on tendon retraction, muscle atrophy, and fatty infiltration.

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2 Rotator Cuff Isometric Strength Across the Life Span in Normal Population and in Patients with Rotator Cuff Pathology

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2.1 Part A: Normal Values

Diagnosis of rotator cuff muscles' pathology is usually based on an initial physical examination, which has a limited prediction value, and can be established with a high precision by much more sophisticated imaging modalities, like ultrasound and MRI scans. It is desirable that the ultimate cost-effective diagnostic tool for this purpose should combine the simplicity and a low cost of the physical examination with the precision of these imaging tools. Since the mechanical force generated by rotator cuff muscles is easily measurable, the pathology of these muscles might be identified by measurement of the isometric force generated by these muscles, in comparison with the data in normal population.

This approach became practical after the large database of profiles of torque-time curves of isometric force generated by *supraspinatus* (SS), *infraspinatus* (IS), and *subscapularis* (SSC) muscles in normal adult population became available [1]. Therefore, the characteristic pathological values of the isometric mechanical force generation by the shoulder rotator cuff muscles in patients with rotator cuff muscle disorders might be diagnosed, following the comparison to matched values in the healthy individuals, and even a specific pattern of difference for different types of pathology might be detected. The recognition of such difference in the patterns of isometric force buildup in normal shoulder and in shoulders with different pathologies of rotator cuff muscles, especially in *supraspinatus* muscle, will allow the standardization of a simple clinical method for diagnosis of rotator cuff muscles' disorders, using a simple and ready available testing method.

Isometric torque/time curves of the rotator cuff muscles can be recorded at standardized positions for the evaluation of the force generation by a specific muscle (Fig. 2.1) [2] and normalized to the lean body mass [3] for a comparison between individuals. The measurements of the isometric force can be easily performed by a dynamometer with digital recording (Fig. 2.2).

The profiles of isometric force torque by rotator cuff muscles from a large group of healthy volunteers (40 individuals of both sexes per each decade of age in the range of 20–60 years of age, in total 360 tested individuals) are now available from both upper limbs [1]. As expected, the matched to the age data shows that the profiles of the generated force by the SS, IS and SSC are higher in men than in women and higher in the dominant limb independently to the gender. The difference in dominancy is specially prominent in the SSC muscle (Fig. 2.3). The dynamics of change in these profiles with age is surprisingly different between men and women.

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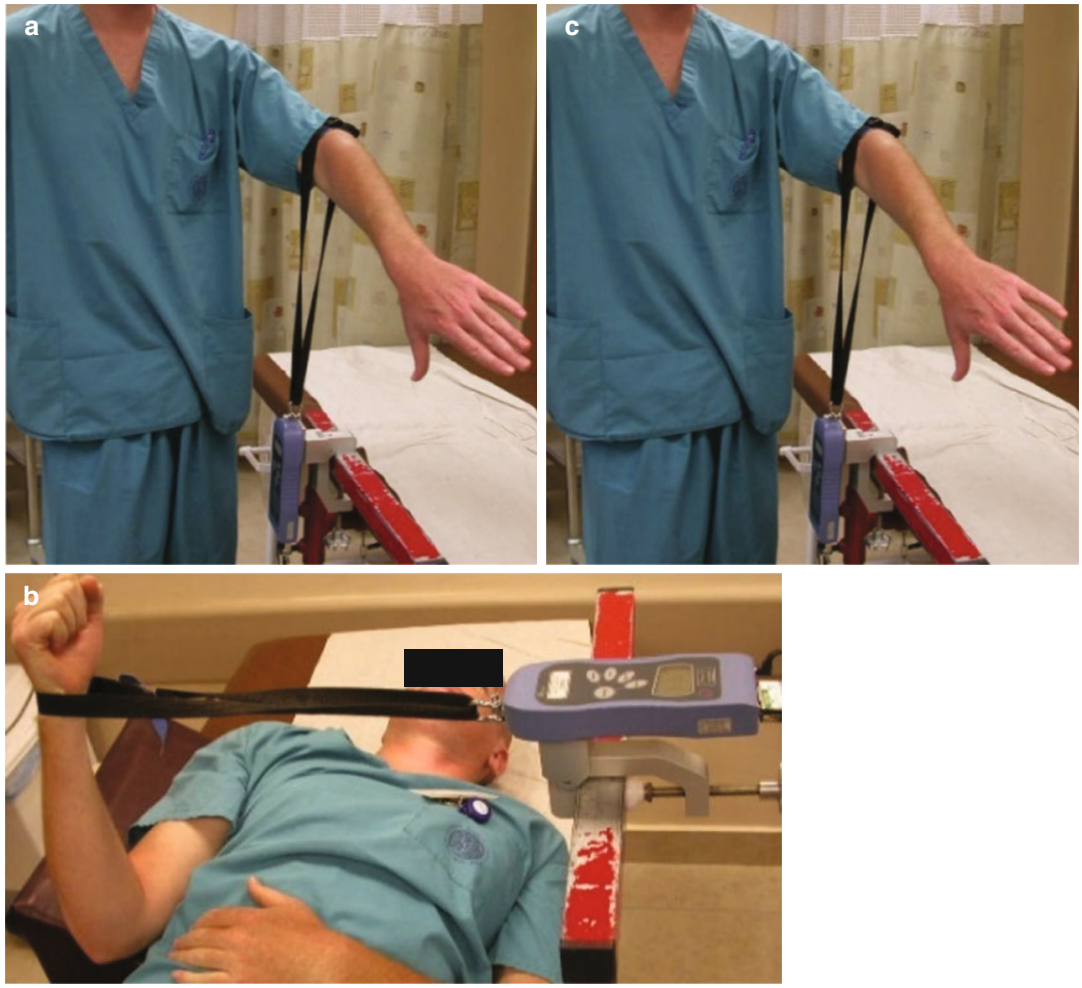


Fig. 2.1 Measurement of the isometric force is performed by a dynamometer with digital record of the generated force over time (sampling 1200/s, 0.04 Newton resolution). For the supraspinatus evaluation (**a**): the arm is positioned at a 45° abduction and 30° forward flexion in a standing position. The cuff of the measuring device is positioned on the arm. The distance from the middle of the cuff up to 3 cm distal to the acromion (approximate point of the fulcrum of the head of the humerus) is considered as the lever arm length. To measure the strength of the *infraspinatus* (**b**) and the *subscapularis* (**c**) muscles, the test subject is on his/her back with the tested arm placed in a 30° forward flexion and in a complete adduction. The arm rests on a support. This position prevents movement by the scapulae and allows the measurement of the motion close to the motion axis of the scapulae. The dynamometer cuff is placed on the forearm, and the motion performed is internal rotation for measurement of the force of the *subscapularis* and external rotation for measurement of the *infraspinatus*. The connection between the cuff and the dynamometer is perpendicular to the forearm in the opposite to the direction of the generated force. In this position the lever arm is negligible

In men the highest profile of the generated force in the tested three muscles raises gradually from the third to the fifth age decade and drops in the sixth decade, both in dominant and non-dominant upper limbs (Fig. 2.3), while in women the highest profile of the isometric force is in the fourth live decade and equally lower in the third and sixth live decade. Therefore, men have the strongest rotator cuff muscles in the age range of 40–50 years, while women have the strongest rotator cuff muscles one decade of age earlier. The reason of this difference is not

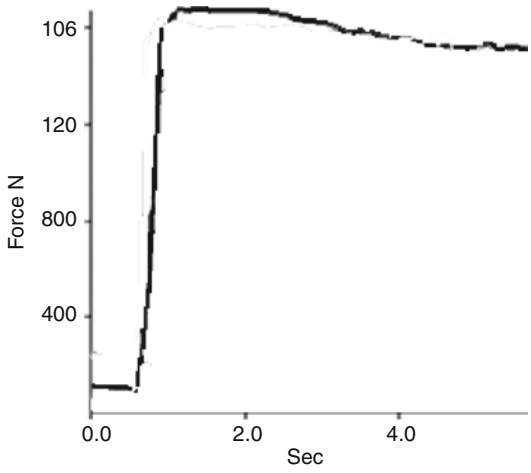


Fig. 2.2 Example of the recorded by a dynamometer profile of a force-time curve. Each strength measurement is performed for a 5-second period. This period of the test was chosen empirically, similarly to the widely accepted Constant's shoulder assessment scoring method [9]

clear but has been observed in additional small-scale studies [4, 5].

It is logical to assume that the drop in the rotator cuff muscles' ability to generate force drops after the age of 50 because of the start of the tendinous degenerative process, even asymptomatic, in rotator cuff tendons at this age.

2.2 Part B: Isometric Strength of Rotator Cuff Muscles with Intrinsic and Extrinsic Pathology

Thus, according to a large database on the normal values of the isometric force generated by SS, IS, and SSC, the evaluation of patients suffering from common rotator cuff disorder, i.e. extrinsic, such as subacromial impingement, and intrinsic, such as calcific tendinitis and medium grade 2 tears of SS [6], by isometric muscle strength measurement became feasible. In this evaluation the main emphasis should be addressed to the SS tendon-muscle unit which is mainly involved in the rotator cuff disease. The disorders of SS cause disabling pain in shoulder and usually are similar in their clinical presentation. Currently, the final diagnosis is based on the imaging modalities. But the described simple mechanical diagnostic method might help to initially distinguish between these disorders and potentially might be used as a simple tool for a diagnosis of rotator cuff muscles' pathology.

In a study on 90 patients, i.e., 30 patients with subacromial impingement syndrome, 30 patients with symptomatic grade 2 complete tears in SS according to ultrasound and/or MRI scans, and a group of 30 patients who suffer from shoulder pain due to calcific tendinitis in the SS muscle without rotator cuff tears, according to radiographic and ultrasonographic evaluation, a diagnostic value of isometric force measurements of SS became evident [7].

The normalized values of force (torque)-time curves from the three groups of patients were compared with data of the matched normal values, according to age, gender, and dominancy [1].

To confirm that a maximal isometric strength is exercised that is obligatory for the discovery of muscle impairment [8], surface EMG was recorded from the anterior *deltoid* and IS muscle as a demonstration of the intended maximal isometric effort (Fig. 2.4).

A significantly lower profile of the torque-time curves in all three pathological conditions in comparison with the normal values was found, as expected (Fig. 2.5). The curves of patients with SS tears and calcifications were undistinguishable ($p > 0.05$) and significantly lower than the curve profile of patients with subacromial impingement syndrome ($p < 0.01$).

In conclusion, the previously unrecognized variations and difference of SS isometric strength buildup patterns in the common intrinsic and extrinsic muscle disorders were revealed indicating on an effectiveness of a simple mechanical diagnostic method for identification of the abnormal patterns of muscle isometric strength in patients with rotator cuff pathology.

The availability of relatively large-scale database of isometric buildup force by the rotator cuff muscles in normal population and in patients with rotator cuff disease provides an important tool for further understanding of these muscles' physiology and pathology. Furthermore, using these data might encourage clinicians to use it as

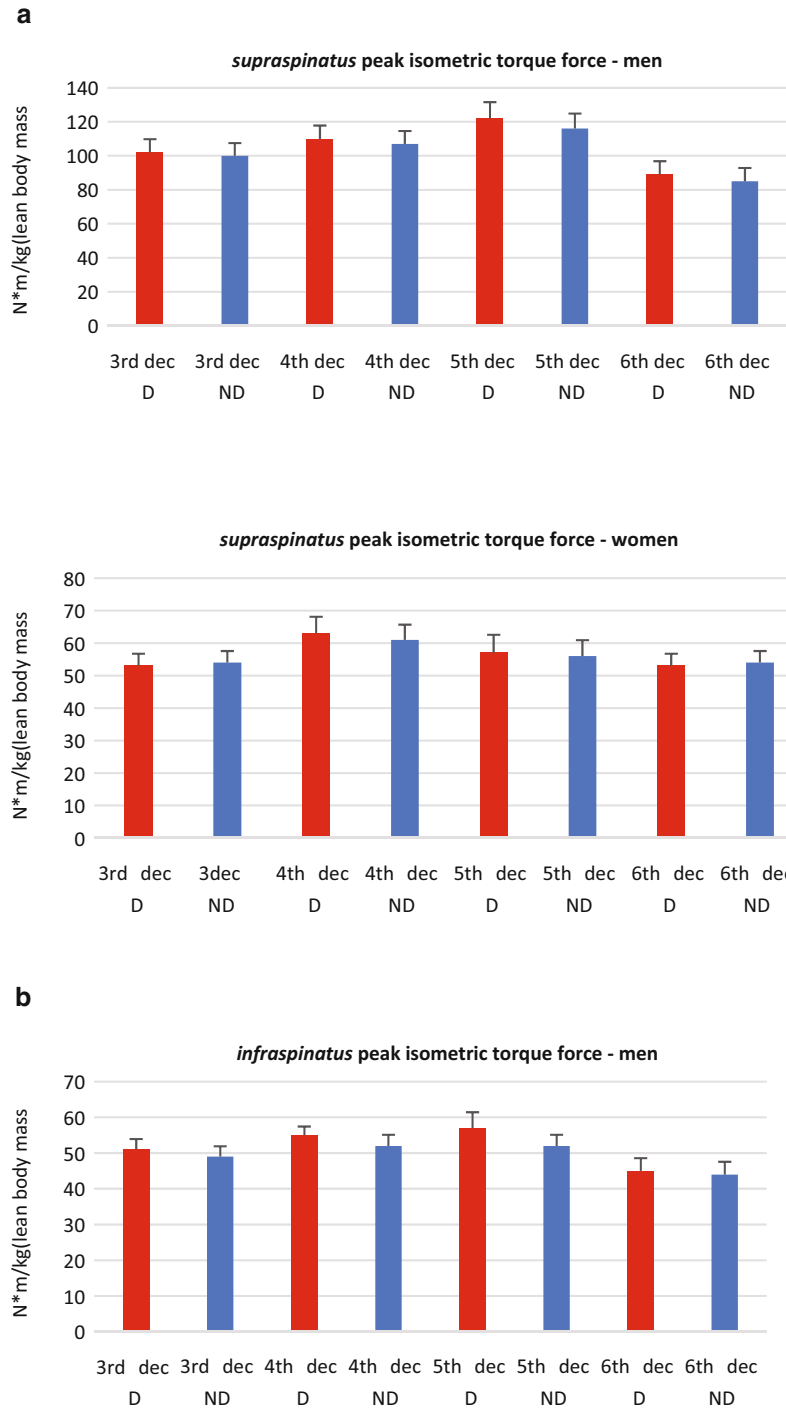
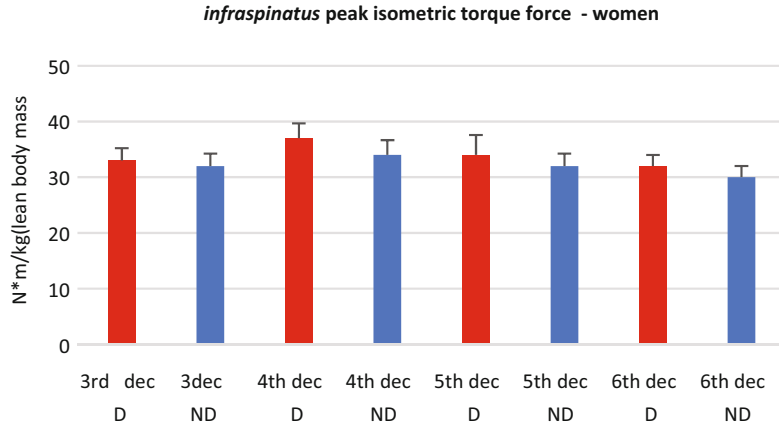


Fig. 2.3 Average peak values (SEM—vertical bars) of torque generated by SS (charts **a**), IS (charts **b**) and SSC (charts **c**) by men and women. Twenty normal individuals of each gender for every decade (dec) of age between 20 and 60 years of age. Shoulders of dominant (D) and non-dominant (ND) upper extremity were examined [1]



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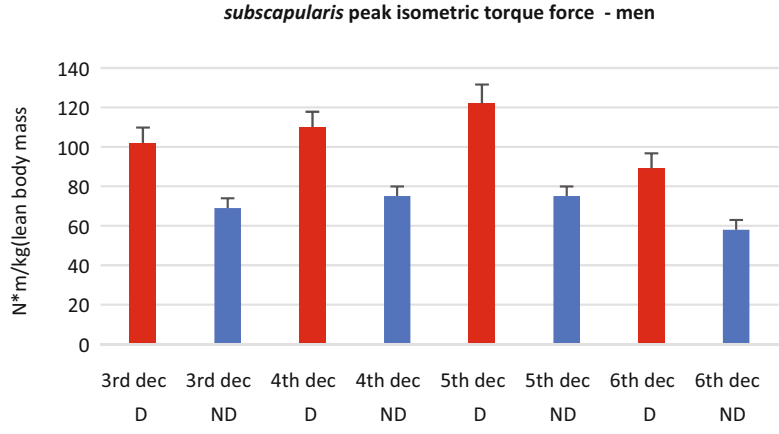

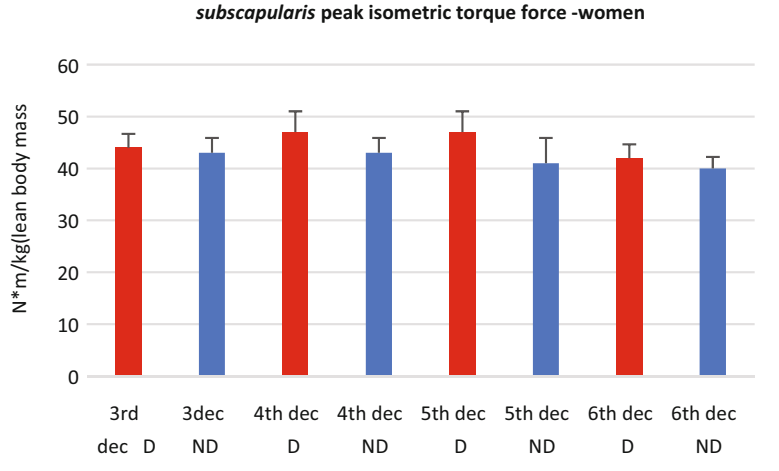

Fig. 2.3 (continued)

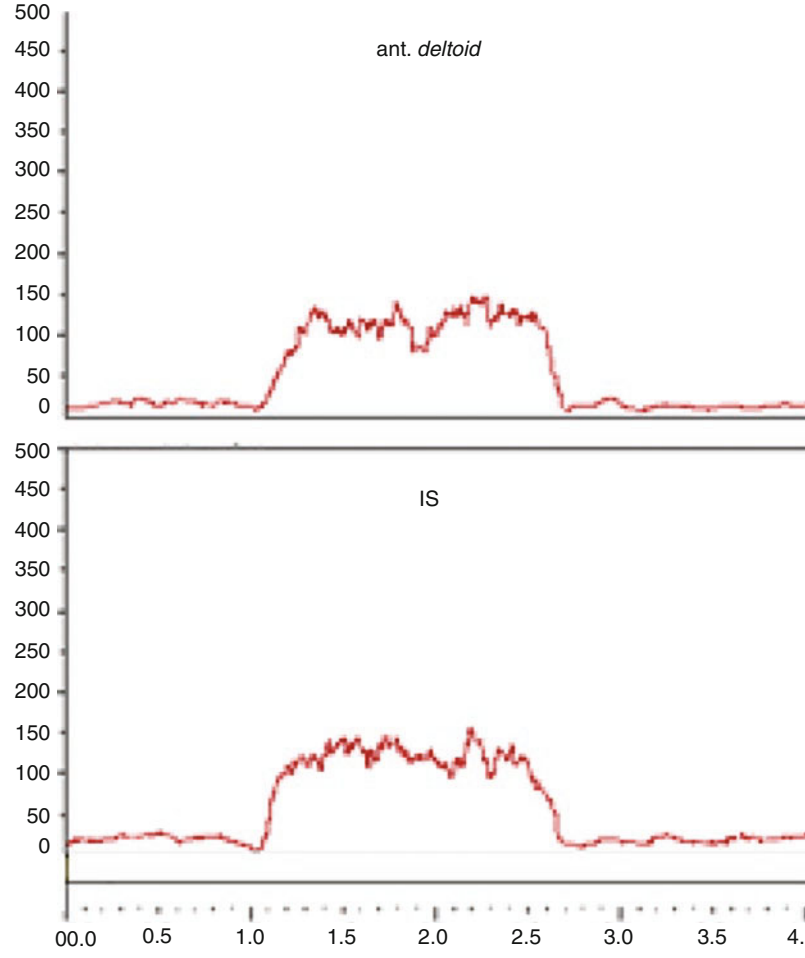

Fig. 2.4 Representative recordings of surface EMG from anterior *deltoid* and IS muscles showing intentional recruitment of shoulder musculature

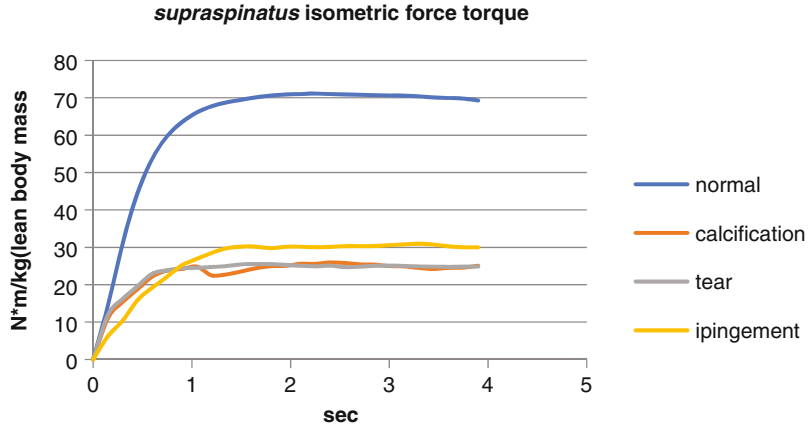

Fig. 2.5 Mean values of SS muscle torque force normalized to lean body mass in patients with subacromial impingement syndrome $n = 30$, grade 2 SS tears $n = 30$, patients with shoulder calcific tendinitis $n = 30$ and normal individuals matched by age and gender [1] The generated torque profiles differ significantly ($p < 0.001$) as following: normal ≫ impingement > tear = calcification [7]

a quick and easy diagnostic modality for the initial detection of rotator cuff pathology and identification of its intrinsic or extrinsic nature. This method might add a more precise evaluation ability of the initial rotator cuff disorder diagnosis and should enable a more efficient decision-making process for the decisive use of imaging.

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Healing of the Rotator Cuff Tendon

3

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3.1 Introduction

Rotator cuff injuries are one of the most common musculoskeletal complaints and affect a significant number of patients, particularly in the aging population. Rotator cuff tears are present in approximately 13% of patients in their 50s, 25% of patients in their 60s, and 50% of patients in their 80s [1]. Surgical treatment with rotator cuff repair is often indicated after failure of conservative treatment in patients with symptomatic rotator cuff tears, but a high rate of failure of healing has been reported in the literature [2, 3]. While patients may improve after surgery even with recurrent rotator cuff tears in regard to decreased pain and increased function, the durability of outcomes after re-tear can be limited [2], and there is literature to suggest that an intact repair results in superior clinical outcomes [3–9]. Tendon-to-bone healing in rotator cuff repair is a multifactorial process that is affected by patient-specific characteristics, intraoperative factors, and postoperative management. This chapter will discuss the normal rotator cuff tendon anatomy and healing response to injury, as well as the various factors that affect rotator cuff tendon healing.

3.2 Anatomy and Pathophysiology

The normal tendon insertion of the rotator cuff is a fibrocartilaginous or direct enthesis. There are four zones of tissue transition between the tendon and bone: Dense fibrous connective tissue, uncalcified fibrocartilage, calcified fibrocartilage, and the bone [10]. The uncalcified and calcified fibrocartilage are separated from each other by the tidemark, which is a line at the outer limit of calcification that is continuous with the articular cartilage. Tendon failure at fibrocartilaginous entheses most often occurs at the subchondral bone rather than the transitional region between the harder calcified tissues and softer uncalcified tissues. The theorized role of the enthesis fibrocartilage is to dissipate stress concentration at the bony interface; there is substantially more fibrocartilage at tendon insertions where a large change in angle occurs through a range of motion and there is more mechanical stress [10].

Tendon healing occurs in three overlapping stages: inflammation (0–7 days), repair (5–14 days), and remodeling (>14 days). The initial inflammatory stage occurs while platelets deposit fibrin and fibronectin and macrophages accumulate in response to insulin-like growth

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factor-1 (IGF-1), platelet-derived growth factor (PDGF), and transforming growth factor β (TGF-β). The repair phase begins when macrophages begin to secrete TGF-β1, which results in fibroblastic proliferation and the formation of scar tissue [11]. The scar tissue is composed of primarily type III collagen (compared to type I collagen in normal tendons and tendon-bone insertions) and undergoes subsequent remodeling to type I collagen. The normal zones and gradations of tissue are not regenerated during tendon-to-bone healing and rather are replaced by fibrovascular scar tissue, which is mechanically weaker and more prone to failure than the native enthesis [12].

3.3 Rotator Cuff Healing

The failure rate after rotator cuff repair has been reported to be as high as 94% [2] and the literature suggests that an intact repair results in superior clinical outcomes [3–8]. Miller et al. [3] found that the majority of recurrent rotator cuff tears occurred in the early postoperative period within the first 3 months, suggesting that the majority of the tears may have never healed. In comparison, Iannotti et al. [13] found a substantial number of re-tears between 12 and 26 weeks after repair. Figure 3.1 shows MRI images from a patient who underwent a one anchor single row rotator cuff repair for a small rotator cuff tear and had subsequent massive failure seen 3 months postoperatively. In comparison, Fig. 3.2 shows MRI images from a patient after rotator cuff repair with an intact repair 5 months postoperatively. Of note, increased signal can be seen postoperatively within an intact tendon; this may be related to tendon degeneration, partial re-tear, scar, or areas of margin convergence [14].

Gamradt et al. [15] used contrast-enhanced ultrasound to investigate the vascular response 3 months after rotator cuff repair and found that tendons with defects after repair had significantly lower vascular volume at rest and following exercise than intact tendons. They were unable to state if the decreased vascularity was a cause or effect of a failed repair, but the vascular supply likely plays a role in rotator cuff healing and numerous studies have attempted to improve healing rates after rotator cuff repair with biologic augmentation. A full discussion of biologic augmentation with platelet-rich plasma (PRP), growth factors, and mesenchymal stem cells (MSCs) is outside the scope of this chapter but is discussed briefly. The remainder of this chapter will discuss the patient-specific characteristics, intraoperative factors, and postoperative management that affect rotator cuff healing.

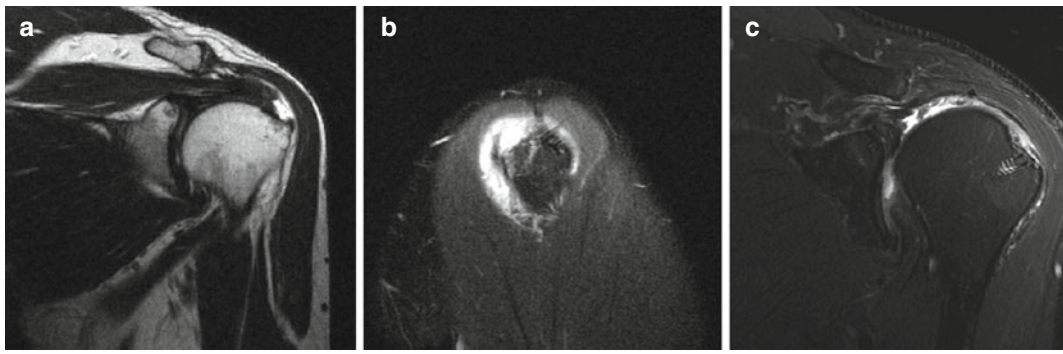

Fig. 3.1 Coronal (left, **a**) and sagittal (center, **b**) MRI slices from a 64-year-old male showing a full-thickness rotator cuff tear. He underwent a single-anchor single-row rotator cuff repair at an outside institution for that injury pattern and presented to our institution with an MRI scan performed 3 months postoperatively (right, **c**) which shows a recurrent full-thickness tear with retraction

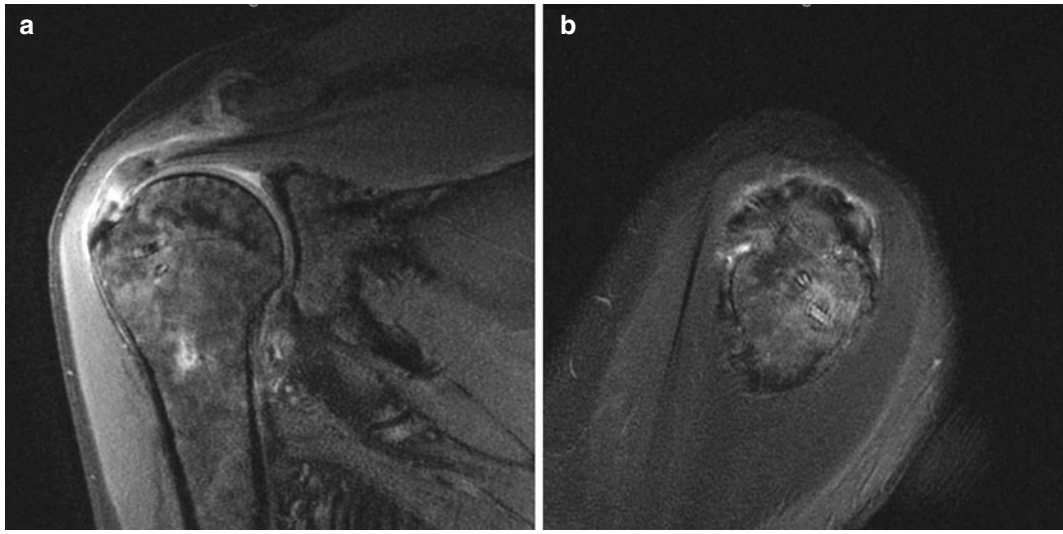

Fig. 3.2 Coronal (left, **a**) and sagittal (right, **b**) MRI slices from a 54-year-old male showing intact rotator cuff repair 5 months postoperatively with increased signal at the area of margin convergence

3.4 Patient and Tear Characteristics

3.4.1 Age

Increasing age has often been cited as a risk factor for poor healing rates after rotator cuff repair [16]. Several studies which showed increased age as a predictor of poor rotator cuff healing on univariate analyses found that tissue characteristics (such as fatty infiltration and tear retraction), and not age, were the only independent predictors of poor cuff healing after rotator cuff repair in multivariate analysis [17, 18]. Selected series have shown good outcomes after rotator cuff repair in patients over 70 years old [19–21]. A recent study by Diebold et al. [22] of 1600 consecutive rotator cuff repairs is likely the largest existing series investigating the effect of age on rotator cuff healing. They demonstrated a low rate of failure to heal or re-tear on ultrasound at 6 months in patients under 50 years old (5%), a 5% linear increase in rate for each decade between ages 50 and 70, and a substantial increase in rate after 70 years old (>45% in patients 85 years old and greater). Performing arthroscopic rotator cuff repair in older patients should be preceded by a thorough discussion with the patient of expected healing rates, surgical risks and benefits, and alternative treatment options.

3.4.2 Smoking

Nicotine has been shown to delay tendon-bone healing with decreased type I collagen expression and inferior biomechanical properties in a rat model [23]. Supraspinatus tendon issue samples from smokers show more advanced degenerative changes, increased density of apoptotic cells, and reduced tenocyte density compared to non-smokers [24]. A systematic review looked at four studies that assessed rotator cuff healing with either MRI or ultrasound after rotator cuff repair. One study showed impaired tendon healing in smokers, two found a trend toward impaired healing in smokers, and one found no association between smoking and tendon healing [25]. It is not known whether nicotine replacement therapy has equivalent deleterious effects as smoking on clinical healing after rotator cuff repair.

3.4.3 Diabetes Mellitus

Patients with diabetes are frequently at a higher risk of poor healing or wound complications due to compromised microvascular supply. An animal study by Bedi et al. [26] showed less fibrocartilage and organized collagen, as well as significantly reduced load to failure and stiffness in diabetic rats after rotator cuff repair. Rotator cuff tissue samples from diabetic patients show an upregulation of matrix metalloprotease-9 (MMP-9) and interleukin-6 (IL-6) compared to normal controls [27]. Clinical studies have also shown inferior outcomes and higher failure rates in patients with diabetes [28, 29]. A recent cohort study by Cho et al. [30] showed a 14.4% re-tear rate in nondiabetic patients compared to 35.9% in diabetic patients ($p < 0.001$) after arthroscopic rotator cuff repair. Furthermore, the rate of re-tear was lower in diabetic patients with hemoglobin A1c (Hgb A1c) levels <7% compared to those with poor glycemic control and Hgb A1c >7% (25.9% versus 43.2%, respectively; $p < 0.001$). Other studies have also found diabetes to be a significant risk factor for poor rotator cuff healing [31]. Thus, attempts should be made to optimize glycemic control prior to rotator cuff repair if possible.

3.4.4 Hypercholesterolemia

Hypercholesterolemia is a pro-inflammatory state that has well-documented effects on cardiovascular health. An animal model of rotator cuff repair showed significant reduction in normalized tendon stiffness in hypercholesterolemic rats 4 weeks after injury; however, there were no differences in collagen organization, cellularity, or cell shape between groups on histologic analyses [32]. A large cohort study by Cancienne et al. [33] showed a higher rate of revision rotator cuff surgery with moderate and high total cholesterol or low-density lipoprotein (LDL) levels compared with patients with normal total cholesterol levels perioperatively. The use of statins resulted in an absolute risk reduction ranging from 0.24% to 1.87% when patients were stratified by cholesterol level and from 0.26% to 1.89% when patients were stratified by LDL level. Kim et al. [31] have also reported dyslipidemia as a risk factor for poor rotator cuff healing in a multivariate analysis. Thus, perioperative lipid control may be a potential avenue to improve outcomes after arthroscopic rotator cuff repair.

3.4.5 Vitamin D Deficiency

An animal model showed a significant decrease in load to failure in vitamin D-deficient rates compared with controls at 2 weeks. This difference was not present at 4 weeks, but there was less bone formation and less collagen fiber organization in vitamin D-deficient subject compared to controls at that time point [34]. A series by Ryu et al. of 91 patients did not find increased rates of poor healing in patients with low preoperative serum vitamin D, though it was underpowered to detect a true difference [35]. Further study is necessary to understand the relationships between vitamin D levels and rotator cuff pathology.

3.4.6 Duration of Symptoms

Duration of symptoms of rotator cuff tears may be a marker of tear chronicity, which may affect tissue quality and thus influence the success of any repair attempts. One study showed a non-statistically significant trend toward improved healing when rotator cuff repair occurred within 12 months of symptoms onset versus more than 12 months (83% versus 71%, respectively) [36]. Similarly, Charousset et al. [37] found a significantly greater rate of persistent rotator cuff defects in patients undergoing surgery with more than 12 months of symptoms compared to those with less than 12 months (60% versus 26%, respectively; $p < 0.05$). Tan et al. also found a higher rate of rotator cuff re-tear in patients with a history of shoulder trauma who waited more than 24 months before surgery; this finding was not present in patients without a history of trauma [38].

3.4.7 Tear and Tissue Characteristics

Smaller rotator cuff tears have been shown to have better healing rates than larger tears in several studies [9, 36, 37, 39]. Similarly, single tendon tears have been shown to have better healing rates than multi-tendon tears [40, 41]. Kim et al. [31] reported that extent of tear retraction and occupation ratio showed highly accurate cutoff values for predicting healing after rotator cuff repair. Lower grades of fatty infiltration have been associated with improved tendon healing during rotator cuff repair [9, 16, 18, 31, 36, 37, 40, 42, 43]. One series reported a 100% failure rate in repairs with a global fatty degeneration index (defined as the mean of Goutallier grade of fatty infiltration for three muscles) of greater than 2 [36]. Severe tendinosis, irrespective of tear size or fatty infiltration, has also been shown to be associated with increased failure rates [44]. However, a recent study by Sethi et al. [45] showed poor correlation between macroscopic tendon appearance and histologic tendinopathy. Furthermore, neither macroscopic tendon appearance nor histologic tendinopathy correlated with healing or patient outcomes, and the authors caution against using gross tendon appearance as the only criteria when deciding to proceed with rotator cuff repair.

3.5 Intraoperative Factors

3.5.1 Open vs. Arthroscopic Technique

Open rotator cuff repair has become less common in practice with technological advances in arthroscopic rotator cuff repair techniques. Some authors have shown superior results regarding repair integrity with open techniques [46, 47], but many studies (including systematic reviews) comparing open and arthroscopic techniques have found no difference in healing rates between these two approaches [48–50]. Selecting a technique should be done based on surgeon comfort, patient preference, and the ability to achieve an appropriate repair with the given technique.

3.5.2 Single-Row vs. Double-Row

Use of single-row versus double-row techniques (Fig. 3.3) has been controversial. Double-row techniques have the theoretical advantage of improved compression of tissue at the rotator cuff footprint but increase the surgical cost and time. In addition, failure after a double-row repair may result in significant loss of tendon length and make revision surgery more difficult. Mihata et al. [39]

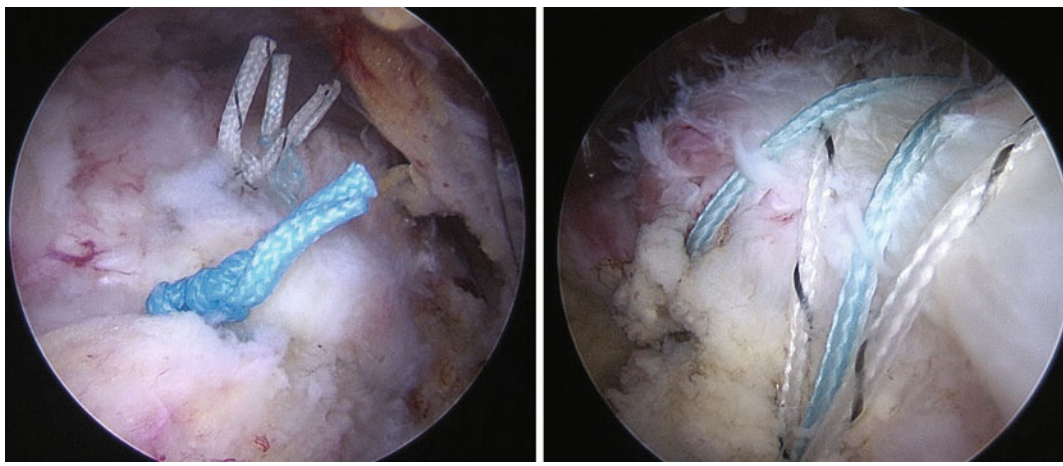

Fig. 3.3 Single-row rotator cuff repair construct with simple sutures (left) and double-row rotator cuff repair construct with two medial and two lateral row anchors (right)

found cuff discontinuity in 11% of single-row repairs, 26% of double-row repairs, and 5% of compression double-row repairs. Gartsman et al. [51] showed a 75% healing rate with single-row repair compared to 93% with double-row suture bridge repair ($p = 0.024$). In a study looking specifically at patients younger than 55 years old, there was a significantly higher healing rate with double-row repair compared to single-row repair (84% versus 61%, respectively; $p < 0.05$), and the authors advocate using double-row repairs in patients younger than 55 with medium to large rotator cuff tears [52]. A biomechanical study of double-row repairs showed that vertical mattress suture pattern in the medial row has a higher load to failure but no difference in gapping compared with horizontal mattress pattern [53].

Lapner et al. [54] reported that double-row repair was associated with higher healing rates, but no significant differences in functional or quality-of-life outcome measures. Similarly, in a systematic review by Nho et al. [55], two of the three studies that utilized postoperative imaging showed improved structural appearance of the repair using double-row techniques without corresponding improvements in clinical outcome measures. Another systematic review of level I and II studies by DeHaan et al. [56] found a 43.1% failure rate with single-row repairs compared to 27.2% with double-row repairs (though this finding did not reach statistical significance).

A biomechanical study of double-row repairs showed that vertical mattress suture pattern in the medial row has a higher load to failure, but no difference in gapping compared with horizontal mattress pattern [53]. Over-tensioning repairs have been suggested as a source of failure after rotator cuff repair [57]; Park et al. [58] recommend keeping bridging suture tension in transosseous-equivalent repairs below 90 N, though assessing this parameter during clinical practice may not be feasible for all surgeons.

3.5.3 Greater Tuberosity Preparation

Preparation of the greater tuberosity during rotator cuff repair is a routine component of the surgical technique in order to increase tendon-bone healing. A goat model showed no difference in tendon healing between the creation of a cancellous trough and fixation to the cortical bone [59]. However, a more recent study by Bilsel et al. [60] using a rabbit model did show that microfracture of the greater tuberosity resulted in increased mean ultimate failure load at 8 and 16 weeks, as well as thicker collagen bundles. A prospective randomized study by Milano et al. [42] using a marrow-stimulating technique with microfracture of the greater tuberosity did not find significant differences in tendon healing between those patients with and without the marrow-stimulating technique; however, their subgroup analysis did find statistically significant improved healing for large rotator cuff tears with the use of the marrow-stimulating technique. Jo et al. [61] found a lower re-tear rate in patients where multiple channels were created in the greater tuberosity (with subsequent release of mesenchymal stem cells demonstrated by flow cytometry) than those without creation of multiple channels (22.2% versus 45.2%, respectively; $p = 0.023$).

3.5.4 Acromioplasty

Acromial morphology has been theorized as a potential initiating factor that can lead to rotator cuff dysfunction and eventual tearing [62]. However, the data does not necessarily support improved rotator cuff healing when rotator cuff repair is performed in conjunction with acromioplasty. A prospective, randomized study demonstrated no difference in rotator cuff healing between patients undergoing rotator cuff repair with or without acromioplasty (failure rate 17% versus 20%, respectively, $p = 0.475$) [63]. Similarly, a systematic review and meta-analysis of earlier data found no significant differences in shoulder-specific outcome measures or the rate of reoperation between patients with full-thickness rotator cuff tears undergoing rotator cuff repair with or without acromioplasty [64].

3.5.5 Scaffold Augmentation

Scaffold augmentation to increase the structural integrity of rotator cuff repairs has been of

increasing interest in recent years. Basic science studies largely show improved repair characteristics during biomechanical testing with scaffold augmentation of rotator cuff repair [65, 66]. A cadaver study by Omae et al. [65] showed improved load to failure with a single-row repair construct augmented with a human dermal matrix graft. Clinical studies have also demonstrated favorable healing rates or improved healing rates with the use of human dermal matrix grafts compared to non-augmented repairs [67–69]. Other studies looking at the use of porcine small intestine submucosa augmentation had unfavorable results and authors have cautioned against their use in rotator cuff repair [70–72]. In evaluating the potential use of scaffold augmentation for rotator cuff repair, it is important to differentiate between the type of scaffold as the biologic response, both of the tendon to the scaffold [73] and of the scaffold to the surrounding milieu including mesenchymal stem cells [74], can vary significantly.

3.5.6 Platelet-Rich Plasma (PRP)

Platelet-rich plasma has also been a frequent subject of study as a means to enhance rotator cuff repair healing. The majority of early literature did not show a beneficial effect or improved healing with the use of PRP in rotator cuff repair, including systematic reviews and randomized controlled trials [75, 76]. In fact, one study by Rodeo et al. [77] found no difference in tendon healing on ultrasound at 12 months in patients with and without platelet-rich fibrin (PRF) matrix augmentation of rotator cuff repair but actually found that use of PRF was a significant predictor of persistent tendon defect at 12 weeks. Zumstein et al. [78] also found no beneficial effects of PRF application during arthroscopic rotator cuff repair in clinical outcomes or healing rates. The composition of PRP and indication for use should be carefully assessed in any study as the leukocyte concentration, platelet concentration, and extent of tendon disease have been shown to be factors in the effect of PRP with rotator cuff disease [79]. The most recent meta-analysis of randomized controlled trials did show improved healing rates, pain levels, and functional outcomes after rotator cuff repair with the use of PRP, but not with PRF [80]. Timing of PRP administration is also important and postoperative administration may be less efficacious than intraoperative use [81]. Thus far, the most consistent favorable data for PRP and its use in rotator cuff repair is regarding pure PRP (P-PRP) or leukocyte-poor PRP (LP-PRP) [80, 82, 83]. However, routine use of PRP in arthroscopic rotator cuff repair may not be cost-effective at this time [84].

3.5.7 Other Future Targets

Research focusing on the concomitant use of scaffolds, PRP, and mesenchymal stem cells (MSCs) is ongoing. MSCs can be easily harvested during arthroscopic shoulder surgery for biologic augmentation of rotator cuff repair (Fig. 3.4) [85]. A reduction in number of MSCs at the tendon-bone interface of the greater tuberosity in patients with rotator cuff tears has been demonstrated [86] and may benefit from augmentation. The following genes and markers have been identified as possible targets affecting rotator cuff healing and may be future therapeutic targets: upregulation of cell differentiation genes including BMP5 [87], downregulation of inflammatory response genes [87], single-nucleotide polymorphisms in the Tenascin-C haplotype [88] and estrogen-related receptor beta (ESRRB) gene [89], exogenous

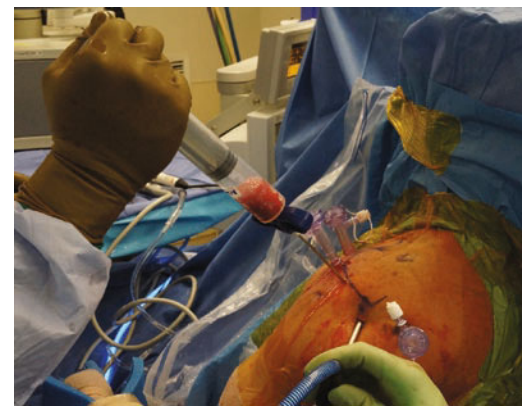

Fig. 3.4 Intraoperative photo of the senior author's technique to harvest bone marrow from the humeral head for augmentation of a revision arthroscopic rotator cuff repair

expression of BMP13 [90], treatment with TGF-β1 [91], activation of MSCs with hyaluronic acid [92], treatment with sclerostin antibody [93], and treatment of scaffolds with fibroblast growth factor-2 (FGF-2) [94].

3.6 Postoperative Management

3.6.1 Postoperative Anesthetic Pumps

The use of continuous subacromial local anesthetic infusion has a theoretical risk of local tissue toxicity, but an animal study comparing bupivacaine infusion and saline infusion showed no differences at 8 weeks in histologic and biomechanical characteristics [95]. A recent study on continuous and patient-controlled subacromial ropivacaine infusions did not show any difference in healing rates compared to other pain control modalities (such as intravenous patient-controlled analgesia and/or interscalene block) [96].

3.6.2 Nonsteroidal Anti-Inflammatory Drug (NSAID) Use

Animal models have shown negative impacts of NSAIDs on tendon healing such as reduced tendon size, poor collagen organization, and inferior biomechanical properties [97–99]. Dosage timing may also be important in mitigating the negative effects of NSAIDs on rotator cuff healing, and some authors suggest avoiding early postoperative use of NSAIDs [100, 101]. Oh et al. [102] have cautioned specifically against the use of cyclooxygenase-2 (COX-2) inhibitors after arthroscopic rotator cuff repair due to negative effects on tendon-to-bone healing.

3.6.3 Immobilization

Most surgeons protect rotator cuff repairs with postoperative activity limitations. Galatz et al. [103] found that complete removal of load negatively affects rotator cuff healing. Several studies comparing early motion with delayed motion found no difference in rotator cuff healing between groups [104–106]. Keener et al. [106] found no differences in functional scores, active motion, strength, or re-tear rates between patients treated with early range of motion versus 6 weeks of immobilization. Lee et al. [104] did report more failures with an aggressive early passive motion group compared to limited early motion, but this difference was not statistically significant. Koh et al. [107] performed a prospective, randomized trial comparing 8 weeks and 4 weeks of immobilization for medium-sized rotator cuff tears and found no difference in healing rates after single-row arthroscopic rotator cuff repair.

There have been several recent meta-analyses comparing early and delayed motion after rotator cuff repair. A meta-analysis by Chang et al. of randomized controlled trials found that early passive motion was associated with a higher rate of recurrent tears after rotator cuff repair; this difference became statistically significant when excluding studies that only recruited small- and medium-sized tears [108]. Kluczynski et al. published two different meta-analyses as well comparing early versus delayed active [109] and passive [110] range of motion. In their study on early passive motion [110], they also found a higher risk of failure with early passive motion for large tears (>5 cm). However, they reported a lower risk of re-tear for small tears (≤3 cm) with a combination of transosseous and single-row repairs. In their study on early active range of motion [109], they reported a higher risk of structural tendon defects with early active motion in small and large rotator cuff repairs. While limiting early motion and immobilization may result in postoperative stiffness, McNamara et al. [111] reported that patients with ≤20° of external rotation at 6 and 12 weeks postoperatively had improved rates of rotator cuff integrity 6 months postoperatively. Overall, the aggregate data seem to suggest that there is either no difference in tendon healing or favoring delayed motion after rotator cuff repair [112]. A consensus statement from the American Society of Shoulder and Elbow Therapists recommends a 2-week period

of strict immobilization and staged introduction of protected, passive range of motion during weeks 2–6 postoperatively [113]. Thus, a period of postoperative immobilization is likely prudent to optimize rotator cuff healing while accepting a risk of some early postoperative stiffness that can be addressed later in the rehabilitation process.

3.7 Conclusion

Rotator cuff healing is a complex process affected by multiple factors including patient characteristics and comorbidities, rotator cuff tissue quality and tear characteristics, intraoperative technique, and postoperative management. Rotator cuff repairs should be performed with adequate construct strength, stability, and compression while also optimizing the biologic environment for tendon-bone healing. Despite a significant body of existing literature, further research is required to improve rotator cuff healing rates in clinical practice.

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4 The Role of Platelet-Rich Plasma and Growth Factors in Rotator Cuff Repair

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4.1 Introduction

The role of biologic therapy in augmentation of tendon to bone healing has gained significant interest in orthopedic surgery, including in rotator cuff repair. Augmentation is of particular interest in challenging revision cases after failed rotator cuff repair, chronic retracted rotator cuff tears with poor tissue quality, and rotator cuff tears in patients with compromised healing potential such as smokers, diabetics, and those with other chronic medical comorbidities.

Histological studies have shown that the rotator cuff tendon insertion is composed of unmineralized fibrocartilage and mineralized fibrocartilage as anatomic intermediates as the tendon transitions to the bone [1]. Unfortunately, studies have shown that a histologically normal insertion site does not regenerate following tendon-to-bone repair [2]. Instead, rotator cuff healing involves a reactive scar formation that differs from native tissue in regard to composition and organization without reformation of the mineralized fibrocartilage. The fibrovascular scar predominated by type III collagen is biomechanically weaker, which likely contributes to repair failure [3]. The goals of biologic augmentation are to increase healing rates, improve clinical outcomes, limit the amount of scar formation, and stimulate the regeneration of a more normal bone-to-tendon interface.

4.2 Growth Factors

Cytokines and chemokines are found in multiple tissues, such as blood plasma and platelet granules, and are key regulators in the healing process. These growth factors play various roles during tissue remodeling and tendon healing. They have become the topic of extensive research on how they may improve healing rates or healing potential. Cytokines are key players in cell chemotaxis, cell proliferation, differentiation, and matrix synthesis [2]. Osteoinductive growth factors are also heavily involved in the healing of the tendon-bone interface. Healing between the rotator cuff tendon and bone is largely affected by the degree of bone ingrowth, which is important for reestablishment of collagen fiber continuity between the tendon and bone [4].

Multiple researchers have investigated the actions of growth factors in rotator cuff animal models. Kobayashi et al. explored the expression of basic fibroblast growth factor (bFGF),

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insulin-like growth factor-1 (IGF-1), platelet-derived growth factor (PDGF), and transforming growth factor-ß (TGF-ß) in a rabbit supraspinatus full-thickness tendon defect model [5]. They found increased expression of these four growth factors, each in specific cells: bFGF was found in fibroblasts and vascular endothelial cells, IGF-1 in blood cells and vascular endothelial cells, PDGF in endothelial cells, and TGF-ß in blood cells [5]. Another study by Wurgler-Hauri et al. found upregulation of eight growth factors (bFGF, bone morphogenetic protein 12 (BMP-12), BMP-13, BMP-14, cartilage oligomeric matrix protein (COMP), connective tissue growth factor (CTGF), platelet-derived growth factor-B (PDGF-B), and transforming growth factor-1 (TGF-1)) in a rat rotator cuff repair model in the first week after rotator cuff repair [6]. Rodeo et al. attempted to use an animal model to evaluate the effect of a combination of bone-derived growth factors on the healing process. They found that a mixture of osteoinductive growth factors loaded on a collagen sponge carrier led to stronger attachment between the tendon and bone at 6 and 12 weeks after repair compared to repair with a collagen carrier alone or no implant [4].

Growth factors have also been studied in animal models of other injuries. A study by Hildebrand et al.[7] looked at the role of platelet-derived growth factor-BB (PDGF-BB) and transforming growth factor-beta 1 (TGF-β1) on healing of a medial collateral ligament (MCL) injury in a rabbit model. There was improved ultimate load, energy absorbed to failure, and ultimate elongation of MCL injuries treated with PDGF-BB in a dose-dependent manner. Addition of TGF-β1 to the model appeared to have a negative effect on MCL healing, though their group had previously demonstrated PDGF-BB positively affected ligament fibroblast proliferation and that TGF-β1 enhanced collagen and total protein synthesis. The authors had expected potentiated improvement in healing with PDGF-BB and TGF- β1 treatment of MCL injuries, but these counterintuitive results of MCL healing in their rabbit model exemplify the complexity of interactions between individual growth factors. Our incomplete understanding of these interactions makes effective treatment in clinical practice difficult. Optimizing results will require not only understanding interactions between growth factors but dose- and time-dependent effects as well. Single and select combinations of growth factors clearly play a role in tendon to bone healing [8], but they are not commercially available in the US market for use in clinical practice at this time. The most common source of growth factors for biologic augmentation in the USA at this time is platelet-rich plasma (PRP), which has numerous commercially available processing systems.

4.3 Platelet-Rich Plasma

The granules within platelets and plasma theoretically allow for delivery of cytokines and biologic proteins in "physiologic balance" [9] and improve the dose- and time-dependent effects compared to single or select combination growth factors. PRP contains many of the growth factors that have been shown to be critical in bone-tendon healing such as TGF-ß, bFGF, PDGF, vascular endothelial growth factor (VEGF), connective tissue growth factor (CTGF), and epidermal growth factor (EGF). In addition, in vitro studies have demonstrated the ability of PRP to increase local concentration of mesenchymal stem cells, macrophages, and fibroblasts, all contributing to the healing process [10]. Fibrin, fibronectin, and vitronectin found in PRP are known cell adhesion molecules and play important roles in matrices of connective tissue [10].

Early studies did not demonstrate consistent clinical benefits of using PRP, but there was inconsistent reporting of harvest techniques or PRP composition in regard to platelet, growth factor, and leukocyte concentration. In response, classification systems of PRP have been developed to help researchers better document and compare results [11, 12]. The concentration of PRP components is influenced by multiple factors including preparation method and processing systems [13, 14]. There have also been attempts to determine the optimal clinical concentrations of PRP components and methods of application.

Mazzucco et al. reported that a platelet concentration greater than 200×10^3 platelets/μL is sufficient to produce a therapeutic effect and that concentrations 2.5 times greater than native blood have positive effects on osteoblasts and fibroblasts in vitro [15]. Adverse effects have been reported at doses higher than 3.5 times platelet concentration of native blood [16]. Giusti et al. suggested that 1.5×10^6 platelets/μL is the optimum platelet concentration for tissue healing [17]. Variation in platelet, as well as WBC concentration, can occur between repetitive blood draws from the same individual and may affect clinical outcomes after serial treatments, which are common in clinical practice [14].

Multiple early studies did not show a beneficial effect or improved healing with the use of PRP in rotator cuff repair [18–20], with some even showing negative effects in terms of re-tear rates or healing [9]. Randelli et al. conducted a randomized control trial comparing arthroscopic rotator cuff repair with and without intraoperative PRP application; their results yielded significant reduction in pain at up to 24 months follow-up, but no significant differences in rotator cuff healing rates on follow-up MRI studies [21]. However, the most recent meta-analysis of randomized controlled trials did show improved healing rates, pain levels, and functional outcomes after rotator cuff repair with the use of PRP, but not with platelet-rich fibrin (PRF) [22]. Timing of PRP administration is also important and postoperative administration may be less efficacious than intraoperative use [23]. Thus far, the most consistent favorable data for PRP and its use in rotator cuff repair is regarding pure PRP (P-PRP) or leukocyte-poor PRP (LP-PRP) [22, 24–26]. However, routine use of PRP in arthroscopic rotator cuff repair may not be cost-effective at this time [27].

4.4 Scaffold Augmentation

Extracellular matrix (ECM) augmentation of rotator cuff repair is based on the idea that the matrix can act as a scaffold for aligned cellular growth and collagen composition. In addition to providing mechanical support, the matrix can then incorporate itself into the host tissue and eventually be replaced by the host tissue. The two principal methods in which scaffolds can augment rotator cuff repair are by providing biomechanical support and as a biologic scaffold in which cell therapy can be delivered to enhance bone-tendon healing. ECM grafts are made using various different types of biologic and engineered materials and are commercially available as xenograft, allograft, or synthetic extracellular matrices [28, 29]. The incorporation of these materials into animal model tissue and a positive effect on tendon repairs without immunologic response has been shown in several studies. However, when used in human tissue for rotator cuff repair, results have been highly variable. Graft rejection, cellular adhesion, and cellular proliferation are among several factors that must be taken into consideration when studying and comparing different ECM models. Several studies have shown negative results with the use of xenograft, often in the form of inflammatory reaction, without an improvement in healing rates [30–32].

Several allogenic extracellular matrices developed using decellularization of cadaveric material such as human fascia lata and dermal tissue are commercially available. Promising results have shown positive effects in several studies when comparing allogenic ECM to unaugmented controls [33–35]. Concerns of using allogenic ECMs revolve around inflammatory responses elicited in response to retained DNA from allogenic source. In hosts, this may cause pain and edema and potentially accelerate degeneration of rotator cuff repair [36]. Derwin et al. compared the biomechanical properties of different ECM allografts and found that the elastic moduli of commercial matrices were significantly lower than those of human tendons, suggesting decreased load-carrying capabilities and theoretically higher predisposition for failure [37]. Synthetic ECM grafts have been developed in an effort to provide an adequate scaffold for cellular and fibrotic growth while minimizing risk of an inflammatory response. Several animal studies have found improvement in cell number and

layering, better collagen fiber alignment, and mechanical strength [38–40].

Scaffolds may also be used as a vehicle for delivery of other biologic augmentation, such as PRP and stem cells. This is a common use in our practice; our methods and rationale are described below in a discussion of the senior author's clinical protocol.

4.5 Mesenchymal Stem Cells

The use of stem cells in orthopedic surgery has gained great interest, but research is still in the early stages of understanding their utility in clinical practice. The ability of stem cells to differentiate and mature into cells of different lineage is termed multipotentiality. Stem cells also have paracrine functions and are able to secrete potent trophic factors that evoke responses from nearby resident cells. Stem cells that have the potential to differentiate into mesenchymal tissue (e.g., tendon, muscle, cartilage, bone) are termed mesenchymal stem cells (MSCs). MSCs can be harvested from several different areas of the body including bursa, bone marrow, synovial tissue, and adipose tissue. Traditionally, the iliac crest has been the most reliable region to harvest bone marrow-derived MSCs. In addition, other methods such as collection from peripheral blood and intra-articular tissue have been described; however, these methods may not translate efficiently into current shoulder surgery techniques due to the harvest-site morbidity, longer operative time, and/or the complex methods needed to isolate and culture cells. In 2010, Mazzocca et al. [41] described a method to reliably extract stem cells from the proximal humerus during arthroscopic rotator cuff cells. This method allowed for aspiration of a large volume of bone marrow without any additional morbidity to the patient and subsequent purification to yield a fraction rich in connective tissue progenitor cells in a simple, efficient, reproducible manner [41]. In this study, these cells were only differentiated into cells of the osteogenic cells line; however, a follow-up study demonstrated the ability to induce differentiation of these cells into tenocyte-like cells by the addition of insulin [41, 42]. Incorporation of cells often requires scaffolds as biologic carriers for cell administration into a repair site. Fibrin carriers, silk/collagen scaffolds, polylactic acid sheets, and polyglycolic acid sheets are among the different methods used to deliver cells; however studies utilizing these methods have had highly variable methodologies and results. Several animal studies have shown promising results with MSCs directed at tendon healing with improved biomechanical and structural qualities, as well as increased type 1 collagen, fibrocartilage, and fibroblastic cell ingrowth [43–46]. There is still no consensus on the most efficient and successful carrier to deliver MSCs to a repair site. A study conducted by Ellera Gomes et al. even showed clinical improvement in rotator cuff repair with direct injection of bone marrow-derived MSCs (harvested from iliac crest before the index procedure) into the repaired tendon borders [47]. However, as this study did not have a control group, the conclusions that can be drawn from the results are limited. It is difficult to draw conclusions from the research in MSC augmentation of rotator cuff repair due to extensive heterogeneity in studies regarding method of cell procurement, concentration, and delivery, as well as the concurrent modulation of the surrounding healing environment.

4.6 Senior Author's Current Clinical Protocol

4.6.1 Indications

Biologic augmentation of rotator cuff repair is performed in our practice for revision rotator cuff repair or in patients at high risk for failure. Revision rotator cuff repair is not attempted if the tear is deemed irreparable (i.e., insufficient tendon length or quality) or in patients with significant arthritis. In these situations, a superior capsular reconstruction or reverse total shoulder arthroplasty may be more appropriate surgical treatment.

4.6.2 Operative Principles

The operative principles for biologic augmentation of rotator cuff repair are similar to that of non-union fracture care. Successful repair requires both adequate stability and biology. Thus, biologic augmentation of rotator cuff repair necessitates adequate tendon length and tissue quality to allow for a repair construct that is robust and under minimal tension. Biologic augmentation should be viewed precisely as that—a tool to augment biologic healing after rotator cuff repair and should not be used to make up for inadequate surgical techniques.

4.6.3 Preoperative Assessment

Evaluation of patients prior to biologic augmentation of rotator cuff repair is the same as in any patient with suspected rotator cuff pathology. This begins with a thorough history, including an assessment of any patient-specific risk factors for failure such as diabetes mellitus [48, 49] and smoking [50]. Operative reports from previous surgeries should be obtained to determine repair technique as failure after double-row techniques can have significant loss of tendon length. A complete physical examination should also be performed with particular attention to active shoulder range of motion, rotator cuff strength, and the presence of pseudoparalysis as these findings may be contraindications to rotator cuff repair in some patients.

Preoperative imaging should include shoulder radiographs (including a true AP or Grashey, scapular Y, and axillary views) and magnetic resonance imaging (MRI) without contrast. Radiographs should be assessed for the presence of arthritis and superior migration, both of which may be quantified with the Hamada classification [51]. MRI can be particularly useful to the surgeon during preoperative planning and assessment of a rotator cuff tear for reparability. The tear size, number of involved tendons, amount of tendon length present, level of tendinous retraction, and fatty atrophy in the rotator cuff muscles may all affect the likelihood of repair success [52–59].

Patients should be counseled preoperatively regarding the limited evidence supporting the routine use of biologic augmentation during rotator cuff repair and the risks of postoperative failure. They should also be advised on any modifiable risk factors that they can control before and after surgery (i.e., smoking cessation, postoperative compliance with immobilization, and rehabilitation protocols).

4.6.4 Operative Technique

Our current surgical protocol utilizes a combination of PRP and MSCs harvested from the humeral head. After administration of general anesthesia, the anesthesiologist performs a peripheral blood draw with a sterile PRP harvest kit prior to draping to increase their access and visibility. The amount of blood required may differ depending on the volume of PRP needed and the specifications of the commercial PRP production system used. We routinely use the Angel system (Arthrex, Naples, FL), which requires 55 mL of blood drawn into a 60 mL syringe containing 8 mL of anticoagulant citrate dextrose (ACD-A). This is then attached to the Angel system, which is set to a standard protocol with 7% hematocrit and 60 mL volume. PRP, platelet-poor plasma (PPP), and RBCs are collected and the PRP and PPP passed onto the sterile field.

We routinely perform rotator cuff repair in the beach chair position, but the surgeon may utilize a lateral decubitus position if preferred. Diagnostic arthroscopy is performed using standard portals. Collection of bone marrow aspirate should be performed as early in the surgical procedure as possible so that it may be processed while the surgeon completes the rotator cuff repair. The bone marrow aspiration kit should be prepared on the sterile surgical field at the start of the case (Fig. 4.1). We prefer to aspirate the bone marrow from the footprint of the torn rotator cuff using the same hole that is made for anchor placement [41]. This is performed with a non-fenestrated bone marrow

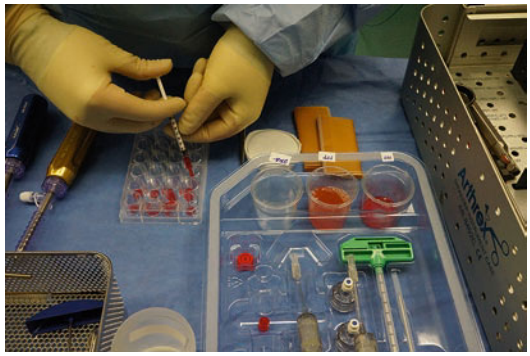

Fig. 4.1 Bone marrow aspiration kit seen in the bottom right portion of the image. The scrub technician is preparing the clot in the 24-well plate in the top left portion of the image

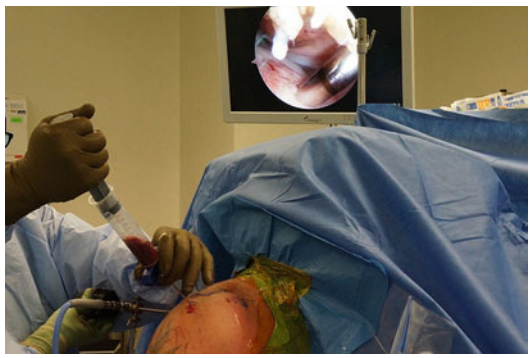

Fig. 4.2 Intraoperative photo of the senior author's technique for harvesting bone marrow from the humeral head; the needle in the humeral head can be seen in the monitor in the background

aspiration trocar (Fig. 4.2). The trocar is inserted in the footprint to a depth of approximately 20–30 mm. A 60 mL syringe prefilled with 3 mL ACD-A is attached to the trocar and bone marrow is aspirated to a total volume of 20 mL. This is repeated with multiple syringes until a minimum of 40 mL is harvested. These syringes are then placed directly into the bag on the Angel system. The system should be set to protocol bone marrow aspirate (BM) 15% to concentrate stem cells and the appropriate volume selected (Fig. 4.3). This will generally produce 2–4 mL of concentrated bone marrow aspirate (cBMA).

A fibrin clot is then prepared on the back table using cBMA, PRP, PPP, and bovine thrombin in a 24-well plate (Fig. 4.1). This clot delivers growth factors from the PRP and stems cells from the cBMA. The PPP serves as a matrix as it contains

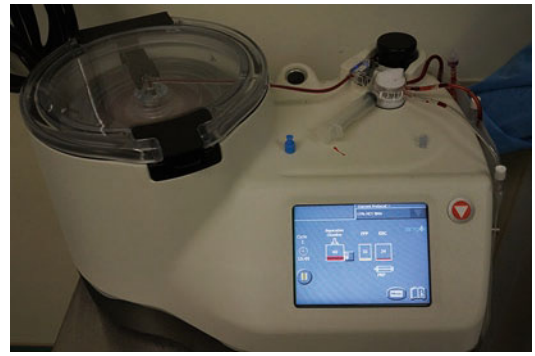

Fig. 4.3 Angel system set to 15% hematocrit for bone marrow aspiration processing

fibrinogen and the bovine thrombin initiates the clotting cascade. The ratio of products to form a fibrin clot is 0.6 mL PPP, 0.1 mL cBMA, 0.1 mL PRP, and 0.2 mL thrombin [60]. Single-row or double-row rotator cuff repair constructs may be performed, depending on the tear configuration. We frequently perform a double-row repair; prior to placing the final lateral row anchors, the fibrin clot can be injected underneath the rotator cuff tendon at the rotator cuff footprint using the same trocar used for aspiration. Alternatively, the clot may be injected on top of a single-row repair (Fig. 4.4). We have also described a technique of forming the clot on the suture of a suture anchor and then delivering the clot into the bottom of the anchor [60].

The clot may also be seeded onto a scaffold. If this is performed, we prefer to use a demineralized bone matrix (DBM) scaffold comprised of cancellous bone (Flexigraft, Arthrex, Naples FL). These scaffolds will incorporate and resorb over approximately 6–8 weeks during the period of initial rotator cuff healing and have been shown to have osteoconductive and osteoinductive potential at the bone-to-tendon junction in rotator cuff repairs in a canine model [61]. Stem cells adhere to the scaffolds even in the setting of arthroscopic fluid flow and cellular adhesion, proliferation, and differentiation is enhanced by the addition of PRP [62]. Combining our fibrin clot with a DBM scaffold may allow for controlled release of growth factors over the period of initial healing and is a topic of active investigation at our institution. Early unpublished results from our institution suggest that the combination of a DBM scaffold with a fibrin clot (cBMA, PRP, and PPP as

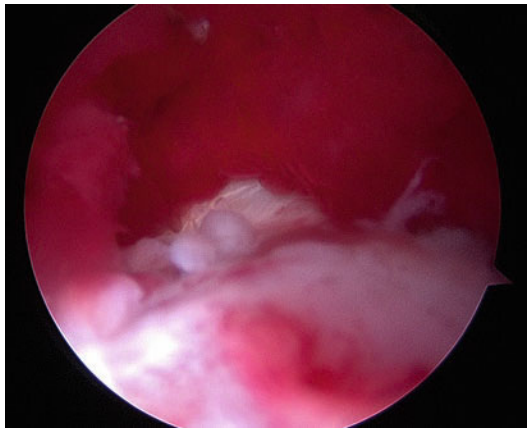

Fig. 4.4 Arthroscopic image of a "red-out" after injection of the fibrin clot over a single-row arthroscopic rotator cuff repair

described above) allows for higher concentrations of PDGF and TGF-β over a 21-day time period than any of the components alone.

4.6.5 Postoperative Management

Patients are placed into an abduction sling immediately postoperative and are non-weight-bearing in the operative extremity. We have not found differences in healing rates after rotator cuff repair when comparing early range of motion with delayed motion rehabilitation protocols [63] but did find lower Western Ontario Rotator Cuff (WORC) scores in the early postoperative period with early motion. Our delayed motion protocol initiates active assistive range of motion exercises after 4 weeks (cane external rotation from 0° to 60°, forward elevation from 30° to 180°). The patient may discontinue sling immobilization after 6 weeks and should have normalized range of motion at that point. Strengthening exercises are initiated 12 weeks after surgery with a goal to transition to an independent home exercise program at 18 weeks.

4.6.6 Follow-Up Treatment

Patients should be followed at regular postoperative intervals to assess appropriate progression within their rehabilitation protocol. If there is concern for tear recurrence or failure of the rotator cuff repair to heal, a repeat MRI can be obtained to assess repair integrity. There can be artifact on the MRI due to any suture anchors in place; metal artifact reduction sequences can be utilized if metal anchors were used. Alternatively, CT arthrograms can be performed to assess the status of the rotator cuff as needed. The surgeon should consider the possibility of occult infection in the setting of failed rotator cuff surgery and an infectious workup may be appropriate.

4.6.7 Tips, Tricks, and Pitfalls

Use of our biologic augmentation protocol with fibrin clot with or without DBM scaffold can add significant operative time to a standard arthroscopic rotator cuff repair. We recommend having a consistent operative team who is well versed in the necessary steps to prepare the clot and scaffold. These steps can be performed on the back table as the surgeon is preparing the rotator cuff, placing suture anchors, and passing sutures. Similarly, it is important to perform the peripheral blood draw for PRP and harvest bone marrow as soon as possible in the surgical procedure so that these components may be prepared while the surgeon continues to work.

Injection of the fibrin clot should be done as late in the surgical procedure as possible as it creates a "redout" environment with poor arthroscopic visualization afterward (Fig. 4.4). Closing as many of the arthroscopic portals as possible prior to injection can help limit extravasation of the fibrin clot. After fibrin clot injection, the surgeon should not utilize suction.

4.7 Conclusion

The evolution of biologic augmentation in orthopedics has gained much attention due to the obvious benefits and potential to positively influence outcomes after many common surgeries such as rotator cuff repair, meniscal repair, and cartilage restoration. The use of growth factors, PRP, and mesenchymal stem cells has shown positive effects on healing qualities in the literature; however studies continue to be variable in methodology and clinical results. Further investigation to

determine the ideal methods of harvest and preparation of PRP and cBMA is necessary as well as how to optimize incorporation of biologic augmentation into target tissue. Future study and development will continue to be affected by regulatory pathways and should also be considered.

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Genetics in Rotator Cuff Tears: First Steps to the Future

5

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Rotator cuff tear (RCT) is among the most common musculoskeletal disorders [1, 2]. It is the third cause of musculoskeletal disease, after the back (23%) and the knee (19%) [3]. It affects 30–50% of the population older than 50 years [4] and is associated with shoulder pain and loss of function [5]. Degenerative rotator cuff tears increase with age; thus, such tears can become an increasingly prevalent clinical problem [6].

The pathogenesis of degenerative RCT is not completely understood. The mechanism is described as caused by extrinsic (mechanical impingement) and intrinsic factors. As intrinsic factors we can describe degeneration of tendons, including increased tendon cell apoptosis, higher proportion of fatty infiltration, aberrant microstructure of structural fibers, and abnormally reduced nutrient vessels [1, 6–8]. It is possible that the biologic changes found are regulated by genes [9].

There are studies that identify demographic factors such as advanced age, dyslipidemia, diabetes, and increased body mass index, which may contribute to the progression of the rotator cuff injury [10–17]. The suggestion that smoking habit increases the risk of rotator cuff lesions is biologically plausible. The negative effects of tobacco occur due to the vasoconstrictive properties of nicotine which decreases the blood supply to the tissues associated with the ability of carbon monoxide to decrease cellular oxygenation levels. Thus, the effect described in a previously hypovascular tendon has an adverse effect on rotator cuff healing [18]. Also Baumgarten et al. found that shoulder pain and rotator cuff lesions are related to the amount and time of addiction [19], while Itoi et al. and Carbone et al. associated the cigarette with the presence of major rotator cuff lesions [20, 21]. Some studies have shown that smokers have impaired healing and worse prognosis in the repair of rotator cuff lesions [22–24]. Galatz et al. describe the adverse effects of nicotine on rotator cuff repair in rats by reducing mechanical properties and the concentration of collagen in rats [25].

It is believed that the association of the etiologies described above, besides trauma, is more and more frequent. It is important to look at episodes of glenohumeral dislocation in patients over 40 years of age: Itoi et al. described by means of an arthrography study that the incidence of rotator cuff lesion in patients over 40 years after the first episode of glenohumeral dislocation is 30% and 57% in patients over 50 years of age [26].

All of these corroborate to the hypothesis of a multifactorial disease. Besides environmental

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factors, there is an important genetic influence to determine the presence of the disease. It is important to emphasize that there are probably a large number of connective tissue diseases that have a genetic component. Some classical Mendelian diseases of connective tissue are well described, such as, for example, imperfect osteogenesis, Ehlers-Danlos syndrome, and Marfan syndrome. However, other connective tissue diseases, among which we can include tendinopathies and ruptures of the rotator cuff, are complex and multifactorial. In these affections, the identification of genetic components is more difficult because the search is made difficult by the probability of involvement of a set of genes in their etiology—each gene having a small contribution to the condition being studied—and gene-environment interactions [27].

As we can see, the etiology of a rotator cuff tear is a multifactorial process, and the interaction of genetic variants with various extrinsic and intrinsic tendon factors has been proposed to explain it [28, 29].

Dabija and colleagues in a recent systematic review describe that prior studies provide preliminary evidence for genetic and familial predisposition to RCD [29].

Harvie et al. evaluated a cohort of patients diagnosed with complete rotator cuff injury, including 129 siblings and 150 spouses (controls). The study showed that siblings had a twofold increased risk of developing complete rotator cuff lesion in relation to the control group. In addition, it was observed that siblings have a fivefold increased risk of presenting symptoms for this condition in relation to the controls. The significant increase in the risk of rupture of the rotator cuff in siblings implies that genetic factors play a fundamental role in the development of this type of lesion [30].

Over the years the understanding of the importance of the genetic component in the genesis of rotator cuff lesions has been increasing, although there is evidence that many studies are still necessary [29]. However, important steps have already been taken.

Knowledge of the genetic markers related to rotator cuff tears can enable identification of susceptible individuals and increase understanding of the pathogenesis of tendon degeneration.

A normal tendon mainly consists of collagen fibrils [31]. Schirachi et al. [32] showed that the expression of both type I and type III collagen increases in the ruptured tendon of rotator cuff. Leal and colleagues found increased mRNA expression of *COL1A1* and *COL3A1* collagens [33]; in the same article, the authors described that HPRT1 + TBP + ACTB seems to be the best combination of reference genes for the analysis of involving different tendon samples of individuals with rotator cuff tears.

It is important to understand the effect of clinical aspects in the gene expression in tendon samples and the relationship between histological findings and molecular alterations. In a recent study, Belangero et al. [34] described that longer duration of symptoms and therefore delayed surgical treatment exhibited an increased ratio of type I/III collagen fibers and showed differential expression levels of matrix extracellular genes and TGFB family members in the degeneration process involved in the rotator cuff tears underscoring the involvement, specifically, of *COL1A1*, *COL1A2*, *COL3A1*, *COL5A1*, *FN1*, *TNC*, *TGFB1*, and *TGFBR1* genes.

Epigenetic mechanisms, such as DNA methylation and microRNAs regulation, are involved in the dynamic control of gene expression. MMPs and their inhibitors are regulated by epigenetic modifications and may play a role in rotator cuff tears [35].

When it comes to risk factors, it is important to emphasize the involvement of single nucleotide polymorphisms (SNPs) in the genesis of degenerative rotator cuff lesion. The findings of previous studies provide evidence that there may be an important relationship between genes and rotator cuff disease. However, data on this issue are still limited [29].

Motta et al. [4] tested 23 SNPs from 6 candidate genes involved in the repair and degenerative processes of musculoskeletal tissue (DEFB1,

DENND2C, ESRRB, FGF3, FGF10, and FGFR1) for a potential association with RCD and identified a potential role for ESRRB in the development of rotator cuff disease. In 2015, Teerlink and colleagues confirmed the association of variants in ESRRB and rotator cuff disease [36]. In a recent study, Assunção and colleagues [37] evaluated 64 patients with full-thickness rotator cuff tears and found association of genetic polymorphism of MMP-1 and MMP-3 and RCD.

Kluger and colleagues [38] investigated selected SNPs in MMP-1, MMP-2, MMP-3, MMP-9, MMP-13, TIMP-1, TNC, and Col5A1 genes in patients with RCD. The authors found 15 SNPs in the TNC gene significantly associated with degenerative rotator cuff tendon tears.

More recently, Ross et al. performed a genome-wide association screen using publically available data from the Research Program in Genes, Environment and Health including 8357 cases of rotator cuff injury and 94,622 controls. They found that individuals carrying one risk allele at rs71404070 (A/T), a SNP located next to *cadherin8* which encodes a protein involved in cell adhesion, had a 29% increased chance of injury compared to individuals with no risk allele (T/T). Therefore rs71404070 shows a genome-wide significant association with rotator cuff injury may be informative in explaining why some individuals are more susceptible to rotator cuff injury than others.

They also attempted to validate previous gene association studies that had reported a total of 18 SNPs, but none of the 18 SNPs were validated in their dataset [39].

Until the present day, understanding the genesis, treatment, and prognosis of rotator cuff lesions remains challenging.

These are very important data, but we may still be a bit far from clinical application of the findings. Even so, identifying a possible genetic association could help our understanding of the disease process that leads to RCD, assist with early detection of individuals at risk for development of nontraumatic tears, identify serious cases, and provide potential future gene therapies.

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Part II

The Young Athletic High Risk Patient (Age 10–30)

The Very Young Athlete (10–15) with Overuse Tear

6

Carina Cohen and Benno Ejnisman

Rotator cuff (RC) injury is rare in the pediatric and adolescent population representing less than 1% of all rotator cuff tears [1]. Pressure to enhance performance at a young age has been implicated as the explanations for rotator cuff tears in the young athlete [2]. From 500 patients seen in 2 pediatric institutions for shoulder pain each year, only 7, or 1.4%, were diagnosed with rotator cuff tears [3]. However, with the increased participation in overhead throwing sports, the incidence of overuse shoulder injuries in this younger group of patients has increased substantially and is responsible for up to 70% of visits to the pediatric sports medicine clinics [3]. Zbojniewicz et al. after 205 examinations in 201 patients (aged 8–18 years) who have undergone shoulder MRI evaluation in a pediatric hospital found 25 (12.2%) cases of rotator cuff tears [4].

Literature involving rotator cuff tears in pediatric patients is in general limited to small case series and case reports [2, 5–8]. Since they have open growth plate and lack of substantial degeneration within the rotator cuff tendon, these injuries in children are relatively rare, so that the differential diagnosis is more commonly expected such as bone lesions (fractures), stress causing widening of the growth plate (Little League shoulder), and alterations in soft tissues (glenoid labrum). But rotator cuff lesions both in isolation and with other associated pathology must be recognized. The physeal patency does not seem to be statistically significant related to rotator cuff tears [4].

Repetitive microtrauma in overhead athletes and also a single traumatic event have been referred as causes to RC injuries. As in the cases reported by Weiss et al. and Tarkin et al., a history of trauma was generally preceded by a subtle onset of previous shoulder symptoms, and it happened in different sports activities including baseball, gymnastics, swimmers, tennis, volleyball, basketball, and wrestling [3, 5].

The supraspinatus tendon is the most frequently involved particularly articular-side partial-thickness tears. However, insertional tears involving the infraspinatus tendon are not uncommon. Weiss et al. found 28% of RC injuries involved the infraspinatus in isolation while 44% of tears involved either the infraspinatus or the junction of the infraspinatus and supraspinatus [3]. They associated the high incidence to the great percentage of athletes (76%) and the known association of internal impingement in overhead athletes with tears of the posterior supraspinatus or anterior infraspinatus tendons [9].

Iniatilly, abduction with external rotation was believed to impinge the rotator cuff, specifically the supraspinatus, and lead to articular-sided fraying and eventually tears of the rotator cuff. Such impingement has even been described in

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asymptomatic throwing athletes [10]. But since Zbojniewicz et al. found large propensity for insertional tears in children and adolescents referred for MRI (205 exams), a traumatic etiology has been also pointed as cause for the large majority of rotator cuff tears in this population [4]. They found five PASTA tears and five PAINT tears, but when expanded the classification of PASTA tears to include all insertional tears, even small insertional tears without evidence or delamination (so-called rim rent tears) as well as insertional bursal-side tears (so-called reverse PASTA tears) then, 87% (20/23) of partial-thickness tears would fall under this classification [4].

Differently from adults, who present a degenerative process of the tendon, insertional partial-thickness tears are much more common than critical zone tears in children. It is appropriate to look for concurrent labral pathology since it can be found in one third of the cases [4].

Treatment considerations should focus on the competitive level of the athlete, their desire to return to sports, and the best procedure for the specific injury. In adults, untreated partial-thickness rotator cuff tears may progress to larger tears or full-thickness tears in 50% of patients [11]; however, long-term outcomes of adolescent rotator cuff injuries have not been studied. It is possible that younger patients have an increased healing capacity because of different mechanisms of injury and less underlying tissue degeneration.

Treatment of rotator cuff pathology in adolescent patients generally begins with a course of physical therapy. If symptoms persist, surgical intervention may be warranted. Shoulder arthroscopy allows to address the rotator cuff and associated capsulolabral, biceps, or cartilaginous pathology. Patients with MRI-diagnosed associated pathology were found to be 1.8 times more likely to require surgical intervention compared with those without [12].

Eisner et al. treated 53 adolescents with a mean age of 15.8 years (8.8–18.8 years) with partial articular-sided RC tendon avulsions. All patients underwent a trial of at least 6 weeks of physical therapy, with 57% failing to improve and requiring subsequent surgery (debridement to stable edges). They concluded that isolated partial articular-sided tendon avulsion injuries may be successfully treated with physical therapy, with return to sports expected. Improvement in pain and activities of daily living can be achieved with surgery after failed conservative management for rotator cuff injuries; however, the adolescent athlete will often have residual shoulder complaints during sports participation [12].

Weiss et al. treated six of seven patients with surgical repair of the injury; they were pain-free and returned to normal activity. However, one patient underwent a nonsurgical rehabilitation program and was completely healed at the 3-month follow-up. Because the patient who did not undergo surgery had an excellent result, future thought and study is warranted to guide decision-making for surgical intervention in this group of patients [3]. Zbojniewicz et al. had 17 out of 25 patients with imaging findings of a rotator cuff tear who did not undergo surgery. Only eight (47%) had documented follow-up, of which seven (88%) showed improvement with physical therapy alone [4].

The outcomes of both conservative and surgical treatment of rotator cuff pathology in adolescent patients remain largely unknown. The key is the prevention. Early detection and activity modification along with focused physical therapy might be helpful in preventing progression of injury, primarily when the underlying etiology (i.e., impingement, instability) is addressed rather than treating the partial-thickness tear [13].

Also to avoid overuse injuries include educating coaches, parents, and children. In addition, to prevent repetitive loading and chronic overuse, guidelines on pitching technique, pitch counts, and frequency of pitching in baseball as well as early recognition of these injuries will help prevent their progression. The American Sports Medicine Institute suggests guidelines for young players and pitch counts, in addition to which type of pitch to introduce at what stage of development [3].

In conclusion, a prospective study on operative versus nonoperative care for these patients is necessary to determine for whom surgical intervention is appropriate. Conservative rehabilitation and activity modification may continue to be appropriate for many of these patients.

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7 The Adolescent Overhead Athlete with SLAP Tear and Partial Infraspinatus Tear

Kelly L. Hill and Felix H. Savoie III

7.1 Etiology of Injury with Historical Perspective

Injuries in the overhead throwing athlete are often a combination of overuse and acute injury. Many authors have attempted to delineate the mechanism by which structures in the shoulder progress to pathology, with most centered around the concept of a loss of balance resulting in impingement and instability without clear cause and effect. Instability in these athletes is manifested in the injuries of the labrum, capsule, and rotator cuff. Adaptive changes to enable overhead sports occur early and are normal, catering to the demands of the activity.

The original concept of the disabled throwing shoulder centered on the observational work of Jobe, in which he thought that anterior laxity was the primary pathology; he managed patients that failed conservative treatment with open anterior capsulolabral reconstruction via a subscapularis split technique with 90% of the surgical group returning to their prior level of competition [1]. ubsequent studies elucidated a multifactorial etiology of the disabled throwing shoulder. The classic series by Morgan, Burkhart, and Kibler brought about the concept of the variable role of scapular dyskinesis, glenohumeral internal rotation deficit (GIRD), and peelback SLAP lesions as factors in the disabled throwing shoulder. More recently, work by Wilk et al. delineated a change in the total arc of motion as one of the key indicators of problems with the shoulder [2].

Andrews et al. observed anterosuperior glenoid labrum tears in throwers and described the mechanism as an imbalance of two normal forces in the throwing shoulder. The internal rotation/flexor muscles act during the acceleration phase of the arm and must be countered by the smaller external rotators, infraspinatus, and teres minor. During acceleration, these external rotators act on the humeral head to centralize it on the glenoid and then with increased force aid to decelerate the arm [3]. They understood this pattern of injury to be a deceleration injury during the follow-through phase of throwing with traction at the root of the biceps tendon pulling on the anterosuperior labrum [4]. They described findings of arthroscopic examinations in overhead athletes and remarked on the frequency and pattern of glenoid labral tears. They

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concluded that the anterosuperior portion of the labrum near the origin of the long head of the biceps was the most common location of labral tear in the overhead athlete. They postulated that the large traction force placed on the labrum via activation of the biceps in the throwing athlete lifts the labrum off the glenoid [4].

Jobe and Pink described the concept of the instability continuum. They proposed that repetitive overhead throwing action gradually stretches the anterior capsuloligamentous complex allowing anterosuperior migration of the humeral head during throwing and believed this pathologic motion to produce subacromial impingement symptoms [5]. Later arthroscopic studies would show the resulting impingement to be intracapsular and posterior, often manifested in peelback labral injury and a more internal impingement of the infraspinatus on the posterior superior glenoid resulting in the rotator cuff pathology noted in overhead athletes. Because these lesions come from the same mechanism, it is not prudent to treat these disorders as distinct in the young overhead athlete [1]. The instability may be subtle on exam and to some extent is an advantageous adaptation for the throwing athlete, but this anterior subluxation was at the core of their proposed mechanism of injury, and they proposed anterior capsule reconstruction in addition to correction of the labrum and rotator cuff [1].

In a cadaveric study, Kuhn et al. tried to describe the mechanism of injury of the labral tear seen in overhead athletes. They applied a large tensile force (346 ± 40 N) replicating the deceleration mechanism described by Andrews and only produced a labral avulsion in 20% of their specimens. However, at a much lower force (289 ± 39 N), they were able to produce type II SLAP lesions in nine out of ten specimens in the abducted externally rotated position of the late cocking phase of the throwing athlete [6]. Jobe recognized posterosuperior glenoid impingement in abduction and external rotation as a mechanism of injury producing rotator cuff injuries in a study examining the patient's recalled history of injury [7].

Van Kleunen et al. examined the differences in patient outcome for athletes with isolated SLAP tears and those with concomitant infraspinatus tears that required repair, measured in return to play at preinjury level of play [8]. In a study of 17 baseball players under 25, of those with repair of the infraspinatus, only 6 (35%) were able to return to the same or superior preinjury level of play.

7.2 Anatomy/Pathoanatomy

The infraspinatus tear often occurs as a normal variant in the overhead athlete. Jobe, Walch, and Andrews have separately described different mechanisms for the injury, including anterior subluxation, mechanical internal impingement, and tension tearing of the infraspinatus. We currently understand the tear to be a normal adaptation to overhead sports. Occasionally, additional pathology will become severe enough to warrant treatment.

Andrews et al. first described the SLAP tear, an injury of the superior labrum that begins posteriorly and extends anteriorly stopping before or at the mid-glenoid notch and including the attachment of the biceps tendon to the labrum (Fig. 7.1) [4].

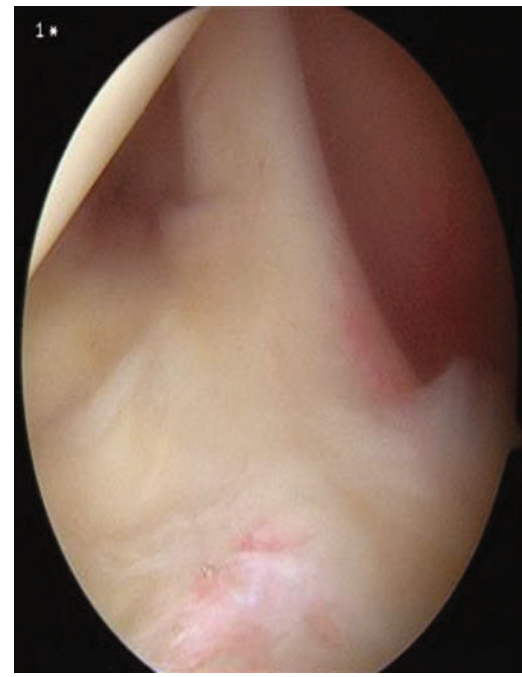

Fig. 7.1 In this view from the posterior portal, the superior labrum-biceps tendon complex can be visualized

Snyder et al. categorized these tears into four groups, but the group II SLAP tears encompass those overwhelmingly seen in the overhead athlete: a tear of the labrum and biceps tendon with detachment from the top of the glenoid, this has been sub-characterized by anatomic position, anterior, posterior, and combined [9].

Huber and Putz, in a dissection of 42 shoulder joints, described that tendon fibers of the long tendon of the biceps continue posteriorly as periarticular fiber bundles and supplement the labrum in the posterosuperior quadrant of the glenoid. They suggested that this periarticular fiber system of the labrum, glenohumeral ligaments, and inserting tendons work together to resist instability in all directions of the glenohumeral joint [10]. The repetitive strains overhead throwers put on this fiber-glenoid attachment through the biceps tendon can cause disruption of the posterosuperior labral attachment leading to posterosuperior instability or combined anterior/posterior superior instability [11].

The humeral head is blocked from dislocating superiorly by the acromion, but with pathologic disruption of the attachment of the labrum, the humeral head can migrate superiorly and cause joint-sided rotator cuff tears. Burkhart noted 31% incidence of rotator cuff injury in patients with chronic SLAP lesions and no associated rotator cuff pathology in patients treated for acute SLAP lesions suggesting the timeline that the labral injury may be causal in relation to the rotator cuff injury.

Walch et al. completed an arthroscopic study of 17 athletes with unexplained shoulder pain [12]. On their preoperative exams, they noted pain on full external rotation at 90° of abduction. On arthroscopic exam, with the arm placed at 90° of abduction and maximal external rotation—characteristic of the late cocking phase of throwing—they witnessed impingement between the posterosuperior border of the glenoid and the undersurface of the tendon insertions of supraspinatus and infraspinatus. This was thought to describe the mechanism of painful structural disease in the thrower's shoulder [12].

Gelber et al. described the forces exerted on various structures of the shoulder throughout the phases of throwing in the overhead athlete. They described posterior capsule stiffness as a result of chronic microtrauma and tearing that promotes a fibroblastic healing response, increased collagen deposition, and loss of tissue compliance [13].

7.3 Clinical Presentation/ Physical Exam

Examination of the thrower's shoulder must acknowledge a coexistence of adaptive anatomic and nonpathologic changes from the repetitive stresses of overhead throwing [13]. Patients usually present with vague posterior shoulder pain but occasionally will have burning pain in the late cocking phase at maximal external rotation. Many athletes will have prodromal symptoms of posterosuperior shoulder pain prior to an acute event [11]. An evaluation of the entire kinetic chain, the mechanism by which the body transmits power from the ground through the throwing arm, is essential in the evaluation of these patients [14].

Trunk strength and stability allow lower extremity power to transmit efficiently to the arm. This group of muscles is often poorly developed in children and adolescent athletes increasing opportunity for injury. Core strength with regard to the overhead thrower is best examined by having the patient perform a one-legged squat to 90° while observing the body for balance and stability.

Scapular position is the next, critical part of the evaluation. Most of these patients will have significant dyskinesia, increasing the internal impingement and producing more damage and inflammation of the infraspinatus [15]. This exam begins with observation of both scapulae at rest. The pathologic resting position has been termed the SICK scapula for *s*capula malposition, *i*nferior medial border prominence, *c*oracoid pain, and scapular dys*k*inesis [13]. The entire medial border winging at rest is associated with upper and lower trapezius and rhomboid weakness [15]. Physical exam should include fatiguing the scapular positioners to elicit occult scapular diskenesis [13].

Evaluation of the rotator cuff is the next step in the exam process. The examination is performed in the patient's normal scapular resting position and then repeated with manual scapular reduction (scapular assist test) to hold the scapula in the retracted position. Each RC muscle is tested in isolation. In particular, the infraspinatus is tested in 0°, 30°, 60°, and 90° of abduction and neutral rotation.

The Whipple test is specific for anterior supraspinatus tear. Performing the exam with and without manual scapular retraction seems to truly delineate the extent of rotator cuff damage. The patient holds their arm in 90° of forward flexion and adducted until their hand (palm down) is in front of the contralateral shoulder. The examiner then applies downward pressure on the arm (Video 7.1).

A positive test will produce pain in the shoulder [16].

Labral exam: Standard exams for SLAP lesions include the modified dynamic labral shear test, SLAP test, O'Brien test, and Kibler test.

Modified dynamic labral shear (DLS) is performed with the patient sitting and then standing, with the involved arm abducted in the scapular plane to above 120° with the elbow flexed at 90°. The patient is then guided into maximal horizontal abduction. The shear load is applied by maintaining external rotation and horizontal abduction while lowering the arm from 120° to 60° of abduction. Here, reproduction of the pain and/or a painful click or catch in the joint line posteriorly between 120° and 90° of abduction [17].

This is altered slightly from the previously described O'Driscoll SLAP test. The arm is placed in maximal horizontal abduction and externally rotated whereas the DLS test only reaches maximal horizontal abduction after abducting in the scapular plane above 120°, this modification was aimed at reducing false-positives from placing the arm into maximal horizontal abduction first [16].

O'Brien test is performed with the patient standing and involved arm in 90° of flexion and 10° of horizontal adduction with the thumb internally rotated (thumb pointed down). The patient was then asked to isometrically resist downward pressure from the examiner. The patient was then asked to externally rotate the arm (palm up) and again resist a downward pressure. O'Brien test is positive if the patient has pain at the shoulder joint in the internally rotated position that is relieved or resolved in external rotation [16].

The Kibler test is performed with the patient standing and the hand of the involved arm on the ipsilateral hip with the thumb pointing posteriorly. With one hand on the glenohumeral joint line and one on the elbow, the examiner applied an axial load through the elbow in an anterosuperior direction. Pain or a painful click on the anterior or posterior joint line indicates a positive test [16].

The total arc of motion may be the most important concept in these patients and can be measured with standard goniometry [14]. Initially Morgan et al. thought of GIRD, a result of contracture of the posteroinferior capsule, to be the most significant factor in the disabled throwing shoulder. We now understand that GIRD often changes day to day and true refractory posterior capsular contracture to be quite rare. The adaptations in the shoulder of an overhead athlete impart a force on the humeral head that shifts the glenohumeral contact point posterosuperiorly during throwing activity. The overhead throwing athlete externally rotates about this new contact point, and the athlete compensates by increasing the excursion of external rotation. This pathologic glenohumeral relation shifts the vector of the biceps tendon posteriorly increasing torsion on the posterosuperior labrum [8]. Wilk et al. described that laxity is necessary to throw and should be greater in the throwing arm. Burkhart et al. described the "180 degree rule" in conclusion that throwers should not lose more internal rotation than they gain in external rotation; up until this threshold, many patients can be successfully treated with a focused posterior capsular stretching program [15].

7.4 Radiographic Findings

On plain films, posteroinferior capsule calcification (Bennett's lesion) was previously noted in throwers. Regular MRI will almost always show pathology in the overhead thrower's shoulder,

including labral tears, partial rotator cuff tears, and inflammation [18]. Imaging with the arm in the ABER position should be considered an essential part of the evaluation of the throwing shoulder.

7.5 Nonoperative Treatment

Rehabilitation remains the most effective treatment for the disabled throwing shoulder. Jobe and Pink found that approximately 95% of their patients, not divided on the basis of their age, were able to return to their prior level of competition with effective rehabilitation [1].

Rehabilitation begins with posture, hip, and core strengthening. The rotator cuff is allowed to undergo "controlled rest" during these early phases. The scapular stabilization muscles- serratus, mid and lower trapezius and rhomboids [1].

Along with rehabilitation of the core, restoration of scapular motion is an essential early part of nonsurgical treatment. The total arc of motion, especially restoration of external rotation, is achieved at the same time as postural correction. As the balance of the trunk and shoulder is restored, the rotator cuff rehabilitation is increased, always pain-free and stopping short of producing a recurrence of inflammation.

Once balance and strength are achieved, functional rehabilitation with plyometrics and proprioceptive neuromuscular facilitation (PNF) exercises are progressed and then a return to play program progressed as tolerated.

7.6 Arthroscopic Findings

The procedure for arthroscopic examination has been described by Savoie. After standard anesthetic induction, the patient is place in either lateral decubitus or beach chair position. The posterior portal is then established between the infraspinatus and teres minor in line with the glenohumeral joint—palpated 2 centimeters below the posterior lateral corner of the acromion—which allows access without damaging the posterior rotator cuff or inferior glenohumeral

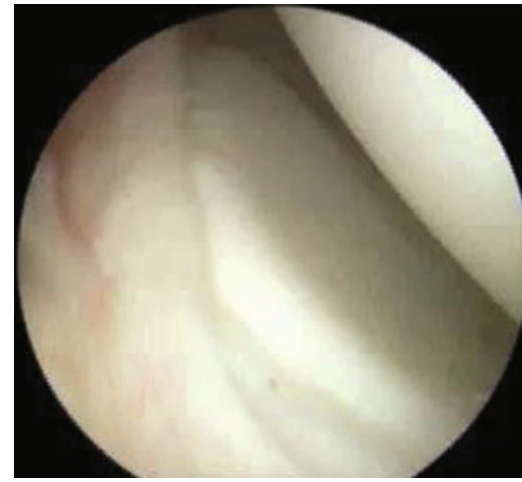

Fig. 7.2 The peelback phenomenon can be observed with the astroscope in the posterior or anterior portal. The arm is abducted and externally rotated, and the superior labrum is noted to roll or "peelback" off its attachment to the glenoid while simultaneously the infraspinatus tendon contacts the posterosuperior glenoid, creating an internal impingement

ligament. An anterior instrument portal is established adjacent to the intra-articular portion of the subscapularis in the rotator interval. Examination includes visualization of the humeral head and glenoid while taking note of chondral lesions. Anterior, superior, posterior, and inferior labrum should be visualized and probed. Biceps tendon, superior glenohumeral ligament, and middle glenohumeral ligament are evaluated and probed. The inferior glenohumeral ligament and its thick anterior and posterior bands are also examined. Attention is then turned to the inferior surface of the rotator cuff with humeral attachment of teres minor, infraspinatus, entire supraspinatus, rotator interval, and intra-articular portion of subscapularis tendon. The arm is then placed into the abducted, externally rotated position while observing for labral peelback, internal impingement, and rotator cuff tearing (Fig. 7.2).

At this point, the arthroscope can be moved to anterior portal and similar examination is performed [3]. Savoie's series of 500 arthroscopic examinations of throwing athletes only yielded 2 patients with primary subacromial pathology [3].

7.7 Arthroscopic Treatment

The primary surgical indication for injuries in the throwing athlete is failure of an adequate and extensive rehabilitation program and nonoperative modalities [3]. Many times, athletes will continue to throw in spite of pain and instability or fear that surgical intervention is required. This may result in minor damage progressing to large lesions of the infraspinatus tendon or extension of the peelback SLAP tear into the biceps or more posteriorly. Surgical repair of pathology in these athletes should not intend to restore native anatomy but rather consider the adaptive changes of repetitive overhead throwing [13].

In their study of 102 type II SLAP lesions with suture anchor repairs, Burkhart and Morgan described their operative technique. Posterosuperior labral tears were repaired via a posterosuperior lateral acromial portal marked 1 cm lateral and anterior to the posterior acromial angle at the lateral acromial margin, the so-called Port of Wilmington. This approach allows an adequate angle of approach for suture anchor placement in the posterosuperior glenoid [11]. Surgical repair of the posterior SLAP lesion requires neutralization of the peelback vector through the biceps tendon. This requires at least one suture anchor stabilizing the labrum posterior to the biceps to effectively counter the torsion. These anchors should be placed at the corner of the glenoid at a 45° angle of insertion to most effectively restore the anatomy in a mechanically effective way (Fig. 7.3) [11].

Vertical knot tying or knotless anchors are recommended to avoid a permanent irritant in the shoulder [11]. With an isolated posterior lesion, anchor placement should be posterior to the biceps root. Suture anchor placement should not violate the biceps root. Anterior placement of the anchor for a posterior SLAP tear repair will tighten the shoulder anteriorly and reduce the adaptive hyperexternal rotation available to the overhead athlete, thus should be avoided in baseball players [13].

Treatment of concomitant infraspinatus tears should involve debridement [8]. Van Kleunen et al. reviewed multiple series of athletes with

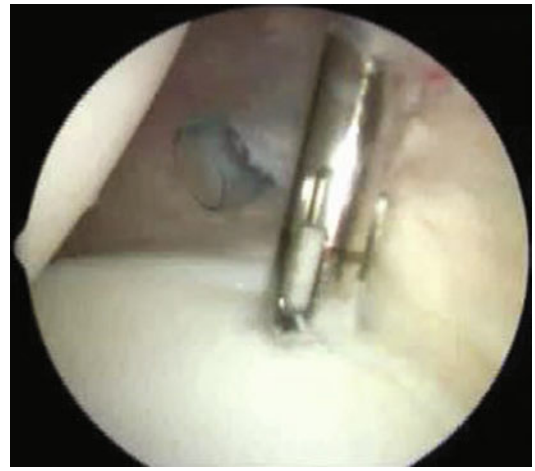

Fig. 7.3 The anchors in the glenoid are placed via a posterosuperior portal (Port of Wilmington) and "cornered" on the glenoid neck face junction to provide proper anatomic restoration of the labrum

articular-sided cuff tears and found that repair had a low return to sport, while debridement offered a high rate of return to play. The presence of a rotator cuff tear that required repair was a negative predictor of ability to return to play [8]. Regardless of the return to play rate in Morgan et al.'s series of 102 arthroscopic SLAP repairs, all failures had a concomitant rotator cuff injury. For shallow (<50% depth) articular lesions, Gelber et al. recommended debridement over repair [13].

Van Kleunen et al. studied the specific subgroup of overhead athletes at scholastic or collegiate level of play with SLAP tear and concomitant infraspinatus tear. The SLAP tears were repaired with a glenoid anchor, and the infraspinatus tears were repaired with either a converging PDS suture or a humeral head anchor depending on surgeon preference for the case. Only 35% of the subjects were able to return to play at a similar or greater level than preinjury. This was noted to be much lower than other studies suggesting that the mechanics of the throwing shoulder are a delicate balance. Patients with the anchor repair of the infraspinatus tendon had lower scores on the Kerlan-Jobe Orthopaedic Clinic (KJOC) Overhead Athlete Shoulder and Elbow score and had a correlation with poorer

return to play. The authors proposed that the more minimal repair lessens the iatrogenic detrimental effect of the tendon repair [8].

7.8 Postoperative Care

For the first postoperative week, the surgical patient will be immobilized in a pillow abduction sling at all times. However, leg, hip, core, and scapular exercises are initiated. During the second and third weeks postoperatively, range of motion is expanded to 0–90° abduction and allowance of external rotation in adduction only to comfort. External rotation in abduction is prohibited. Sling immobilization continues while not participating in range of motion activities. At the third postoperative week, the sling is discontinued, at which point, progressive passive range of motion expanded to full range of motion in all planes. At this stage, the athletes begin passive posterior capsule stretching with internal rotation stretching. During weeks 3–6, the athletes add passive and manual scapulothoracic mobility program, allow external rotation in abduction, and allow use of the affected extremity for light ADLs. From weeks 6 to 16, integrated rehabilitation continues with all stretching and flexibility exercises. Three months postoperatively, most athletes begin an interval throwing program and are allowed to progress as tolerated, with a return to play usually occurring between 4 and 6 months postoperatively.

7.9 Pitfalls and Complications

A tight posterior capsule was part of the mechanism creating the SLAP lesion to begin with and recurrence of the tightness can place the repair at risk. Postoperative physiotherapy must continue to stretch the posterior capsule to prevent damage to the repair. Large knots on the posterosuperior labrum may accentuate the internal impingement and create more, rather than less, internal impingement, furthering damage of the infraspinatus. Lastly, repair of the infraspinatus is associated with a lower return to play and should be avoided in active throwers.

7.10 Summary

- Overhead athletes have adaptive changes to their physioanatomy that are advantageous to their sport and not necessarily pathologic.
- Posterior type II SLAP lesions have distinct clinical and anatomic features that distinguish them from anterior type II SLAP lesions.
- Rotator cuff tears in these overhead athletes are frequently associated with typically joint-sided undersurface tears.
- Tight posteroinferior capsule predisposes to type II SLAP lesions and progressive infraspinatus damage in overhead athlete and must be addressed during conservative treatment and after operative repair.
- Repair of posterior SLAP lesions can return athlete to the same level of play.
- Repair of a rotator cuff injury concomitant with a SLAP tear is a negative indicator of return to play at the same or higher than preinjury level.
- Be protected against external rotation in abduction postoperatively.

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8 Rotator Cuff Injuries in the Elite Athlete

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8.1 Prevalence of Rotator Cuff Tears in Throwers

Rotator cuff pathology is a common cause of dysfunction in the throwing athlete [1]. There are several possible etiologies of rotator cuff tears in the throwing athlete. One cause is a result of internal impingement as the rotator cuff is pinched between the glenoid and humeral head. A second cause is a result from the supraphysiological loads placed on the shoulder during the deceleration phase of the throwing cycle as the posterosuperior rotator cuff eccentrically contracts [2]. A prospective epidemiologic study which investigated injuries in collegiate baseball players over 3 years found that rotator cuff tendonitis represented 64% of the shoulder problems in all players and accounted for 15% of all musculoskeletal complaints reported. Rotator cuff tendonitis also represented the most common complaint among pitchers, infielders, and outfielders [3]. Despite representing the majority of shoulder complaints in throwing athletes, the prevalence of rotator cuff injury is likely underestimated in the throwing athlete. Magnetic resonance imaging (MRI) exams of asymptomatic professional baseball pitchers revealed findings consistent with rotator cuff tendonitis (68%) and partial-thickness rotator cuff tears (32%) [4]. These findings were echoed in a study following elite overhead athletes for 5 years, with 40% of asymptomatic shoulders having findings consistent with partial- or full-thickness rotator cuff tears [1]. Hence, rotator cuff tears in overhead athletes are common but may or may not be symptomatic.

8.2 Pathophysiology of Rotator Cuff Tears in Throwers

Throwing athletes are of particular risk of rotator cuff injuries, commonly secondary to internal impingement. As described by Walch et al., abnormal impingement between the undersurface of the posterosuperior rotator cuff and superior labrum is often seen in late cocking and early acceleration phases of the throwing athlete [5]. With repetitive pathological contact, there is a consequent structural change resulting in superior labral lesions and articular-sided partial-thickness rotator cuff lesions along the posterosuperior cuff (i.e., posterior supraspinatus and superior infraspinatus) (Fig. 8.1) [6]. The development of internal impingement was investigated by Burkhart et al., who identified the etiology as a posterior capsular contracture, itself, secondary to eccentric contraction of the infraspinatus resisting the tensile forces placed on the posterior capsule during

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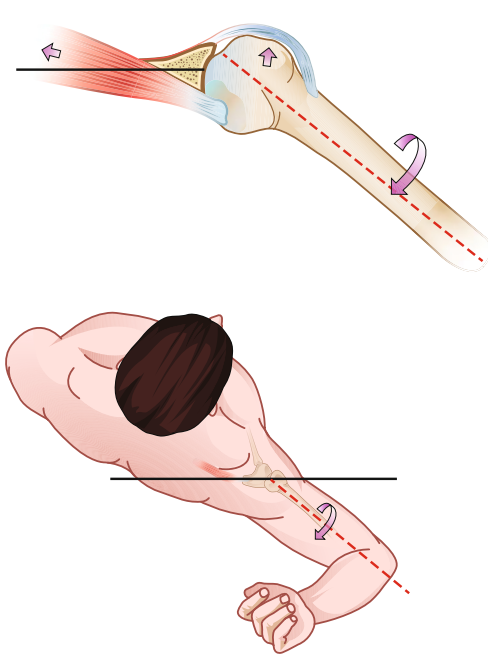

Fig. 8.1 Internal impingement of the undersurface of the rotator cuff against the posterior aspect of the labrum with shoulder in maximum abduction and external rotation [6]

the deceleration phase of throwing [7–9]. Repetitive eccentric contraction leads to a hypertrophic, contracted, and less compliant posterior capsule, shifting the center of rotation posterosuperior, further increasing shear forces on the rotator cuff, and limiting internal rotation. Finally, there is also be a tensile stress placed on the rotator cuff during the deceleration phase of throwing as the rotator cuff contracts in an attempt to center the humeral head. This violent contraction can lead to damage to the rotator cuff.

The complex interplay between glenohumeral motion and scapulothoracic kinematics is also important in rotator cuff function in the throwing athlete. Specifically, during the cocking phase of throwing, the articulation of the externally rotated and abducted glenohumeral joint is maintained by upward scapular rotation [10]. Imbalance in this dynamic interaction can lead to scapular dyskinesis and manifest as SICK (scapular malposition, inferior medial border prominence, coracoid pain, and dyskinesis of scapular movement) scapula [9]. With weakness of the periscapular and posterior rotator cuff musculature, the glenoid protracts, resulting in anterosuperior tilting of the glenoid fossa and tightening of the inferior glenohumeral ligament. An anterosuperior tilt of the glenoid fossa places the posterosuperior labrum and rotator cuff at risk for impingement and subsequent injury as described above.

8.3 Classification of Rotator Cuff Tears

The classification of rotator cuff injury can both suggest the etiology of injury and help guide treatment. Importantly, an acute process—such as a contusion—should be distinguished from a more chronic process. A rotator cuff contusion is an acute, traumatic injury, commonly seen with a direct impact such as a fall onto the shoulder, with hallmark findings on MRI. These MRI findings include increased signal intensity in rotator cuff tendon, bursa, and may concomitantly present with a bone bruise. Comparatively, chronic tendinopathy is consistent with an overuse process, with signal changes restricted to the rotator cuff tendon. This pathology is often seen with the repetitive and often supraphysiologic activities seen in overhead athletes leading to tensile failure. With a chronic change in tendon morphology and underlying disorganization of tendon fibers, rotator cuff tears may develop. Rotator cuff tears can be classified as full-thickness or partial-thickness tears. Partial-thickness tears can be further divided into articular-sided (Fig. 8.2), bursal-sided, or intratendinous tears. Partial articular supraspinatus tendon avulsions, or "PASTA" lesions, are common in the overhead athlete [11, 12]. Explanations for this include the relative hypovascularity of the articular side and differences in collagen organization compared to the bursal side of the rotator cuff [13, 14]. Partial-thickness articular-surface tears with intratendinous extension, or PAINT lesions, can also be seen, secondary to intratendinous shear forces during overhead

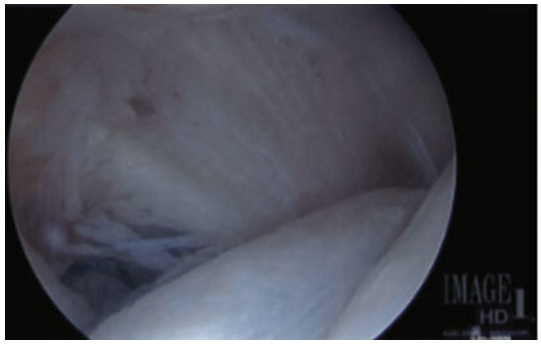
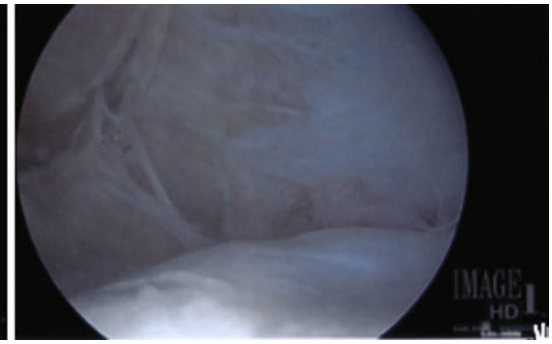

Fig. 8.2 Partial articular-sided supraspinatus tear

Fig. 8.3 Delamination of articular portion of tendon with retraction

Table 8.1 Ellman classification of partial-thickness rotator cuff tears [18]

Location	Depth	Area of defect
Partial-thickness tear		
(a) Articular surface (b) Bursal surface (c) Interstitial	<3 mm deep (<25% of tendon thickness) 3–6 mm deep (25–50%) >6 mm deep (>50%)	Base of tear × maximum retraction = mm^2

activity (Fig. 8.3) [15–17]. The Ellman classification of partial-thickness rotator cuff tears is presented in Table 8.1 [18]. Articular-sided partial-thickness rotator cuff tears are often seen in patients with additional pathology of the shoulder girdle, which includes glenohumeral internal rotation deficit (GIRD), scapular dyskinesia, and superior labral tears.

8.4 Clinical Presentation

Clinical presentation of a rotator cuff injury can be present within a spectrum of complaints. These complaints often vary by etiology, chronicity, and specific athletic limitations of the injury. Initially, a complete history should be obtained including duration of pain, duration (if any) of limitation of activities, and any prior treatments rendered (including if the athlete has been shut down from throwing and for how long). Presentation in a throwing athlete can vary from mild shoulder discomfort to an inability to throw. Overhead athletes may complain of decreased throwing velocity, loss of throwing accuracy, early fatigue, or instability. In contrast to these insidious complaints, athletes may also experience abrupt pain or "pop" (representing a rotator cuff or labral tear), commonly a result of an acute-on-chronic process [19].

8.5 Physical Examination

If acute, the mechanism of injury as well as the position of the arm can assist in the diagnosis. While an assessment of active range of motion can identify rotator cuff injury, comparing the arc of passive range of motion to the contralateral extremity may assist in diagnosing GIRD, loss of external rotation, or loss of total shoulder rotation. Physical exam should also extend to the motion and strength of the scapula and cervical

spine proximally, and the elbow, distally. A complete neurovascular exam should also be performed. Careful assessment of the scapula will aid in the identification of weak periscapular musculature contributing to shoulder pathology. For instance, weakness in the serratus anterior may result in posteroinferior translation of the humerus in order to compensate for the lack of scapular elevation, causing worsening internal impingement. Similarly, excessive scapular internal rotation causes increase stress on the shoulder and elbow that can lead to injury [20]. These sites may not only cause referred pain but may present with concomitant pathologies. An accurate assessment of surrounding musculature is also important when determining appropriate rehabilitation protocols, as described below.

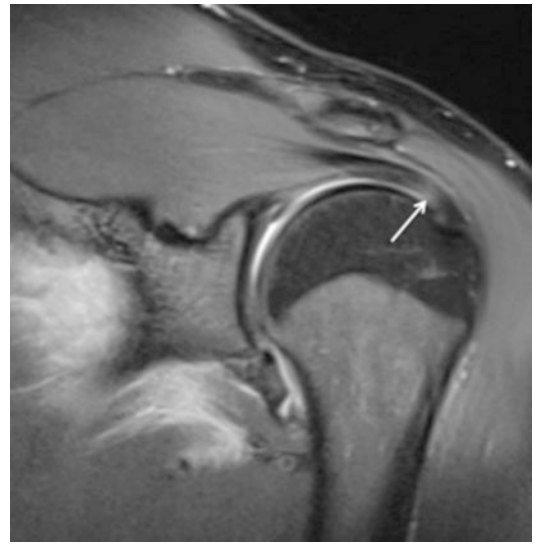

Fig. 8.4 Coronal MRI demonstrating a partial-thickness articular-sided rotator cuff tear in a throwing athlete (arrow)

8.6 Imaging

Following a thorough history and physical, imaging studies should be obtained. Plain radiographs can be used to assess humeral head positioning within the glenoid, assess acute bony injuries, as well as identify degenerative changes. Cystic changes appreciable on plain radiography in the greater tuberosity have been associated with partial-thickness articular-sided rotator cuff tears; however these are nonspecific [21]. Ultrasonography can be used to supplement diagnostic imaging and allows for dynamic assessment of rotator cuff injury, biceps tendon pathology, labral tears, and glenohumeral instability. While diagnoses of partial-thickness and full-thickness rotator cuff tears have demonstrated a sensitivity of 0.84 and 0.96, respectively, and a specificity of 0.89 and 0.93, respectively, it remains highly operator dependent [22, 23].

MRI remains the gold standard in assessing rotator cuff injuries (Fig. 8.4). A meta-analysis querying the accuracy of MRI in detecting partial-thickness and full-thickness rotator cuff tears demonstrated a sensitivity of 0.80 and 0.91, respectively, and a specificity of 0.95 and 0.97, respectively [24]. Augmenting imaging with contrast arthrography can also assist in the detection of rotator cuff tears, as well as additional intra-articular pathology. Moreover, placing the arm in abduction and external rotation improves the detection of rotator cuff tears [25]. Assessing signal uptake in the tendon or surrounding bursa, as well as differentiating between full and partial rotator cuff tears, is paramount in determining an accurate diagnosis as well as delineating a treatment algorithm. Care should be taken when interpreting MRI in throwing athletes, as abnormalities may represent adaptive changes rather than sources of pain. These changes include capsular remodeling with stretching of the anterior capsule and contracture of the posterior contracture, along with remodeling of the osseous architecture [26]. Furthermore, MRI identified abnormal signal changes in rotator cuff muscles of collegiate baseball pitcher, 40% of whom did not have positive findings on physical exam [27]. Importantly, a musculoskeletal radiologist with a complete history of injury is an invaluable partner in the interpretation of the aforementioned studies.

8.7 Nonoperative Management

Treatment of rotator cuff injuries in the elite athlete is not only guided by the pathology itself but is often nuanced by positional demands and time

of year (i.e., in-season vs. postseason). Often a result from chronic overuse, rotator cuff injuries should first be treated with a thorough evaluation of sports-specific mechanics. Reviewing film of the athlete throwing prior to their injury can provide valuable information on their pitching mechanics and any flaws in their throwing motion. Initial management of the elite athlete is often rest. Rest includes complete shutdown from throwing activities for a variable period of time (often 3–6 weeks depending on the pathology). This period of rest is then followed by shoulder-specific rehabilitation protocols for elite athletes [28–31]. A therapeutic regimen that reduces pain and inflammation, restores range of motion, increases strength, and improves neuromuscular control for sports-specific efforts is often employed in addressing rotator cuff injuries conservatively. The foundation for the rehabilitation program is working scapular stabilization exercises. A properly positioned scapula provides a stable backbone for the glenohumeral joint during the throwing motion which is paramount in the overhead athlete.

Once pain has abated (either through cessation of activity or through use of mobilization techniques), joint stiffness should be addressed either through passive mobilization techniques or active-assisted exercises, if otherwise unattainable via active techniques alone. The sleeper stretch remains a salient example of active-assisted joint mobilization when addressing range of motion (Fig. 8.5) (specifically, glenohumeral internal rotation deficit) [28]. Furthermore, as it is important to examine the entire kinetic chain of the shoulder when first assessing a patient, it is important to address those pathologies in the rehabilitation protocols. For instance, range of motion of periscapular musculature is paramount when addressing the possible derangement in the thrower's kinetic chain. Once range of motion has improved, regaining or improving muscle tone should be addressed. A number of exercises have been developed to strengthen the rotator cuff muscles [32]. However, it is crucial to understand that rotator cuff strengthening cannot be done in isolation. As periscapular musculature is paramount in the overhead athlete and directly involved in the kinetic chain of the glenohumeral joint, programs which focus on scapulothoracic motion should not be neglected. The scapula serves as a fulcrum which connects the core to the upper extremity [6]. As aforementioned, abnormal scapular positioning can lead to impingement of the posterosuperior rotator cuff. Numerous techniques have been developed to balance the interplay between the periscapular muscles [33]. Targeting the serratus anterior as the antagonist to trapezius can help in resolving the malpositioned, anteriorly tilted scapula. Finally, neuromuscular coordination and sports-specific training should be initiated, with particular emphasis on proper mechanics and avoidance of any deleterious techniques. This often involves video assessment of the athlete's throwing motion to evaluate their hip to shoulder separation, knee flexion angle at front-foot contact and ball release, elbow flexion angle at ball release, and many others [34].

Fig. 8.5 Sleeper stretch

Often used as an adjunct to rehabilitation techniques, nonsteroidal anti-inflammatories and corticosteroid injections have been widely used to abate the pain and inflammation associated with rotator cuff injuries [35]. Both of these measures should be used with recognition of risks (i.e., gastrointestinal disturbances and tendon rupture, respectively). Corticosteroid injections have been evaluated in the professional setting, with Cohen et al. finding success in the treatment of rotator cuff contusions using corticosteroid injections [36]. Platelet-rich plasma (PRP) has also become

available as an intra-articular agent, although current use of PRP has failed to demonstrate efficacy in treating rotator cuff tendinopathy [37].

8.8 Operative Management

If nonoperative treatment is unsuccessful, then operative treatment of rotator cuff tears is considered. Generally, indications for surgical intervention of a rotator cuff injury in an elite athlete are the same as that of a nonathlete, although the outcome is much more guarded. In the elite athlete, caveats such as position, performance limitations, in-season/off-season timing, and concomitant pathologies should be part of the decision-making process. Specifically, a collaborative discussion between the player, physician, and athletic training staff should be undertaken to determine whether a rotator cuff injury can be effectively managed nonoperatively until the off-season, or if the injury precludes elite performance, such that a player requires in-season operative intervention. While the demands of an elite athlete are often supraphysiologic compared to that of a nonathlete, the goal of full-thickness rotator cuff repair remains the anatomic restoration of the rotator cuff footprint.

The approach to partial-thickness rotator cuff tears in the elite athlete is evolving. In the general population, the treatment for these tears is debridement of articular-sided partial-thickness tears less than 50% and repair of those greater than 50% [38, 39]. As the results following rotator cuff repair in elite overhead athletes are not as reliable, many surgeons will consider debriding tears up to 75%, or even more. This stems from the lack of reliability in returning these athletes to an elite level of competition following repair. Approaching partial-thickness articular-sided rotator cuff tears is surgeon dependent. Small, articular-sided rotator cuff tears can be debrided until healthy tissue is reached. Should the tear be larger in depth or essentially complete, a possible approach is converting this to a full-thickness rotator cuff tear and anatomic restoration of the tendinous footprint using suture anchors. Tensioning these partial-thickness rotator cuff tears may create a length-tension mismatch, and alternatively, a transtendinous repair can be used to restore the tendon to a more anatomic position [38]. However, it is important to recognize the supraphysiologic demands placed on elite athletes when compared to that of the general population: Rudziki and Shaffer suggested that partial-thickness tears should approach 75% in elite athletes prior to repair due to the possible failure of repair secondary to exaggerated stresses [23]. This algorithm is expanded by Shaffer and Hultman, who recommend debridement of partial-thickness articular-sided tears when less than 75% and transtendinous repair when greater than 75% [40]. When addressing intratendinous tears, they recommend debridement if the segment is less than 1 cm and horizontal mattress repair if the tear exceeds 1cm [40] (Figs. 8.6 and 8.7). Furthermore, if the depth of the intratendinous segment will dictate the approach and if the depth is 1–2 cm, they recommend an arthroscopic approach,

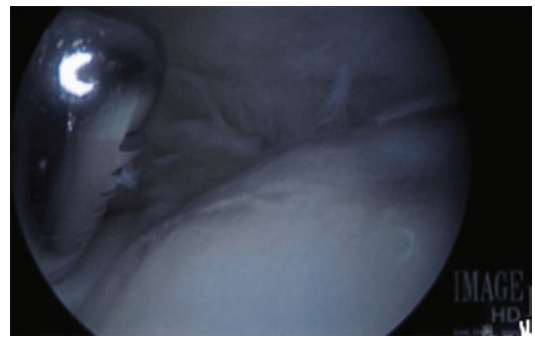

Fig. 8.6 Rotator cuff debridement

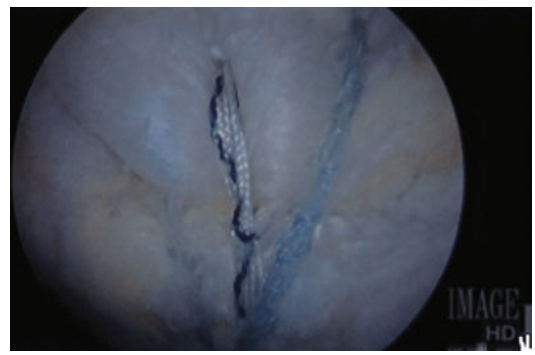

Fig. 8.7 Knotless rotator cuff repair

whereas if the depth exceeds 2 cm, they will consider a mini-open repair [40]. The authors recommend a conservative approach when treating partial-thickness rotator cuff tears in these elite throwing athletes. In players who fail an extended period of nonoperative management, these partial-thickness tears are almost always treated with a debridement, with repair reserved for select cases. In players with symptomatic full-thickness tears, a rotator cuff repair can be considered. Finally, the most important aspect of care of these patients is preoperative counseling and expectation management. A thorough discussion must be had regarding outcomes in the literature in these elite throwing athletes to ensure proper education and decision-making for all parties involved.

8.9 Return to Play

Prior to intervention, a thorough understanding between the player, surgeon, and athletic training staff regarding postoperative expectation is essential. Klouche et al. performed a meta-analysis on 25 studies examining the return to play following rotator cuff repair and found the return to preoperative level of play of 49.9% [41]. Another meta-analysis performed by Harris et al. found that rotator cuff surgery among major league pitchers was 55–73% [42]. When considering both partial- and full-thickness rotator cuff tears in the professional athlete, a systematic review by Reuter et al. found 48% of overhead athletes returned to their preoperative level of play, whereas 91% of contact athletes returned to preoperative level of play [43]. While the expectation of the player may be to return to a pre-injury level of play, Mazoue and Andrews found only 1 of 12 pitchers was able to return to a high level of competition following mini-open full-thickness rotator cuff repair [19]. Further, when examining rotator cuff repair of dominant shoulders in position players, one of two players was able to return to professional baseball. These findings have been expanded by Dines et al., who followed six Major League Baseball pitchers that underwent arthroscopic rotator cuff repair, and found a decrease in postoperative pitching statistics and innings pitched compared to preoperative levels [44]. Again, it is important to appreciate the specific positional demands of the athlete suffering from rotator cuff dysfunction. For instance, in sports with fewer repetitive overhead demands, such as football, return to play following rotator cuff repair has been much more promising: Tambe et al. followed 11 professional rugby players who underwent arthroscopic rotator cuff repair, all of whom returned to preoperative level of play [45]. In fact, Plate et al. found the return to play at 91% in contact sports compared to 40% in professional overhead athletes [46].

Although treatment of partial-thickness rotator cuff tears can vary, when treated with debridement, Payne et al. found that 9 of 14 overhead athletes with acute traumatic injuries were able to return to pre-injury levels of play [47]. They also found that 19 of 29, 13 were able to return to preoperative levels of play. More recently, Reynolds et al. found that 51 of 82 professional baseball pitchers were able to return to play; however only 27 of 82 (55%) were able to return to preoperative levels of play [48]. Intratendinous repair of partial-thickness rotator cuff tears has been investigated by Conway, who showed that 8 of 9 baseball players with intratendinous rotator cuff tears and concomitant SLAP tears were able to return to pre-injury levels of play [16].

8.10 Conclusion

Rotator cuff injuries in the elite throwing athlete are a complex and common cause of pain and dysfunction. Identification of the etiology is an important step in creating an initial treatment protocol. Coupling a thorough history and physical will aid in determining any common concomitant pathological processes, including scapular dysfunction, core weakness, or internal rotation deficit. Once a diagnosis is confirmed with appropriate imaging modalities, a multidisciplinary discussion between the player, physician, and athletic training staff should be employed to determine the most appropriate treatment plan for the player. Variables, including position, performance limitations, in-season/off-season timing,

and concomitant pathologies, can guide the length and type of nonoperative management. Prior to surgical intervention, postoperative expectations should be clearly explained to the athlete and treatment team.

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Management of Rotator Cuff Injuries in the Very Young

9

Jorge Rojas Lievano, Stephen C. Weber, and Edward McFarland

9.1 Introduction

Very young patients (i.e., skeletally immature patients) with rotator cuff injuries are a distinctive patient population that needs to be approached differently from older patients. Unlike older patients in whom rotator cuff tears are frequently seen as atraumatic injuries stemming from long-standing degeneration, rotator cuff tears in the very young are rare injuries resulting from traumatic events or chronic overuse related with sports. The presence of open physes and the absence of degenerative changes in the tendons determine a specific pattern of injuries in which partial articular supraspinatus avulsion (PASTA) lesions and lesser tuberosity avulsions predominate. Despite the rarity of rotator cuff injuries in this age group, their presence must be recognized to make a timely diagnosis avoiding complications and chronic shoulder pain. A high index of suspicion should be maintained in very young athletes with shoulder pain and weakness, especially after a fall or an eccentric external rotation injury. It is difficult to draw conclusions or make recommendations on treatment methods in this population with current evidence limited to case reports and small retrospective reviews. Treatment considerations should focus on the specific injury, level of sports participation, and desire to return to sports. Moreover, prevention programs of overuse in the very young athletes are an important means of decreasing the incidence of these injuries.

9.2 Literature Overview Summary

While age plays a major role in most rotator cuff tears as a result of degeneration of the tendons [1, 2], younger patients are also susceptible to rotator cuff tears due to traumatic injuries and overuse syndromes related with sports participation [3, 4].

The literature fails to clearly delineate between younger and older populations of rotator cuff tear patients. However, it has been suggested that patients younger than 40 years may be defined as "young" considering their differences in aspects related to cuff healing potential, etiology of the tear, levels of activity, physical demands, and differing long-term expectations compared with older patients [4]. Skeletally immature patients are a characteristic subgroup of young patients given the presence of epiphyseal plates and the higher strength, elasticity, and resilience of their tissues [5]. Therefore, this subgroup of young

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patients may be recognized distinctively as the "very young" population in this context, and they are the focus of this chapter.

Shoulder injuries in the very young are common especially in athletes resulting from acute traumatic injuries, recurrent shoulder instability, or repetitive overhead motions while competing in sports [6, 7]. Common patterns of injury involving the shoulder girdle in this age group include Little League shoulder, proximal humerus fracture, clavicle fracture, and glenohumeral instability [7, 8]. Rotator cuff injuries are rare in the very young with only case series present in the literature [5, 9–40]. However, they are more common than initially thought and reports have increased considerably during the last decade (Fig. 9.1). Some factors that may explain the increasing report of these injuries are the higher participation of very young patients in organized sports [41], an improved understanding of rotator cuff disease, and a more widespread use of advanced imaging modalities and arthroscopic procedures.

Despite the fact that they currently have a greater recognition in the literature, rotator cuff tears in the very young continue to be overlooked as a cause of shoulder pain, leading to significant delays in diagnosis with the potential for both short- and long-term disability.

9.3 Epidemiology and Demographics

The prevalence and incidence of rotator cuff tears in the very young are unknown and can be variable among different populations considering factors such as the level of exposure to organized sports, the diagnostic methods, and the setting where the studies are performed (i.e., general population versus tertiary care referral hospitals). However, these injuries are relatively rare as evidenced by the fact that only 0.8–1% of all rotator cuff tears occur in patients younger than 20 years [19, 42] and that only 1.4–8.5% of the very young patients seen with shoulder pain are diagnosed with rotator cuff tears [24, 43]. Despite the above, if only very young patients whose shoulder symptoms required magnetic resonance imaging (MRI) or arthroscopic procedures are considered, the reported prevalence of rotator cuff tears is higher. Zbojniewicz et al. [26] reported that 12.2% of the very young patients that underwent shoulder MRI for pain or instability were found to have a rotator cuff tear. Similarly, Edmons et al. [33] reported that almost one-third (28%) of the very young patients that underwent shoulder arthroscopy had rotator cuff tears, being the second more frequent intra-articular pathology in this age group after labral injuries.

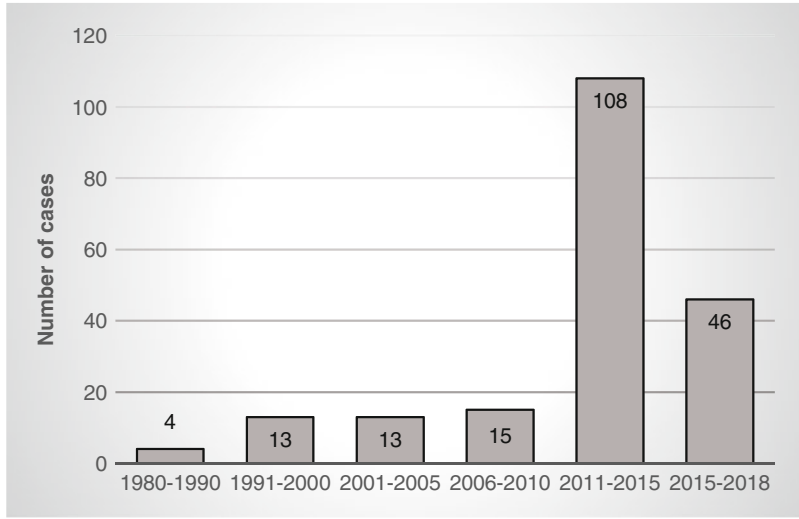

Fig. 9.1 Number of cases of rotator cuff injuries in very young patients reported in the literature, by year

Rotator cuff tears in the very young occur predominantly in male athletes during the middle adolescence. Of the cases reported in the literature [5, 9–31, 35–40], 80% were male patients with a mean age of 15 years and a range of age between 9 and 18 years. While avulsions of the lesser tuberosity also occur more frequently in male athletes, these injuries are more frequent in the early adolescence (mean age 13 years) and have a narrower age range between 12 and 15 years [27]. This narrow range of age may reflect a relative weakness of the lesser tuberosity during this period of skeletal growth and maturation and may represent a transitional fracture of adolescence [29].

Sporting activity accounts for 95% of rotator cuff injuries in the very young. Sports involving throwing or overhead repetitive movements like baseball, basketball, football, and volleyball account for approximately 70% of the rotator cuff injuries in the very young [5, 9–31, 35–40]. However, these injuries are not exclusive of overhead athletes and they can occur in sports without overhead movements like wrestling [22–24], hockey [23, 27, 29], lacrosse [32, 33], ski jumping [31], motorcycle sports [9, 20, 22], cycling [12], and skateboarding [22, 28, 44].

9.4 Etiology and Mechanism of Injury

The etiology of injury of rotator cuff tears in young patients is notably different from that in older individuals. For older patients, rotator cuff tears are frequently seen as atraumatic injuries with a multifactorial etiology including long-standing degeneration leading to tendon failure [45]. In contrast, in the very young, there are two clear patterns of rotator cuff tears: traumatic and overuse secondary to participation in overhead sports.

The association between overhead sports and rotator cuff tears likely stems from the supraphysiologic tensile loads and shear forces secondary to the high velocity and torque experienced during the throwing motions [46–48]. It is theorized that these forces applied in combination with improper mechanics, fatigue, and overload from overtraining can result in a sequence of microinstability, where the rotator cuff is unable to maintain the humeral head in a centered position on the glenoid leading to internal impingement, rotator cuff overload, and, in some cases, rotator cuff lesions [48].

Rotator cuff tears in the very young are also commonly seen in conjunction with shoulder instability. Azzam et al. [22] reported in a series of 32 adolescent athletes with rotator cuff tears that instability episodes were involved in the mechanism of injury in 55% of the patients. Of these patients with instability events, 70% had dislocations that required reduction. Massive rotator cuff tears associated with shoulder dislocations have also been reported in adolescents involved in high-energy trauma [9, 18]. While rotator cuff tears in association with dislocation are most common in adults >40 years of age, this association must not be dismissed in the very young patient.

9.5 Anatomy, Examination, and Imaging

Rotator cuff injuries in the very young can be categorized in two major groups: tendinous injuries (i.e., rotator cuff tears) and avulsion fractures of the tuberosities (i.e., rotator cuff tear equivalents).

9.5.1 Rotator Cuff Tears

The supraspinatus is the most commonly involved tendon in the very young patients. Almost two-thirds (63%) of the cases reported in the literature [5, 9–40] are isolated tears of the supraspinatus. Isolated tears of the infraspinatus and subscapularis have been reported in more rare instances and, respectively, account for 7 and 5% of the cases reported in the literature [17, 22, 23, 26, 40]. Other patterns reported less frequently are injuries to the supraspinatus-infraspinatus junction [26] and partial-width combined injuries of the supraspinatus-infraspinatus [22] or supraspinatus-subscapularis [40].

9.5.1.1 Partial-Thickness Tears

Approximately 70% of all rotator cuff injuries in the very young are partial-thickness tears (Fig. 9.2).

According to their location, most of the tears are reported in the articular side (93%) [16, 17, 22, 23, 26], and a small proportion are located in the bursal side (6%) [17, 26, 39] or interstitial (1%) [26]. In the very young, low-grade partial-thickness tears (i.e., Grade I and II Elman or involving less than a half tendon) are twice as frequent as high-grade partial-thickness tears (i.e., Grade III Elman or involving more than a half tendon) [16, 17, 22, 23, 26, 39]. Overall, low-grade partial articular supraspinatus tendon avulsion (PASTA) lesion represents by far the most common type of rotator cuff injury in this age group.

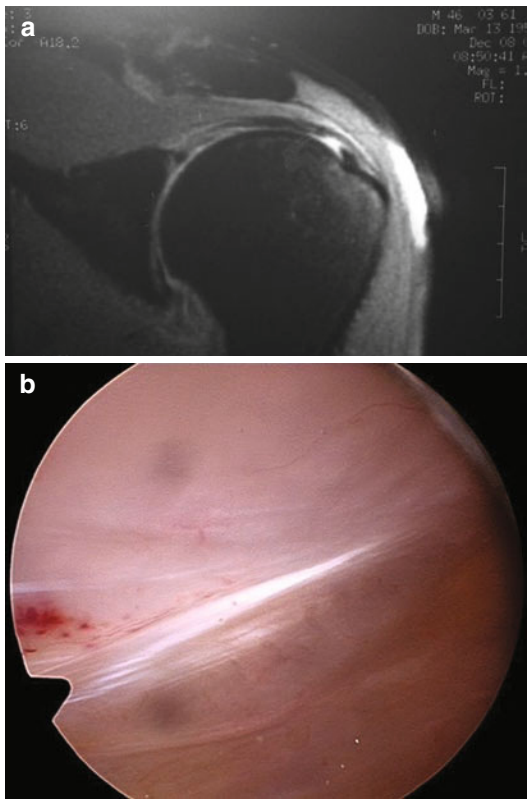

Fig. 9.2 High-grade partial-thickness tear in a 17-year-old gymnast. (**a**) MRI read as "high-grade partial or complete rotator cuff tear." (**b**) Bursal view of shoulder. Note that the bursa is pristine, consistent with the absence of impingement in these cases

9.5.1.2 Full-Thickness and Massive Rotator Cuff Tears

Full-thickness tears are uncommon in the very young and account only for 16% of the cuff tears in this age group [12, 14, 22, 23, 26, 40]. Massive rotator cuff tears are very rare events in this age group with only four cases reported in the literature [9, 18, 20, 22]. All of those cases involved high-energy trauma and in two of those cases, there was a shoulder dislocation associated with trauma [9, 18].

9.5.1.3 Associated Injuries

Rotator cuff tears in the very young are commonly associated to concomitant shoulder injuries. Approximately 50% of the cases reported at least one associated intra-articular pathology [14, 16, 17, 22, 26]. Labral tears are the most common associated lesion including posterosuperior labral tears [14, 16, 17], SLAP tears [17, 22], and anterior labral tears [12, 16, 17, 22]. Other associated injuries are humeral avulsions of the glenohumeral ligaments (HAGL) [12, 22], Hill-Sachs lesions [17], lesions to the long head of the biceps [17, 22], and posterosuperior synovitis [16]. Posterosuperior labral tears may be secondary to internal impingement in overhead athletes, and the presence of injuries representative of shoulder instability including anterior labral tears, HAGL lesions, or Hill Sachs lesions reflects the association of shoulder instability with cuff tears in this age group.

9.5.2 Avulsion Fractures of the Tuberosities

Tuberosities and rotator cuff are a single functional unit and therefore avulsion fractures of the tuberosities may be considered as a "rotator cuff tear equivalent" [24]. The presence of epiphyseal plates in the very young makes this population more prone to avulsion fractures of the tuberosities than older patients. Avulsion fractures of the tuberosities are frequently sustained after traumatic events including falls and eccentric external rotation injuries. However, a small proportion of avulsion injuries occur without direct trauma; rather, the injuries are due to repetitive overuse including pitching and fly fishing [27]. Consequently, the absence of a

traumatic event does not rule out an avulsion of the tuberosities and a history related with repetitive overuse may be consistent with this injury.

The lesser tuberosity is the most commonly involved and represents the most common pattern of subscapularis injury in the very young (Fig. 9.3). Approximately 80% of the subscapularis injuries reported in this age group [5, 21, 22, 27] involved the avulsion of the subscapularis tendon associated with a fragment of the lesser tuberosity of varying size. Avulsion of the greater tuberosity is rarely reported with only three cases in the literature [22, 40].

9.5.2.1 Associated Injuries

The frequency of associated injuries with avulsion injuries is lower than that reported for isolated rotator cuff tears. Reported cases have noted concomitant biceps tendon subluxation or dislocation [49, 50], HAGL or BHAGL lesions [44, 51], labrum tears [12, 33], and supraspinatus partial tears [12, 52]. Unlike the adult version of this injury (i.e., isolated lesser tuberosity fracture), posterior dislocation is not a part of the injury spectrum of lesser tuberosity avulsion in the very young, but anterior instability and dislocation are frequently seen [28].

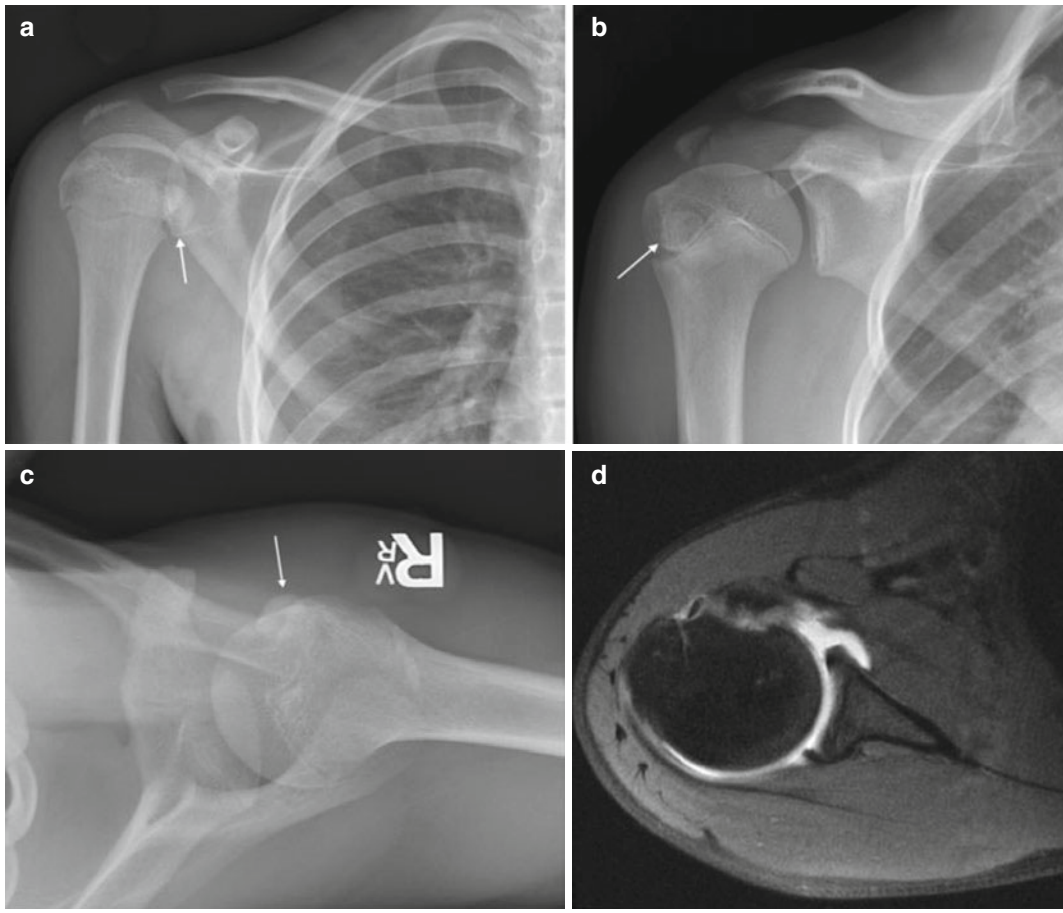

Fig. 9.3 A 12-year-old male sustained an injury to the right shoulder while playing baseball. The lesser tuberosity avulsion (white arrow) is seen on (**a**) AP radiograph with internal rotation (**b**) Grashey view and (**c**) axillary view. (**d**) Axial T2-weighted slice on a MRI with intra-articular contrast showing the same avulsion of the lesser tuberosity with minimal displacement

9.6 Clinical Evaluation

The most common complaints at presentation in the reported cases are pain, both at rest and with overhead activities, and subjective weakness during participation in sports. Other less common complaints include instability, numbness, "feeling of a pop," and limited range of motion.

9.6.1 Physical Examination

Since low-grade partial-thickness tears are the most common pattern of injury in this age group, subtle physical examination findings may be frequently seen. The literature reports that physical examination findings in very young patients with rotator cuff tears are not specific which adds difficulty to the diagnosis of these injuries [27, 28]. Positive Neer and Hawkins [14, 23, 34, 39], pain with supraspinatus tests [39], and pain with resisted external rotation [39] are reported only in a small proportion of the very young patients with rotator cuff tears. Therefore, their absence does not rule out the diagnosis and further studies assessing the accuracy of those tests in this age group are required. Like in older patients, the presence of severe weakness or lag signs should raise the suspicion for full-thickness and massive tears [18, 20].

Regarding subscapularis tears and lesser tuberosity avulsion injuries, weakness has shown to be the most sensitive physical examination finding (87% sensitivity) [27]. Lift-off and belly press signs are positive in the majority of the cases [21, 28, 51, 53–56]; however, with avulsion of lesser tuberosity in the very young, a partially intact periosteal sleeve may remain that could allow for some internal rotation, which could diminish the reliability of these tests [56]. Other physical examination findings in subscapularis tears include increased passive external rotation of the shoulder compared with the unaffected contralateral upper limb (62% sensitivity) [27], anterior shoulder tenderness to palpation [51, 53, 55, 56], decreased internal rotation [53], and transient numbness or "dead-arm" symptoms during the initial episode [28]. Apprehension test may be positive in up to 50% of the patients [27]. It is unclear whether this is because of the anterior stabilizing effect of the subscapularis or to associated capsuloligamentous injuries [28].

9.6.2 Imaging

A number of imaging modalities have been utilized to aid in diagnosis, including radiographs, ultrasonography, and magnetic resonance imaging (MRI). Plain radiographs are the initial investigation due to its speed, availability, and low cost. In the very young patient, radiographs are useful in making the differential diagnosis with other conditions and can be helpful in diagnosing an avulsion injury when positive (Fig. 9.3a–c). However, a negative plain radiograph cannot rule out an avulsion injury due to its low sensitivity (16%) in diagnosing these injuries [27]. Some factors that account for the low sensitivity of radiographs in this setting are the plane of injury, the small size of the avulsed fragment, and the low diagnostic accuracy of radiographs in chondro-epiphyseal injuries [27]. When radiographs are positive for an avulsion injury, the axillary view has been reported as the most helpful in visualizing the avulsed fragment (Fig. 9.3c). Ultrasonography has many advantages compared with radiographs, including its ability to identify cartilaginous and tendinous structures, avoidance of radiation, and dynamic evaluation of anatomic structures [57]. However, ultrasonography is operator-dependent, and its accuracy and diagnostic value for rotator cuff injuries in the very young are unknown. MRI is the diagnostic modality of choice given its higher diagnostic accuracy and its ability to detect associated injuries of other structures of the shoulder, including cartilage, capsule, labrum, and biceps tendon. MRI has proven a high sensitivity in diagnosing full-thickness subscapularis tears and lesser tuberosity avulsion injuries in the very young. In a systematic review of the literature, Vavken et al. [27] reported that MRI correctly diagnosed 38 of 40 patients with subscapularis tears or lesser tuberosity avulsion injuries, consistent with a sensitivity of 95%. While MRI has showed a high accuracy

in diagnosing full-thickness tears and avulsion injuries, its diagnostic accuracy in the setting of partial articular-side tears is lower with a higher proportion of patients misclassified as false negatives or false positives [58]. It is known that partial articular-side tears, the most common pattern of injury in the very young, can be difficult to diagnose and can be missed or overcalled on MR imaging, potentially mimicked by synovitis, tendinopathy, and superficial fraying [26]. In a study of ten very young patients published in 2018, Perez et al. [17] assessed the accuracy of conventional MRI findings in diagnosing rotator cuff lesions in the very young. Of the preoperative MRIs, 28.5% missed rotator cuff lesions visualized arthroscopically (i.e., false negatives) and 20% reported tendon involvement not observed intraoperatively (i.e., false positives). Some authors advocate the use of MRI arthrography and additional MRI sequences in abduction and external rotation (ABER) positioning to further characterize articular surface partial-thickness rotator cuff tears aiming to improve MRI accuracy. Burns et al. [14] reported two cases of very young softball players with rotator cuff tears where the ABER images demonstrated the complete nature of the tear that was not as readily apparent with standard coronal oblique images. Selective use of MRI arthrography and ABER series may be beneficial in very young patients with suspected articular face rotator cuff tears.

9.6.3 Indications and Techniques

Because of the rarity of rotator cuff injuries in the very young, no definitive recommendations regarding treatment can be made. Determining the most appropriate treatment for these uncommon injuries will require further studies with larger numbers of patients comparing different treatment options. While the current literature describes predictable good results after surgical treatment, there is a scarcity of studies comparing operative and non-operative treatment. Treatment considerations therefore should focus on the specific injury, level of sports participation, and desire to return to sports.

9.7 Rotator Cuff Tears

9.7.1 Full-Thickness and Massive Tears

Little controversy exists regarding the treatment of very young patients with full-thickness and massive rotator cuff tears. Very young patients with this type of tears may generally fare better with immediate surgical management and the role of non-operative treatment for this specific subgroup of tears may be limited, as these tears may become unrepairable with time. The literature has showed more successful outcomes in younger patients receiving surgery for traumatic tears compared with older patients receiving surgery for atraumatic tears [59].

9.7.2 Partial-Thickness Tears

Contrary to full-thickness tears, there is more controversy regarding the best treatment for very young patients with partial-thickness tears. Most of these patients are overhead athletes and surgical repair of rotator cuff tendons in this population fails to return them to the same level of performance in more than 50% of the cases [16, 22]. Therefore, the level of sports participation and desire to return to same sport performance should be considered when deciding treatment options in this population.

9.7.2.1 Non-operative Treatment

Non-operative treatment may be considered for the initial treatment of partial rotator cuff tears in very young overhead athletes. Many partial tears are asymptomatic in overhead throwers, and the tears resulting in symptoms may be effectively treated without surgical repair. Non-operative treatment begins with a cessation from all overhead activities, anti-inflammatory medication for pain control, and physical therapy with an emphasis on range of motion and rotator cuff strengthening. Internal rotation deficits and posterior capsule contractures must be addressed as well. In adults, untreated partial-thickness rotator cuff tears progress to larger tears or full-thickness

tears in 80% of patients [60]; however, long-term outcomes of very young patient with partial rotator cuff tears have not been studied. It is possible that younger patients have an increased healing capacity, and early detection and treatment might be helpful in preventing progression of injury [26]. Non-operative treatment may have a high rate of failure in the very young as evidenced by the fact that only 30% of the cases of rotator cuff tears in the very young reported in the literature were non-operatively treated [5, 9–40].

Eisner et al. [16] reported the outcome of non-operative treatment in 53 very young patients with partial-thickness rotator cuff tears. Of these patients, 57% failed to improve after 6 weeks of physical therapy and required subsequent arthroscopic debridement. In this study, patients with MRI-diagnosed associated pathology had 80% more probability of requiring surgical intervention compared with those without MRI-diagnosed associated pathology. As a result, the presence of associated pathologies was proposed as a risk factor for failure of non-operative treatment. These authors were able to contact 19 patients at a mean 16 months after treatment and found no significant differences in outcome scores between operatively and non-operatively treated tears. However, patient with non-operative treatment were more likely to return to their previous level of competition (100%) compared with those that required surgical treatment (70%).

9.7.2.2 Operative Treatment

Operative treatment has been the treatment of election in the majority of the cases of partial-thickness tears in the very young reported in the literature [14, 16, 22, 23, 27]. However, there is a paucity of data concerning functional outcomes and return to sports among these reports. Azzam et al. reported the functional outcomes of rotator cuff repairs in 32 very young athletes at mean 6.2 years of follow-up. Of these patients, 25 (93%) could return to sports. Of the 14 patients who were overhead athletes and had surgery on their throwing shoulders, 13 (93%) returned to the same level of play, but 9 (64%) had to switch positions because of a loss of throwing velocity or distance. The overall mean ASES score was 93, mean Western Ontario Rotator Cuff Index was 89%, and mean numeric pain rating was 0.3. While the results of these patients are excellent, there was no control group or cohort of patients with rotator cuff tears treated non-operatively to compare with.

Another controversy in the operative treatment of partial-thickness tears in the very young is the indication of debridement versus repair. Based on the assumption that high-grade tears in very young patients are likely to progress to full-thickness tears because of their young age and high activity level, some authors [14, 22] advocate repair for high-grade tears, while low-grade tears may be treated with debridement. Long-term follow-up studies that assess the prognosis of partial-thickness tears treated with debridement and non-operatively are required to clarify the indications of these procedures. Similarly, controversy exists regarding repair of the partial tear by completing the tear versus in situ repair, but no data exists regarding this decision.

9.7.3 Lesser Tuberosity Avulsion Injuries

9.7.3.1 Non-operative Treatment

Non-operative treatment may be an option in mildly symptomatic, nondisplaced avulsion injuries [27]. Only 17% of the cases reported in the literature received non-operative treatment consisting of rest and immobilization, followed by gradual strengthening and return to activities [27]. Cases with displaced avulsion injuries with non-operative treatment or delayed diagnosis can go on to develop chronic shoulder pain, exostoses at the site of the avulsed tuberosity, as well as degeneration within the subscapularis muscle, which eventually require surgical management. Therefore, multiple authors have advocated operative treatment [5, 21, 28, 44, 50, 61, 62], even in minimally displaced cases. However, most of those cases were patients with a missed diagnosis and without appropriate treatment and may not represent the population of patients with a prompt diagnosis and a well-indicated and supervised non-operative treatment.

9.7.3.2 Operative Treatment

Operative treatment was recommended in more than 80% of the very young patients with subscapularis and lesser tuberosity avulsion injuries reported in the literature [27]. The most common approach for this type of injuries is the open repair (55%), followed by a combined approach of a diagnostic arthroscopy and open repair (17%) and less commonly arthroscopic reduction and internal fixation with suture anchors (11%) [27]. Both open and arthroscopic repairs have been reported with successful results [5, 21, 28, 44, 50, 61, 62]. In a systematic review of the literature, Vavken et al. [27] did not find any statistical difference in the clinical scores of the patients treated with open or arthroscopic repairs. Important technical aspects of surgical repair include the use of transosseous suture repair or larger threaded suture anchors designed for cancellous bone to ensure sufficient purchase in the soft bone of the lesser tuberosity and avoid accidental tenodesis of the long head of the biceps tendon which may be inadvertently incorporated during medial to lateral suture passage and bony excision and direct tendon repair for smaller or comminuted fragments [21, 28, 29]. If an open approach is used, arthroscopic examination may be a helpful adjunct for diagnosis and treatment of associated injuries [28]. In isolated tendinous SCC injuries, arthroscopic techniques described to repair the SCC in adults may be appropriate for restoring anatomy and function in the very young [21].

9.8 Conclusions

Rotator cuff injuries in the very young are rare injuries resulting from traumatic events or overuse sports participation. Despite its rarity, these injuries are being reported with increasing frequency and a timely diagnosis is critical to avoid long-term complications and to establish the best treatment option. A high index of suspicion should be maintained in very young patients with shoulder pain and subjective weakness, especially in male overhead athletes after traumatic events. Partial articular-side supraspinatus tendon avulsion and lesser tuberosity avulsion injuries are the two most common patterns of injury. In any patient with a suspected rotator cuff injury, including avulsion injuries, MRI imaging should be used early on given that plain radiographs have a very low sensitivity. Non-operative treatment may be the initial option for partial-thickness rotator cuff tears and minimal displaced avulsion injuries. Operative treatment is safe and successful in restoring anatomy and function; however, overhead athletes may not return to the same level of competition. Further studies comparing non-operative and operative treatment are required to further delineate the indications of treatment in this age group.

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10 Definition and Classification of Different Forms of Impingement

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10.1 Introduction

Armstrong reported in 1949 that the major causes of painful shoulder were frozen shoulder and cuff pathology, which he called the "supraspinatus syndrome" [1]. Later, this was named as "impingement syndrome." The impingement syndrome is defined as "impingement of the rotator cuff beneath the coracoacromial arch which causes chronic disability of the shoulder" [2]. As this form of impingement is observed in the subacromial space, it is also called the subacromial impingement. Later, a new form of impingement was reported in throwing athletes [3–6]. With the arm in abduction and external rotation, the undersurface of the supraspinatus and infraspinatus tendons comes in touch with the posterosuperior glenoid, causing an articular side partial-thickness cuff tear. This is called posterosuperior impingement or internal impingement as opposed to external impingement, which is synonymous to subacromial impingement. Furthermore, not only superior (subacromial impingement) and posterosuperior (posterosuperior impingement) but also anterior impingement has been recognized. The anterior impingement includes various types of impingement such as subcoracoid impingement (impingement between the coracoid process and the subscapularis), anterosuperior impingement (impingement between the anterosuperior glenoid and the subscapularis tendon and the long head of the biceps), and so on. In this chapter, we classify various forms of impingement into three categories: (1) subacromial impingement, (2) posterosuperior impingement, and (3) anterior impingement.

10.2 Subacromial Impingement

10.2.1 Definition

Mechanical impingement on the tendinous portion of the rotator cuff by the coracoacromial ligament and the anterior third of the acromion is defined as "impingement syndrome" when it is responsible for a characteristic syndrome of disability of the shoulder" [2]. As this impingement occurs in the subacromial space, it is also called subacromial impingement. The term "subacromial impingement syndrome" or "impingement syndrome" is used to cover a wide range of rotator cuff pathologies ranging from rotator cuff tendinitis to full-thickness tears of the rotator cuff tendon.

10.2.2 Classification

Subacromial impingement is classified into two groups: primary (structural changes) and secondary

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Table 10.1 Classification of subacromial impingement

Subacromial impingement	
Primary	Structural changes
– Outlet	Bony narrowing (acromion, greater tuberosity)
– Non-outlet	Increased volume of tendon/bursa
Secondary	Functional disturbances (muscle imbalance)

(functional disturbances), and the primary is further subdivided into outlet and non-outlet impingement [7] (Table 10.1). The primary impingement is caused by structural changes of the bony structures that create the supraspinatus outlet or the soft tissues inside the outlet such as the subacromial bursa and the rotator cuff tendon. The acromion and the greater tuberosity that create the bony outlet may cause narrowing of the outlet when there is a bony spur of the acromion, malunion of the acromion, malunion of the greater tuberosity, etc. This is an outlet impingement. On the other hand, the contents of the outlet may cause impingement when the contents increased in volume such as bursal/tendon swelling caused by bursitis/tendinitis or space-occupying lesion such as calcified deposit in the tendon. This is called non-outlet impingement.

10.2.3 Acromioplasty

The lateral acromionectomy or total acromionectomy had been commonly performed [8] until Neer introduced a concept of anterior acromioplasty [2]. He thought that the anterior third of the acromion and the coracoacromial ligament caused impingement on the tendinous portion of the rotator cuff. He proposed to remove the anterior one-third of the acromion with the coracoacromial ligament [2]. The anterior acromioplasty had been widely performed [2, 9, 10] until the arthroscopic procedure gained popularity. During the arthroscopic procedure, only the undersurface of the anterior portion of the acromion is removed and thus is called "subacromial decompression" [11]. This procedure has been widely used ever since, and the outcome of this procedure is reported to be satisfactory in the mid-term and long-term follow-ups [12–14].

Since the diagnostic label "subacromial impingement syndrome" covers wide spectrum of rotator cuff pathologies, it is almost synonymously used as shoulder pain. This has widened the diagnostic criteria and made the indications for acromioplasty increasingly more liberal. For example, the population-based number of acromioplasties increased 2.4 times between 1996 and 2006 in New York State, and the surgeon-based number of acromioplasties increased by 142.3% as opposed to that of all orthopedic surgery procedures by 13.0% between 1999 and 2008 on the national level in the United States [15]. Also, the number of patients undergoing acromioplasties increased 7.5 times between 2000/2001 and 2009/2010 in the United Kingdom [16]. These skyrocketing numbers of acromioplasties might indicate the over-indication of this surgical procedure.

In order to avoid this over-indication, there have been a couple of recommendations reported in the literature, proposing to discontinue the diagnostic label of "subacromial impingement syndrome" and to use a more specific diagnostic label related to the pathology [17, 18]. Regarding the pathology, the Copeland-Levy classification evaluates the pathological changes of both surfaces of the acromion and the rotator cuff tendon [19]. We propose to pay more attention to specific pathologies of the acromion and the rotator cuff when we use the term "subacromial impingement." Using more specific and pathology-based diagnosis, we should be able to provide better patient care.

10.2.4 Acromioplasty Combined with Rotator Cuff Repair

In 2007, one of our committee members, Guiseppe Milano, and his colleagues published a prospective randomized clinical trial comparing 40 patients treated with arthroscopic rotator cuff repair (ARCR) with arthroscopic subacromial decompression (ASD) and 40 patients with ARCR alone [20]. At 2-year follow-up, they could not find any significant difference in Constant score and in DASH score between these two groups. They concluded that ASD did not

seem to significantly affect the outcome of ARCR. In 2012, there was a systematic review, analyzing four randomized clinical trials, which concluded that there was no significant difference in subjective outcome after ARCR with and without ASD based on the current available literature [21]. In this review, they pointed out that one of the four trials showed a significant difference in reoperation rate: those without ASD underwent reoperation significantly more often than those with ASD. Later on, another member of our committee, Geoffrey Abrams, and his colleagues also performed randomized clinical trial, comparing 52 patients with ASD and 43 patients without [22]. At 2-year follow-up, they could not find any significant difference in the functional outcomes between those with and without ASD. The reoperation was done in one patient in the ASD group and four in the non-ASD group ($p = 0.11$). With larger number of patients, a significant difference is likely to be seen between the groups. During our Closed Consensus Meeting in Munich, we asked the committee members what their preference was. Half of them perform ASD and the rest half perform no more ASD during ARCR. Therefore, our consensus as of 2018 is that we need more robust evidence based on larger series with longer terms of follow-up.

10.3 Posterosuperior Impingement

10.3.1 Definition

This impingement is defined as an impingement between the undersurface of the supraspinatus/infraspinatus tendon and the posterosuperior border of the glenoid. This lesion was first reported by Bennett [3]. Later, Andrews et al. also reported articular side tears of the supraspinatus tendon with either anterosuperior or posterosuperior labral tears in throwing athletes [4]. Jobe et al. speculated that rotator cuff lesions observed in throwing athletes might be related to occult anterior subluxation, which was most sensitively detected by relocation test [5]. In throwing athletes, Walch et al. found impingement between the posterosuperior border of the glenoid and the undersurface of tendinous insertions of supraspinatus and infraspinatus with the arm in abduction and external rotation [6]. They said that in addition to Neer's "impingement syndrome" [9] and Jobe's "instability with secondary impingement" [5], impingement of the undersurface of the rotator cuff on the posterosuperior glenoid labrum may be a cause of painful structural disease of the shoulder in the thrower. This impingement in throwers was further confirmed in a study with frozen cadaveric shoulders [23]. This impingement is called "internal impingement" because impingement occurs inside the glenohumeral joint, whereas conventional subacromial impingement occurs outside of the glenohumeral joint, which is also called "external impingement." However, another form of internal impingement, i.e., anterosuperior impingement, was reported later on [24]. In order to avoid confusion, it is no longer called internal impingement but more specifically "posterosuperior impingement" or "anterosuperior impingement" based on the location of pathology.

10.3.2 Classification

Jobe classified the posterosuperior impingement into three stages: early stage, intermediate stage, and advanced stage (Table 10.2) [25]. He recommended 2–4 weeks of rest with anti-inflammatory medication for Stage I patient. Strengthening the scapular rotators is also essential. In Stage II, rehabilitation program to strengthen the rotator cuff muscles as well as the scapular rotators is important. If this program does not work, a surgical intervention called anterior capsular reconstruction is indicated in Stage III.

Table 10.2 Classification of posterosuperior impingement [25]

Stage	Symptomatology
I: Early	Stiffness and slow warm-up
II: Intermediate	Posterior pain, positive relocation test
III: Advanced	Similar symptom to stage II plus failure of rehabilitation program

10.4 Anterior Impingement

10.4.1 Definition

Anterior impingement refers to various forms of impingement occurring around the anterior aspect of the shoulder such as impingement between the coracoid process and the subscapularis tendon, between the subscapularis/supraspinatus tendons and the anterosuperior glenoid, between the long head of the biceps tendon and the articular cartilage of the humeral head, and between the superior margin of the subscapularis tendon and the thickened synovial band or hypertrophic MGHL.

10.4.2 Classification

There have been various types of anterior impingement reported in the literature. Cunningham and Lädermann performed systematic review of the literature and classified them into four subtypes (Table 10.3) [26].

10.4.3 Subcoracoid Impingement

Subcoracoid impingement was first reported more than 100 years ago [27]. However, little attention has been paid until Gerber et al. reported the pathology [28]. The normal distance of coracohumeral interval is 8.4–11.0 mm [29–31]. If it is less than 6 mm, it is called subcoracoid stenosis. However, the prevalence of subcoracoid impingement varies greatly among the reporters, ranging from 5% to 56% [30, 32, 33]. The pathology of the subscapularis is almost always at the upper margin and articular side of the subscapularis. If there is a mechanical impingement between the subscapularis and the coracoid process, why does a tear occur not on the bursal side but on the articular side? To this question, Lo and Burkhart introduced a mechanism called a "roller-wringer effect" [30]. According to their explanation, this effect created greater tensile force on the articular side of the subscapularis tendon, which might play a role to cause an articular side partial-thickness tear. However, our question still remains: why does the roller-wringer effect occur during the subcoracoid impingement, but not during the subacromial impingement? Most of the committee members expressed their feeling that it seemed difficult to understand why the subacromial impingement caused a bursal side tear of the supraspinatus tendon, whereas the subcoracoid impingement caused an articular side tear of the subscapularis. Furthermore, we do not see fraying or fibrillation of the undersurface of the coracoid in case of subcoracoid stenosis and subscapularis tear. This also causes argument why acromioplasty is done to the pathologic undersurface of the acromion, whereas the coracoplasty is done to the seemingly normal coracoid process. The concept of "subcoracoid impingement" remains very controversial among the committee members.

Table 10.3 Classification of anterior impingement

Subtype	Imaging	Arthroscopic findings
Subcoracoid	Reduced coracohumeral interval	Upper subscapularis tear, subcoracoid scarring
Anterosuperior	Subscapularis lesion and biceps pulley lesion	Subscapularis tendon tear, biceps pulley lesion, biceps tendon subluxation
Chondral print	Unstable biceps tendon	Humeral head chondral lesion
FUSSI lesion	NA	Upper subscapularis fraying, thickened synovial band, hypertrophic MGHL

10.4.4 Anterosuperior Impingement

This entity was first described by Gerber and Sebesta who reported that friction between the anterosuperior rotator cuff tendon and the anterosuperior glenoid rim led to an articular side tear of the subscapularis tendon and a biceps pulley tear [24]. As this impingement is often observed in tennis players, they speculated that the

repetitive impingement was the cause of partial-thickness tear. It is much easier to understand that a direct mechanical impingement called "anterosuperior impingement" between the subscapularis tendon and the anterosuperior glenoid leads to an articular side tear of the subscapularis tendon rather than the subcoracoid impingement causes an articular side tear of the subscapularis tendon. A recent kinematic study of tennis players revealed that anterosuperior impingement occurred in 29% during forehand movement, but subcoracoid impingement never occurred during any stage of the tennis motion [34]. Also, it was reported that subcoracoid injection did not improve anterior shoulder pain in patients with anterosuperior impingement [24]. These reports suggest that the subcoracoid impingement and anterosuperior impingement are discrete entities with no overlapping between them.

10.4.5 Chondral Print

This lesion was first reported by Castagna et al. [35]. They found an indentation of the articular cartilage near the long head of the biceps tendon, which was unstable. They observed the chondral print in 100% of cases with dislocation of the long head the biceps tendon and 89% of cases with subluxation of the biceps tendon. We still do not know whether the indentation itself causes any symptoms and whether it needs to be treated.

10.4.6 FUSSI Lesion

The FUSSI lesion stands for *f*rayed *u*pper edge *s*ub*s*capularis lesion with *i*mpingement lesion. This was reported by Snyder on VuMedi (2009) (https://www.vumedi.com/video/fussi-lesions). This lesion is distinguished from other types of anterior impingement because pain is induced with the arm in adduction and external rotation. It has not been clear whether this lesion, fraying of the upper boarder of subscapularis tendon, is caused by the synovial band, or hypertrophic MGHL, or something else. We have had very limited information on this pathology as yet. More information is needed to clarify whether this lesion is an independent lesion or a part of other lesion.

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11 Arthroscopic Subacromial Decompression: The US Perspective

Stephanie C. Petterson and Kevin D. Plancher

Subacromial impingement syndrome, accounting for 44–70% of all shoulder pain, is a common cause of shoulder pain that afflicts both athletes and nonathletes alike, leading to decreased ability to participate in sports and daily activities [1–3]. Impingement syndrome was first coined by Neer in 1972 to describe the trauma to the supraspinatus tendon encountered as it passes below the coracoacromial ligament and the anterior 1/3 of the acromion [4]. External impingement has been thought to be caused by the bony anatomy, specifically the shape of the acromion, as well as abnormalities in the surrounding soft tissues, such as the subacromial bursa and coracoacromial ligament, contributing to a physical loss of the subacromial space due to bony growth or inflammation. Secondary external impingement is often the result of altered scapulohumeral mechanics from glenohumeral instability and muscle imbalances [5]. Subacromial impingement syndrome can lead to a variety of sequelae not limited to but including rotator cuff tendinopathy, partial- or full-thickness rotator cuff tears, calcific tendinitis, and subacromial bursitis [6].

11.1 Anatomy/Pathoanatomy

Understanding the anatomy of the subacromial space, including the relationship between the bony anatomy and interposed subacromial bursa, is important in making the diagnosis of subacromial impingement syndrome and avoiding complications with surgical intervention. The subacromial space is defined by the coracoacromial ligament and acromioclavicular joint superiorly, the anterior edge and undersurface of the acromion, and the humeral head inferiorly. The rotator cuff tendons, subacromial bursa, long head of the biceps tendon, and coracoacromial ligament are located within this space. On average, the subacromial space, measured as the width of the space between the inferior surface of the acromion and the head of the humerus on anteroposterior radiographs, known as the acromiohumeral distance, is 1–1.5 cm [6, 7].

The acromion has three cartilaginous growth centers that ossify during development. In up to 15% of people, one or more of these growth centers do not ossify (os acromiale) [8]. The presence of an os acromiale may increase the risk of subacromial impingement syndrome. Failure of this growth plate to close allows for some motion

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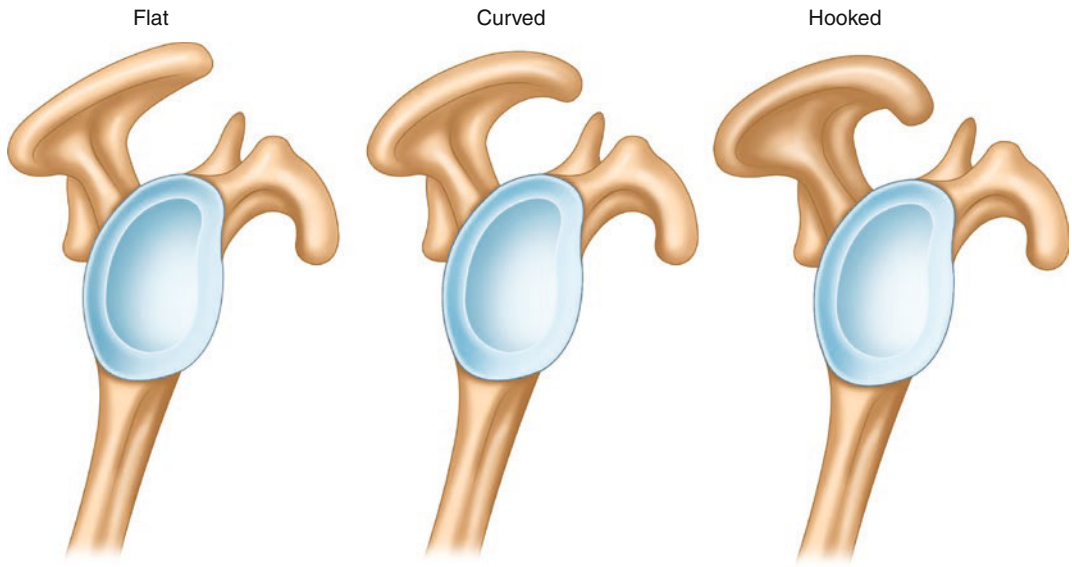


Fig. 11.1 Bigliani classification of acromial shape: type I (flat), type II (curved), and type III (hooked). Copyright Kevin D. Plancher

of the acromion which may impinge on the rotator cuff tendons or bursa.

The shape of the acromion dictates the size of the subacromial space and the room for the rotator cuff tendons. Bigliani et al. classified three different acromion shapes. Type I acromion is flat, type II acromion is curved, and type III acromion is hooked, which as a result decreases the subacromial space (Fig. 11.1) [9]. A type III acromion has also been associated with a higher incidence of rotator cuff tears [10]. The subacromial bursa lies between the undersurface of the acromion and the superior surface of the rotator cuff. The subacromial bursa does not have a sturdy ligamentous capsule which can lead to fluid extravasation into the muscle and subcutaneous envelope of the shoulder although its vascularity may lead to in situ rotator cuff tears [11]. Coracoid impingement, while less common, may also occur between the anteromedial portion of the coracoid process and the lesser tuberosity of the humerus, when the distance between the coracoid and humeral head is less than 6 mm from the lateral edge of the coracoid [12].

The cause of true external impingement is thought to be the result of the rotator cuff impinging against the anterior edge of the acromion with forced forward flexion. The subacromial bursa lies between the undersurface of the acromion and the superior surface of the rotator cuff. Inflammation of the subacromial bursa can also lead to a reduction in the subacromial space due to hypertrophy and pain with overhead movements. Additionally, hypertrophy of the coracoacromial ligament may decrease the subacromial space leading to external impingement of the shoulder. Existing subacromial pathology can also be correlated with altered scapular kinematics during humeral elevation which includes decreased upward rotation or posterior tilting of the scapula. These kinematic changes have the potential to mechanically impinge on subacromial structures and narrow the subacromial space [13]. Supraspinatus tendon thickness may also be a causative factor of impingement [14]. Patients with a subacromial impingement disorder often have significantly thicker supraspinatus tendons and greater tendon occupation ratios of the subacromial space.

11.2 Biomechanics and Clinical Signs

The functional range of motion of the shoulder can alter the dimensions of the subacromial space and contribute to clinical signs of impingement syndrome, specifically, shoulder abduction and rotation [15, 16]. As the shoulder moves from 30° to 120° of abduction, the distance between the humerus and the acromion significantly decreases by almost 50% [16]. The minimum distance between the acromion and humerus is also smallest with the arm in external rotation at 90° [14]. Graichen et al. reported that when the arm is in 90° of abduction and 45° of internal rotation, the supraspinatus is closest to the anteroinferior border of the acromion [16]. Pressure in the subacromial bursa is also noted to change with arm position as well as with changes in the demand of certain activities [17]. While arm elevation leads to a decrease in subacromial space width, adduction muscle forces substantially increase the acromiohumeral distance and claviculohumeral distance compared to the abduction muscle forces (138% at 90° relative to abduction forces). Biomechanics support strengthening of the adductor muscles, including the latissimus dorsi, subscapularis, and teres major and minor, in both conservative and postoperative rehabilitation programs to avoid, lessen, and eradicate the symptoms of impingement syndrome [18, 19].

Scapular dyskinesis or dynamic scapular winging, seen on evaluation of the scapula during overhead range of motion, may contribute to clinical signs of impingement as a result of abnormal scapular muscle activity and subsequent abnormal scapular kinematics. Patients with impingement demonstrate decreased output force, muscle balance, electromyographical activity, and activation latency of the trapezius and serratus anterior muscles which stabilize the scapula and control scapular rotation. Silva et al. reported that the subacromial space is smaller in patients with scapular dyskinesia than in control patients and that the subacromial space undergoes greater reduction when the shoulder is moved from neutral abduction to 60° of elevation in patients with scapular dyskinesia than in control patients [19]. Additionally, weakness of the rotator cuff can lead to abnormal glenohumeral and scapulothoracic kinematics and subsequent narrowing of the subacromial space [6]. These findings have been shown in both tennis and basketball players [19, 20].

Patients with full-thickness rotator cuff tears have a narrower subacromial space than patients with impingement or no pathology [21]. Several factors contribute to changes in the subacromial space in these patients including the shape of the acromion (rotator cuff tears are more prevalent in patients with hooked type III acromion), the shape of the coracoid, the acromial angle, and the spine-scapula angle [22]. Additionally, there is increased superior translation of the humerus in patients with rotator cuff deficiency due to altered muscle activation patterns contributing to subacromial impingement symptoms. Eighty-four percent of patients undergoing rotator cuff repair also undergo subacromial decompression though results of repairs with or without subacromial decompression have been shown to be equivocal in some shoulders [23].

Patients with shoulder instability may also present with signs of impingement syndrome. If patients present with persistent posterior shoulder pain, the surgeon must have a high suspicion for internal rather than external impingement. This diagnosis is most commonly restricted to overhead athletes. Up to 30% of patients with clinical signs of subacromial impingement syndrome also have degenerative changes in the acromioclavicular joint [24]. If associated degenerative osteophytes form inferiorly and project into the subacromial space, the dimensions of this area are reduced (Fig. 11.2). This is more common in people older than 40 years of age. Furthermore, 21% of patients following superior labrum anterior posterior (SLAP) repair have signs of clinical impairment with 35% requiring subsequent subacromial decompression (SAD) following SLAP repair [25, 26]. Additionally, some studies have shown improved outcomes post SLAP repair and SAD compared to SLAP repair alone.

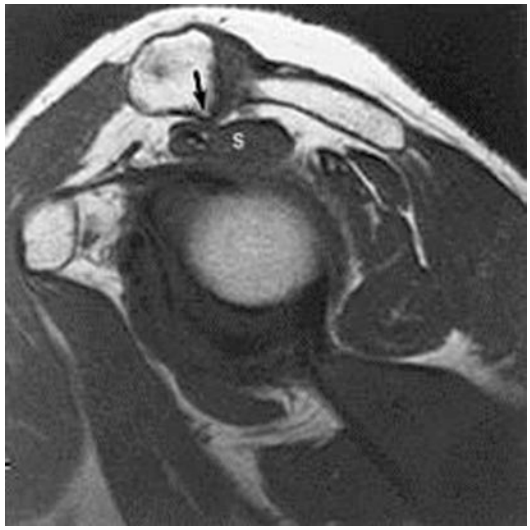


Fig. 11.2 MRI demonstrating inferiorly directed osteophyte of the acromioclavicular joint causing a reduction in the subacromial space

11.3 History and Physical Examination

Patients often relay a history of an onset of symptoms that may be gradual and progressive located in their shoulder while doing overhead activities or when placing their arm behind their back such as putting on a coat or grabbing a wallet out of their back pocket. Frequently, patients will also complain of weakness and limitations of shoulder movement as a result of the shoulder pain. Many individuals cannot turn to reach to put on their seatbelt or turn to reach items in the back seat of their car. Some patients complain of sudden pain after a traumatic event or when pursuing a new sport. Pain due to impingement is most commonly localized to the anterolateral aspect of the acromion. Patients will often wake at night due to pain or have difficulty sleeping on the affected shoulder. Although anterolateral shoulder pain is not specific for impingement syndrome, it guides the examiner to a spectrum of disorders of the rotator cuff and the subacromial space.

Insidious onset of symptoms due to extrinsic impingement is more commonly seen in athletes and workers that perform activities with repeated overhead motion. Traumatic onset of impingement syndrome can be seen after a direct blow to the superolateral aspect of the shoulder or axial load on the upper extremity, compressing the humeral head into the inferior aspect of the acromion (e.g., snow skiing accident, football or hockey player with poorly fitted shoulder pads). The resultant inflammation of the subacromial bursa or contusion of the underlying rotator cuff causes the discomfort noted with overhead motion.

Physical examination is the key to diagnosis of impingement syndrome. In order to perform an adequate examination, the patient, if male, must remove his shirt or, if female, wear an appropriate shoulder "gown" that allows for inspection of the neck, shoulder, and periscapular musculature. The exam should begin with evaluation of the cervical spine and shoulder girdle. Limitations in neck range of motion, pain reproduced with provocative testing of the cervical spine, and pain radiating from the neck into the shoulder may indicate underlying cervical pathology and should not be confused with impingement syndrome. The shoulder contours and musculature should be compared to the contralateral shoulder observing for any muscle atrophy or squaring of the shoulder girdle. Changes in the resting position, contours, or atrophy of shoulder musculature indicate a possible neurological cause for abnormal shoulder motion resulting in secondary impingement. Tenderness localized to the subacromial bursa and rotator cuff, anterior and anterolateral to the acromion, and along the coracoacromial ligament is a common finding noted in patients who have extrinsic impingement syndrome.

Active forward flexion and abduction of the shoulder are frequently limited secondary to pain. A painful arc of motion between 60° and 120° of active forward elevation in the plane of the scapula is indicative of impingement. The patient often reports pain or painful catching in the shoulder. This test has a sensitivity of 73.5% and specificity of 81.1% [27]. However, passive range of motion must be tested to adequately assess terminal pain in

forward flexion and/or abduction to ensure that the diagnosis of adhesive capsulitis is not made in error.

Strength testing may also be limited due to pain and may suggest rotator cuff dysfunction, specifically with supraspinatus and infraspinatus testing differentiated with a lidocaine test. The infraspinatus muscle test also has diagnostic value, as it has a sensitivity of 41.6% and specificity of 90.1% [27]. This test is performed with the arm at the side, and the elbow flexed to 90° elicits pain when the patient resists against an internal rotation force. Subtle dynamic scapular winging of the shoulder during range of motion may be present. This denotes scapular dyskinesis, although it will not distinguish impingement as a primary or secondary condition.

A diagnostic lidocaine anesthetic injection into the subacromial space can improve the accuracy of the diagnosis of subacromial impingement syndrome. We instill 10 mL of 1% lidocaine using a 25-gauge, 1½-inch needle into the subacromial space through an anterior approach. Ultrasound can be used as an adjunct to guide the needle to ensure accuracy. Alternatively, the needle can be placed 1 cm inferior to the posterolateral corner of the acromion directed toward the coracoid. Provocative maneuvers should be performed following the injection to confirm the diagnosis. Alleviation of symptoms on impingement tests is highly indicative of subacromial impingement syndrome. The authors believe that a 1½-inch needle is essential if using a posterior approach to avoid a false-negative result. The accuracy rates (60–90%) of the anterior, lateral, and posterior approaches to subacromial bursa injections are not significantly different [28, 29].

Several tests are essential to include in physical examination to aid in the diagnosis of subacromial impingement syndrome. The Neer impingement sign causes provocation of pain at the anterolateral edge of the acromion when the examiner passively forward flexes the arm greater than 120° with the humerus internally rotated and the scapula stabilized (Fig. 11.3). The Neer sign has a sensitivity and specificity of 68.0% and 68.7%, respectively [27]. Hawkins and Kennedy also described an alternative

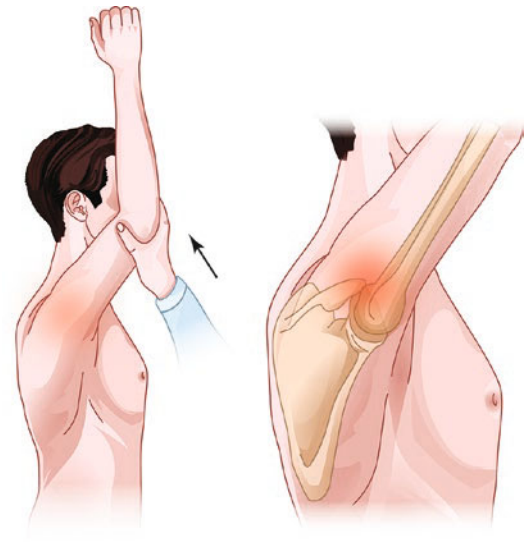


Fig. 11.3 Neer impingement sign. The examiner stabilizes the scapula and passively flexes the arm greater than 120° with the arm internally rotated. Provocation of pain at the anterolateral edge of the acromion is indicative of subacromial impingement. Copyright Kevin D. Plancher

impingement test which elicits symptoms when the arm is placed in 90° forward elevation and then gently internally rotated (Fig. 11.4). The Hawkins-Kennedy sign has a sensitivity and specificity of 71.5% and 66.3%, respectively [27]. Both sensitivities increase when patients without underlying rotator cuff disease are excluded. These impingement tests place the greater tuberosity, rotator cuff, or biceps tendon against the undersurface of the acromion or coracoacromial ligament causing aggravation of an inflamed bursa. The likelihood of a diagnosis of impingement is >95% when a specific battery of tests is positive including the Hawkins-Kennedy impingement test, painful arc, and infraspinatus test [27]. When this battery of tests is negative, the likelihood of impingement is <24%.

11.4 Diagnostic Imaging

The specificity of special tests on physical examination is low; therefore, imaging of the shoulder should also be utilized in the diagnostic process

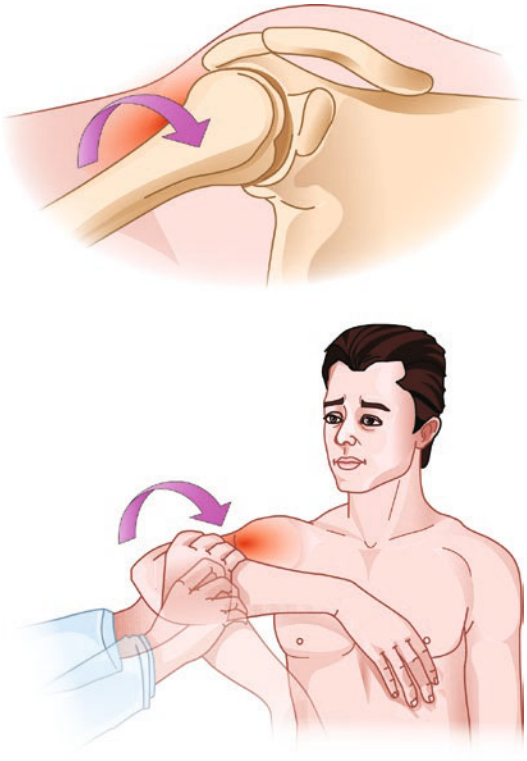


Fig. 11.4 Hawkins-Kennedy impingement test. The patient's arm is positioned in 90° of forward elevation with the elbow flexed to 90°. The examiner then gently internally rotates the arm. Provocation of pain at the anterolateral edge of the acromion is indicative of subacromial impingement. Copyright Kevin D. Plancher

in order to make an accurate and complete assessment of the underlying pathology [19]. Radiographs can aid in evaluating the concavity of the undersurface of the acromion and assessing for the presence of subacromial spurs and for the presence of degenerative changes at the greater tuberosity, the acromioclavicular joint, or the anterior acromion. A supraspinatus outlet view radiograph is best to evaluate acromial shape. The scapular outlet view, on the other hand, best evaluates the anteroinferior acromion (Fig. 11.5). This view is a true scapulolateral with the x-ray tube angled 5°–10° caudally. An AP view of the shoulder with the x-ray tube angled 30° caudally can also be used to evaluate the anteroinferior acromion as well as for the presence of a calcified coracoacromial ligament

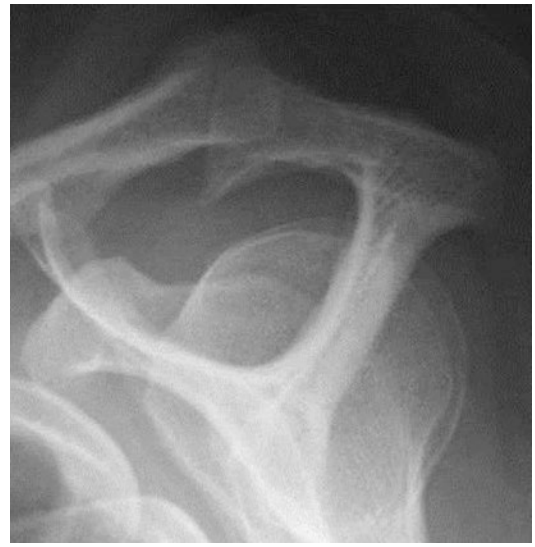


Fig. 11.5 Scapular outlet view demonstrating a type III, hooked, acromion. The scapular outlet view best evaluates acromial morphology. Copyright Kevin D. Plancher

(Fig. 11.6). This AP caudal tilt view has been shown to have the highest interobserver reliability [30].

This radiographic series is extremely useful in surgical planning to determine the amount of undersurface of the acromion to be surgically resected to establish a flat acromion. A study by Kitay et al. demonstrated that the distance from the acromial cortex to the end of the acromial spur on x-ray significantly correlated with intraoperative spur length [30]. Acromial slope is a line drawn on the undersurface of the acromion and another line connecting the posteroinferior border of the acromion with the inferior border of the coracoid and can be measured on either the supraspinatus outlet view or the caudal tilt view. Acromial slope has been shown to correlate with intraoperative acromial thickness; however, there does not appear to be a relationship between acromial slope and impingement syndrome or rotator cuff tear [30–32]. Therefore, the authors believe these views should be included in routine radiographic evaluation and surgical planning when presented with suspected subacromial impingement or rotator cuff involvement prior to acromioplasty. Magnetic resonance imaging (MRI) can also be useful to evaluate the bony pathology associated

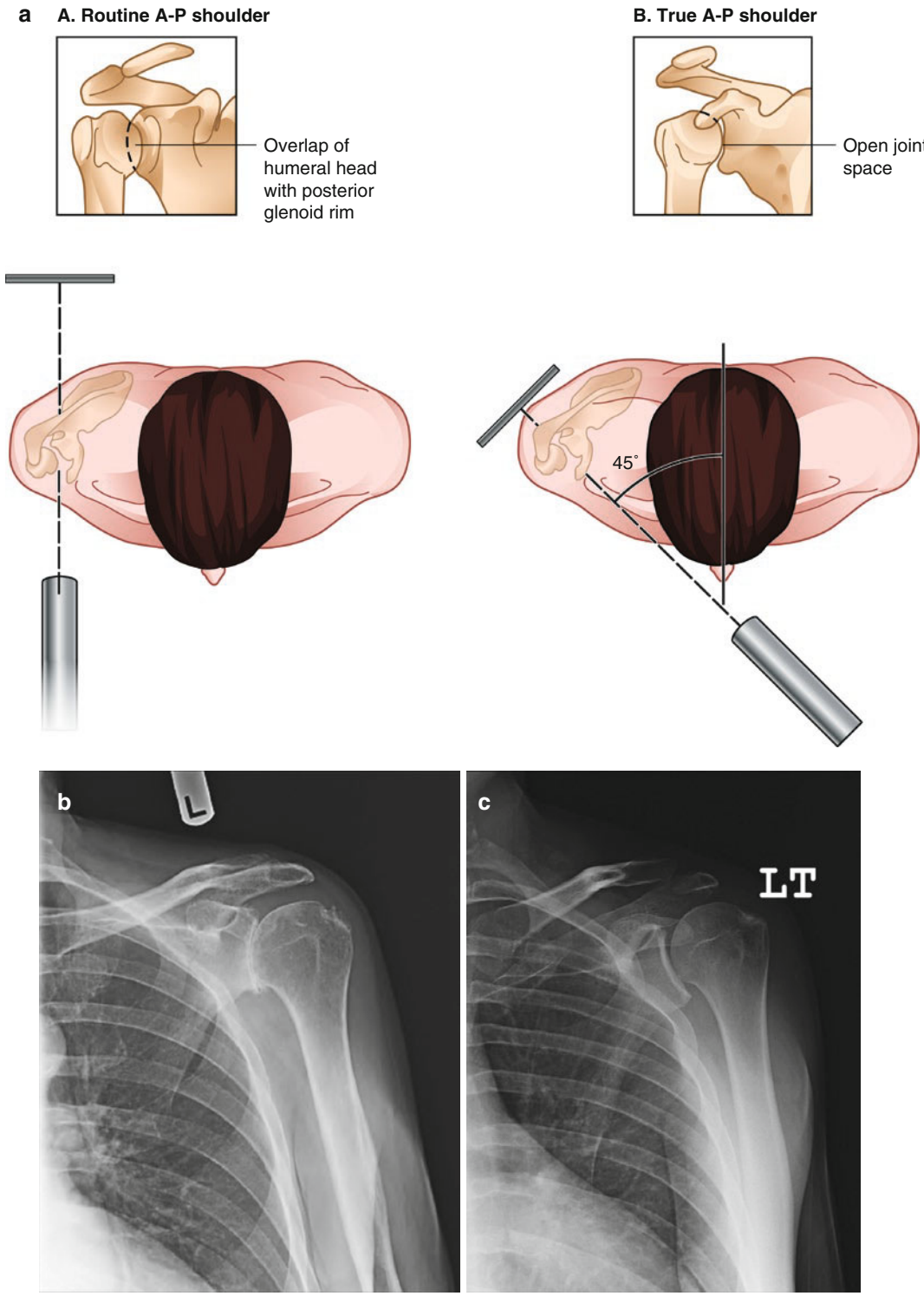


Fig. 11.6 (**a**) Artwork demonstrating the difference and correct way to obtain a true versus routine AP view of the shoulder. (**b**) Routine AP in a left shoulder. (**c**) True AP (Grashey) in a left shoulder. Copyright Kevin D. Plancher

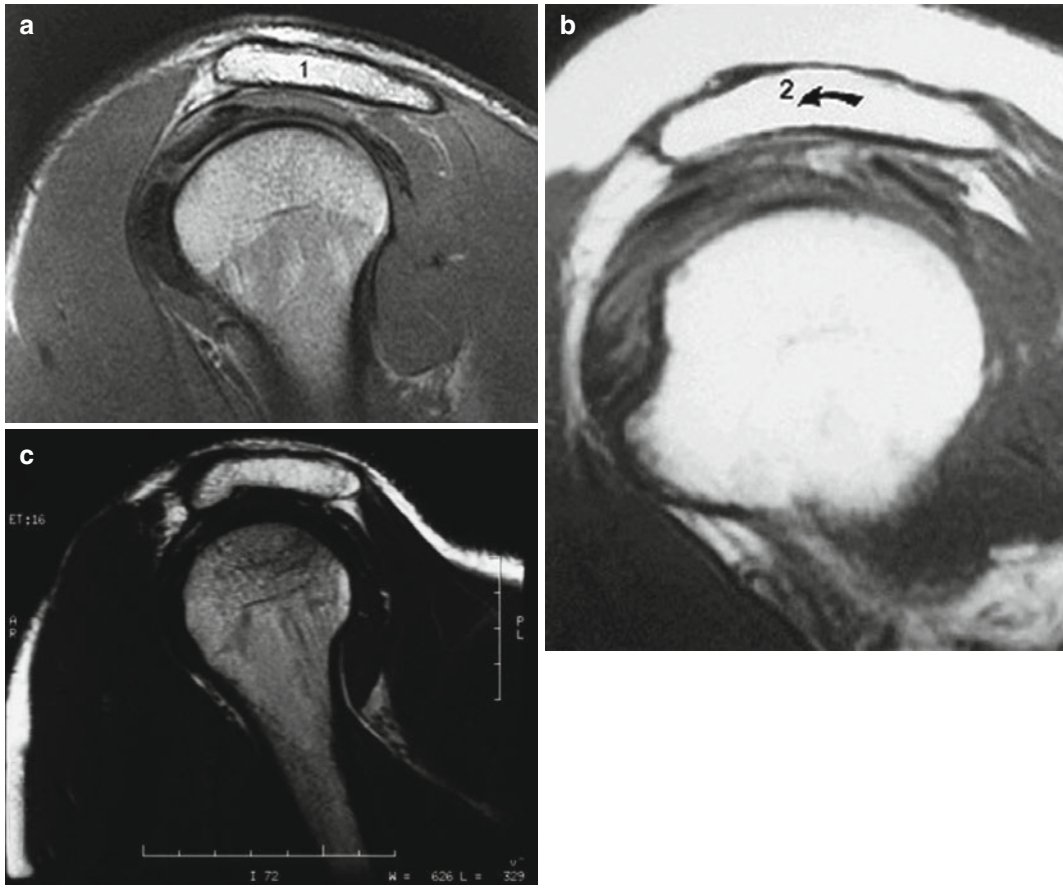


Fig. 11.7 MRI evaluation of acromial morphology. (**a**) Type I, flat. (**b**) Type II, curved. (**c**) Type III, hooked. Copyright Kevin D. Plancher

with rotator cuff pathology and assess the subacromial-subdeltoid bursa. Evaluation of subacromial spurs as well as for the presence of a type III or hooked acromion is best visualized on the coronal or sagittal oblique cuts (Fig. 11.7). Small spurs appear black (hypointensity) on T2-weighted images, whereas larger spurs appear as high signal on both T1-weighted and T2-weighted images because they contain marrow. Degenerative changes of the acromioclavicular joint can also be visualized on MRI, indicated by hypertrophy of the joint capsule as a medium signal intensity surrounding the acromioclavicular joint on pulse sequences with short repetition time (TR) and short echo time (TE). Changes in the subacromial-subdeltoid bursa and peribursal fat are signs of a rotator cuff tear as a complete tear allows extension of intra-articular fluid in the bursa. This is represented as high signal intensity or white within the bursa on T2-weighted images. The use of ultrasound, computed tomography (CT), and MRI have been shown to be reliable methods for measuring acromiohumeral distance [33]. The normal acromiohumeral distance is approximately 10.5–11 mm and is smaller in females compared to males [34, 35]. The distance is also dependent on arm position and has been shown to be smallest (8.1–9.9 mm), when the arm is flexed to 90° and in neutral rotation and is largest in positions of internal rotation (range 11.2–12.2 mm) [35, 36].

Additionally, an acromiohumeral distance less than 7 mm has been correlated with a complete rotator cuff tear [20, 24, 37–39].

11.5 Treatment Options

Conservative treatment is the preferred initial treatment in patients with isolated impingement syndrome though it is important to note that this process can be complex and prolonged [40, 41]. The goal is to limit inflammation while preserving range of motion. The offending overhead movement should be identified and limited to help symptoms resolve. Nonsteroidal anti-inflammatory medications and modalities such as ice, heat, iontophoresis, and ultrasound are beneficial in reducing inflammation and should be started early in the course of treatment. Physical therapy that includes range of motion, scapular positioning and stabilization, and specific strengthening exercises should be implemented once symptoms begin improving [40, 42, 43]. Decreased soft tissue flexibility must be addressed, and strength inadequacies must be restored in order to promote appropriate muscle activation patterns in functional sequences [41]. Specifically, tightness of the upper trapezius, pectoralis minor, and latissimus dorsi can inhibit the lower trapezius. Additionally, glenohumeral derangement can also inhibit the scapular musculature and therefore must be carefully evaluated in order to promote normal muscle activation and movement patterns. When strengthening the shoulder girdle, exercises should encourage activation of the lower trapezius and serratus anterior while reducing activation of the upper trapezius and be performed in functional positions.

An ultrasound- or landmark-guided corticosteroid with an anesthetic injection can be therapeutic and will often help reduce successfully bursal inflammation in most cases [40, 44]. Those patients that have recurrent symptoms after responding to the subacromial injections may need operative intervention. In contrast, patients that have a concomitant pathology and secondarily develop impingement syndrome will be unlikely to respond to conservative treatment.

11.6 Operative Treatment of Impingement Syndrome

Operative intervention is suggested for patients that do not respond to a prolonged course of conservative treatment or have a recurrence of symptoms after initial improvement. Patients with symptoms of impingement that fail to receive any relief of symptoms after subacromial injection require further diagnostic workup before proceeding with any operative intervention. The indications for subacromial decompression are:

1. Structural abnormalities causing extrinsic impingement (type II or III acromion, hypertrophic coracoacromial ligament, inferior spur from the acromioclavicular joint, or hypertrophic subacromial bursa).
2. Patients that fail a minimum of 3-month nonoperative management but have previously responded to subacromial injections.
3. Patients undergoing debridement of bursal-sided partial rotator cuff tears.
4. Patients having a rotator cuff repair.

Acromioplasty and release of the coracoacromial ligament are contraindicated in patients with massive or irreparable rotator cuff tears and shoulder instability. The release of the coracoacromial ligament during acromioplasty increases the risk of anterior and superior glenohumeral translation after release and increases the demand on the rotator cuff to maintain glenohumeral biomechanics [45]. Therefore, in patients with a massive, irreparable rotator cuff tear, there is a significant concern of superior escape, and acromioplasty with release of the coracoacromial ligament should be avoided. Performing an acromioplasty as an adjunct to subacromial bursal debridement in patients with adhesive capsulitis is controversial and beyond the scope of this chapter.

In patients with shoulder instability and changes in the subacromial space, a subacromial decompression is indicated in conjunction with the primary superior labral repair [38]. However, the differential diagnosis is important. Subacromial decompression is contraindicated in patients with internal impingement, e.g., throwers, as this could lead to further destabilization and a worsening of symptoms [38].

Arthroscopic subacromial decompression may be performed in the setting of rotator cuff repair in order to enhance visualization for the surgeon; however, most studies suggest that subacromial decompression in these patients offers no clinical benefit over repair alone [46, 47]. However, some studies have suggested that patients with primary impingement and articular-sided partial supraspinatus tears (e.g., type 1 or 2) demonstrate good results with subacromial decompression alone, without concomitant repair, if the tear size is less than 50% of tendon thickness [48, 49]. Subacromial decompression alone is typically contraindicated in patients that demonstrate superior migration of the humerus on AP radiographs as the result of insufficient force couples and anterior-superior escape as previously explained. Removing a portion of the acromion and releasing the coracoacromial ligament in these patients increase the risk of loss of superior containment of the humeral head [38].

Arthroscopic subacromial decompression is a safe and efficacious procedure to treat subacromial impingement syndrome. Resection of the anteroinferior acromion and subacromial bursa and release of the coracoacromial ligament all lead to an increase in volume of the subacromial space. The anatomy of the subacromial bursa can make it difficult for the surgeon to navigate because of the lack of easily identifiable landmarks. Furthermore, its weak ligamentous capsule can lead to fluid extravasation into the muscle and subcutaneous envelope of the shoulder. Therefore, surgical time should be limited, and the fluid pump pressure and flow should be kept to a minimum.

For optimal visualization of the subacromial bursa, the arm should be positioned in 20° of abduction and 5° of forward elevation. Less than 15 pounds (6.8 kg) of traction are needed to move the greater tuberosity inferiorly and laterally out of the way to open the subacromial space if being performed in the lateral decubitus position [35, 50]. If performed in the beach chair position, traction is not needed to improve visualization of the subacromial space. To perform a diagnostic bursoscopy, the arthroscopic cannula should be placed into the posterior portal aiming for the posterolateral border of the acromion and advanced to the posterior acromial edge. The 30° arthroscope is inserted into the subacromial space and directed to the tip of the cannula. A radiofrequency device can be used to ablate and debride the bursal adhesions and the posterior bursal curtain (posterior "veil of tears"). Visualization can be hindered throughout the procedure without debridement of this posterior bursal curtain. A medial to lateral "sweep" is performed from the medial border of the acromion to the level of the lateral portal to break up any bursal adhesions and create a "room with a view."

In order to delineate the subacromial space and widen it, the anterior and lateral borders of the acromion should be defined, and the undersurface of the acromion should be debrided using a radiofrequency device. The remaining bursa can then be debrided using a full-radius motorized shaver (Fig. 11.8). Caution should be taken

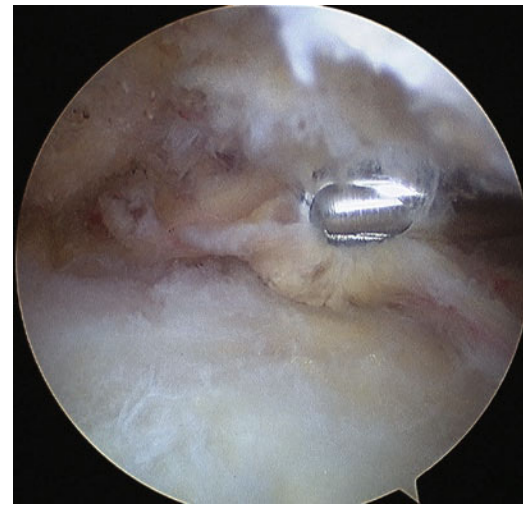


Fig. 11.8 Arthroscopic view using an arthroscopic shave to completely debride the subacromial bursa. Copyright Kevin D. Plancher

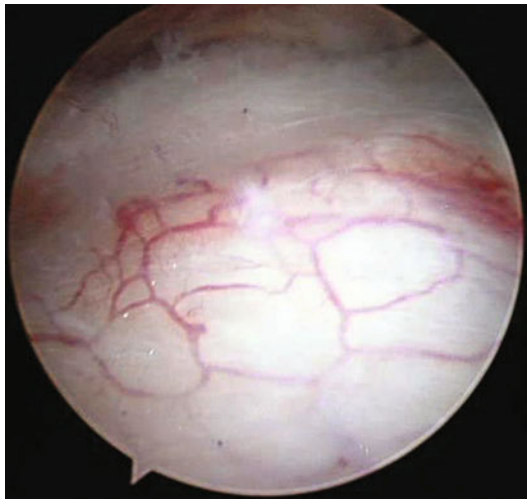


Fig. 11.9 Arthroscopic view showing the blood vessels on the superior aspect of the rotator cuff signifying a bursectomy has been performed. Copyright Kevin D. Plancher

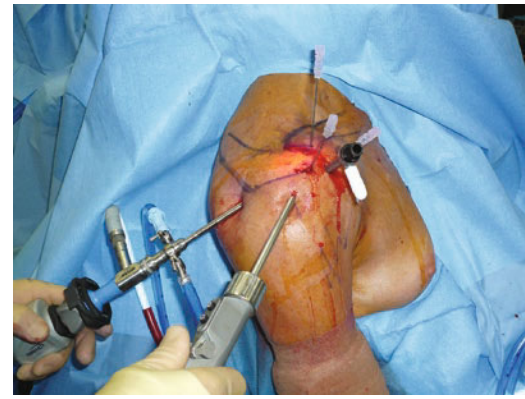


Fig. 11.10 Subacromial decompression, lateral technique. The arthroscope is placed in the posterior portal and the burr in the lateral portal. The burr is parallel to the front of the acromion to begin the acromioplasty. Copyright Kevin D. Plancher

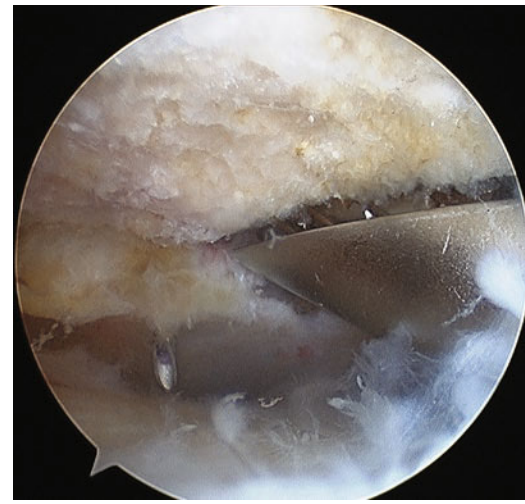


Fig. 11.11 Subacromial decompression, lateral technique. Arthroscopic view of the burr buried the diameter of the burr. The remainder of the acromioplasty will be based off the depth set during this step. Copyright Kevin D. Plancher

when resecting the medial bursal tissue to avoid disruption of its blood supply (Fig. 11.9). The use of the motorized shaver medial to the supraspinatus myotendinous junction should be avoided due to bleeding. When releasing the coracoacromial ligament, bleeding from the acromial branch of the thoracoacromial artery may be avoided and if needed subsequently should be ablated with a radiofrequency device. The coracoacromial ligament should be performed at the most lateral aspect to avoid this vessel.

To gain a better appreciation of the acromial morphology especially with a type III or hooked acromion, visualization from the lateral portal is best. A 6.0 mm oval hooded burr is placed through the lateral portal and oriented along the anterior border of the acromion (Fig. 11.10) [39]. A 4.0 mm burr should be utilized for smaller individuals. The depth of the acromial resection is established by burying the burr to the diameter of the burr (Fig. 11.11). The resection is begun just lateral to the acromioclavicular joint to avoid violation of the acromioclavicular joint capsule. Once the extent of the most anterior resection is established, the remaining hook of the acromion is resected until the acromion is flat (Fig. 11.12).

The arthroscope is placed underneath the acromion staying in a plane parallel to the acromion. Scraping the trochar of the arthroscope directly under the acromion is avoided as the cannula may end up above the bursa. Conversely, aiming the trochar inferiorly may penetrate the infraspinatus and miss the bursa inferiorly. The cannula is aimed toward the anterior and middle (anterior to posterior) third of the acromion because the subacromial bursa is located in the anterior half of the subacromial space in front of the orientation line drawn at the beginning of the case.

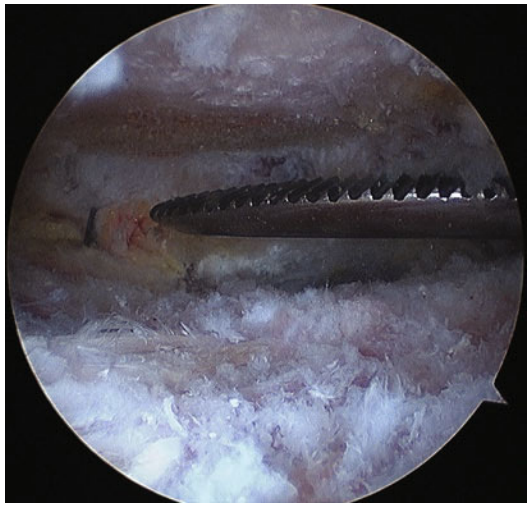


Fig. 11.12 Arthroscopic view of co-planed acromion after completed acromioplasty. Copyright Kevin D. Plancher

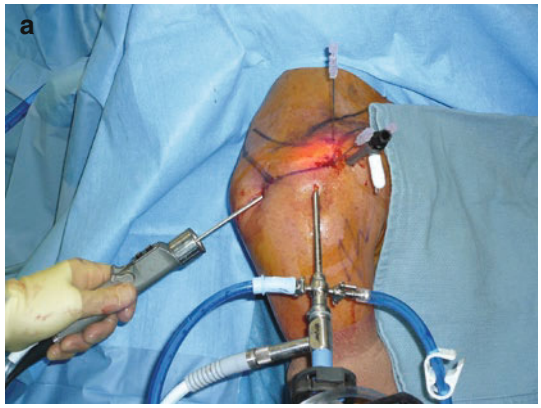
If an inside-out portal is desired to be created anteriorly, a long guide rod can be inserted to palpate the coracoacromial ligament. The rod is gently placed underneath the coracoacromial ligament and out through the anterior-superior portal. An outflow cannula is placed over the guide rod back into the bursa in a retrograde manner. The arthroscope and camera are inserted in to the trochar and the pump is turned on. The distended bursal space should immediately open up into "a room with a view." If the muscle or fatty tissue is seen, the instruments are removed, and the steps are repeated until a bursal view is achieved. If you continue to have difficulty, the shaver is placed into the anterior portal, and the bursa is carefully removed, aiming the blades superiorly toward the acromion and away from the rotator cuff tendons.

Alternately, an outside-in portal can be made laterally in the middle third of the acromion as previously described. The shaver is introduced, and resection of the bursa is completed in a routine fashion [51].

The posterior, "cutting block," approach, popularized by many, is another alternative to the lateral approach for subacromial decompression [24]. The posterior portal is created 1–2 cm superior and slightly lateral to the usual posterior portal for glenohumeral arthroscopy which is too low and could therefore increase the risk of overresection of the anterior aspect of the acromion (Fig. 11.13). A 6.0 mm oval burr, or a 4.0 mm burr in smaller individuals, is placed into the posterior portal, and the arthroscope is placed in the lateral portal at the "50-yard line" for adequate visualization. Co-planing of the acromion is initiated at the posterior border of the clavicle and advanced forward to the anterior border of the acromion using the undersurface of the posterior acromion as the "cutting block." Each pass of the burr serves as a guide for each subsequent pass, beginning at the medial acromion moving laterally toward the lateral border (Fig. 11.14). The AC joint capsule should never be violated unless an infraclavicular spur is noted on preoperative x-rays. The hooded portion of the burr can be used as a guide to assess the "flatness" of the acromioplasty (Fig. 11.15). The arthroscope is placed in the posterior portal to check the lateral edge of the acromion for any remaining spurs. A nasal rasp introduced through an arthroscopic portal can be used as a reference to ensure the surface of the acromion is flat.

11.7 Postoperative Rehabilitation Protocol

Immediately postoperatively, we place all patients in a sling. For isolated subacromial decompression, we encourage early motion and physical therapy. On the first postoperative day, all dressings are changed, and patients are encouraged to begin Codman exercises and gentle active and passive range of motion. By the end of the first week, patients are weaned from the sling and encouraged to return to daily activities as tolerated. During the subsequent weeks, progressive strengthening of the shoulder girdle and scapular stabilization are encouraged. We allow return to full activities once the patient is pain-free and has 90% strength of the contralateral shoulder. For patients that undergo a procedure for concomitant pathology, the postoperative rehabilitation protocol is based on the protocol for that procedure.



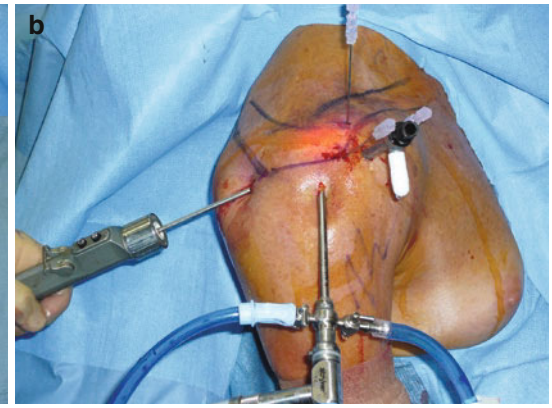


Fig. 11.13 Subacromial decompression, cutting block technique. (**a**) The burr in the posterior portal is positioned too vertical increasing the risk for overresection of the anterior acromion. (**b**) The burr can be oriented parallel to the posterior acromion using the alternate posterior portal placement described allowing the posterior acromion to be used as a cutting block. Copyright Kevin D. Plancher

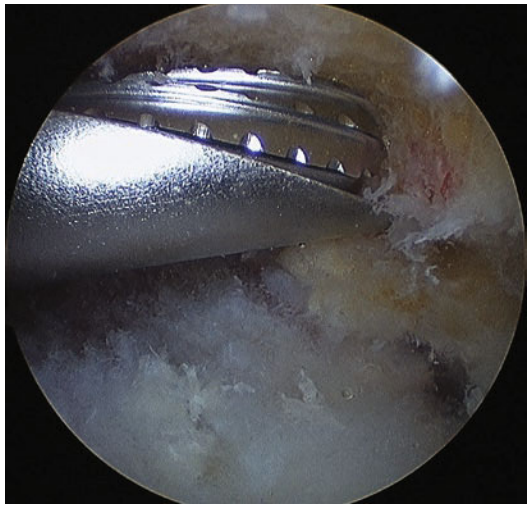


Fig. 11.14 The posterior acromion is used as a cutting block guide. Each pass of the burr serves as a guide for each subsequent pass, beginning at the medial acromion moving laterally toward the lateral border. Copyright Kevin D. Plancher

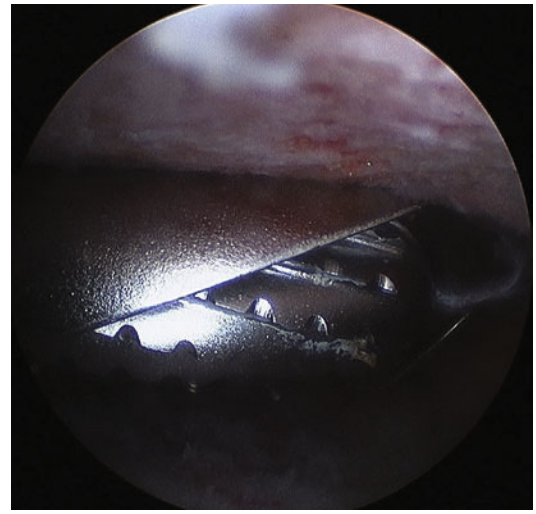


Fig. 11.15 The hooded portion of the burr can be used to assess the flatness of the acromioplasty. Copyright Kevin D. Plancher

11.8 Complications

Complications from an arthroscopic subacromial decompression can be limited by proper patient selection and diligent preoperative planning. Performing an isolated subacromial decompression in patients with concomitant glenohumeral pathology or shoulder instability will more often than not fail treatment and result in persistent symptoms. Failures can be limited by a meticulous history and thorough physical exam and proper diagnosis and confirmed by performing a lidocaine test. Preoperative evaluation of the radiographs is essential to understanding the topography

of the acromion and any osteophytic spur that should be resected. Proper posterior portal placement is imperative to avoid under- or overresection of the acromion when using the cutting block technique. The placement of a posterior portal 1–2 cm superior and slightly lateral to the standard posterior portal can minimize this complication. Other complications include deltoid detachment from an overzealous anterior or lateral resection, infection, postoperative stiffness, and failure to identify a symptomatic os acromiale.

11.9 Outcomes

Overall, satisfactory results have been reported in 67–88% of patients undergoing arthroscopic subacromial decompression for impingement, comparable to outcomes reported by Neer using an open technique [52–56]. However, studies describing long-term outcomes of treatment of patients with shoulder impingement are still rather rare, and the results tend to be controversial. Some studies suggest overall clinical benefit from surgical treatment [37, 52], while others suggest nonoperative treatment with physical therapy is equally efficacious [42, 57–60].

In a randomized study by Farfaras et al. in 2018, 87 patients with subacromial impingement syndrome underwent either open acromioplasty, arthroscopic acromioplasty, or physical therapy alone [37]. Patients had persistent subacromial pain for greater than 6 months and failed a course of conservative treatment including unstructured physical therapy, nonsteroidal anti-inflammatory medication, and local corticosteroid injection. Outcomes were measured using the Constant score, the Watson and Sonnabend score, and the 36-Item Short Form Health Survey as well as ultrasound examination to detect rotator cuff tears or shoulder osteoarthritis (OA). Both the arthroscopic and open acromioplasty groups had improved functional outcomes at 10-year follow-up, though these improvements were not seen in the physical therapy group. Six percent of patients in the open group, 7% of patients in the arthroscopic group, and 14% of patients in the physical therapy group had a full-thickness rotator cuff tear at follow-up, and 15% of patients in the open group, 7% of patients in the arthroscopic group, and no patients in the physical therapy group had shoulder OA at follow-up, though none of these differences were statistically significant. Other studies have also shown similar outcomes with arthroscopic subacromial decompression with improved functional and pain scores for at least 6 years after surgery [52].

On the contrary, a multicenter, randomized, placebo-controlled trial by Beard et al. in 2018 investigated the effectiveness of arthroscopic subacromial decompression, diagnostic arthroscopy, and no treatment in 313 patients with persistent subacromial pain for greater than 3 months [57]. While both surgical groups had statistically improved pain and functional outcomes compared to the no-treatment group at 12-month follow-up, these differences were not clinically meaningful, calling into question the value of isolated decompression in these patients [56]. Similarly, Paavola et al. showed no difference between arthroscopic subacromial decompression and diagnostic arthroscopy in pain and functional outcomes at 24 months in patients with shoulder impingement syndrome [58]. Furthermore, while the arthroscopic subacromial decompression group had statistical improvements in pain compared to the exercise therapy group, these differences did not reach the minimal clinically important difference. Other studies have also shown the positive benefit of physical therapy suggesting eccentric rotator cuff strengthening and eccentric and concentric scapular stabilization for at least 3 months [42, 43, 59–61].

Few studies have reported return to work after subacromial decompression. Return to full duty occurs on average 6–12 weeks postoperatively, though manual laborers are reported to have longer periods of sick leave compared to nonmanual laborers [62–65]. Return to preoperative hobbies and preoperative work have been reported in 79% and 76% of patients, respectively [64].

11.10 Conclusion

Both the lateral and cutting block techniques for arthroscopic subacromial decompression are safe and efficacious methods to treat impingement

syndrome with results equivalent to open surgical techniques, though we prefer the lateral technique because it is less dependent on portal placement. A structured physical therapy program with concentric and eccentric strengthening of the rotator cuff and scapular stabilizers should be pursued for a minimum of 3 months to aid in surgical decision-making and to help identify those patients requiring surgical intervention for persistent subacromial pain. We believe with proper patient selection, careful preoperative planning, and meticulous surgical technique, impingement syndrome can be safely treated arthroscopically with low morbidity and rapid return to activities.

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12 Arthroscopic Acromioclavicular Joint Resection

Taku Hatta and Eiji Itoi

12.1 Introduction

The acromioclavicular (AC) joint connects the scapula and the clavicle, supporting the upper limb girdle on the thorax. Osteoarthritis of the AC joint frequently occurs in the adult population, especially in the fourth decade. For patients of AC joint osteoarthritis resistant to conservative treatment, AC joint resection has been considered the gold standard. In addition to conventional open procedure, arthroscopic procedure has gained popularity due to potential advantages of quick return to activities and lower rate of complications.

12.2 Epidemiology of Acromioclavicular Joint Osteoarthritis

DePalma [1] described that the degenerative features of the AC joint could be a natural consequence of aging, beginning in the second decade. Needell et al. [2] investigated magnetic resonance (MR) images of the AC joint in 100 asymptomatic volunteers ranging from 19 to 88 years of age and found osteoarthritic changes with the prevalence of 39% in those younger than 40 years, 89% in those aged 40–60 years, and 90% in those aged 60 years or over.

Edelson [3] investigated the pattern of degenerative changes of AC joints in 280 dry bone skeletons. They revealed consistent patterns of degeneration in the joint: an anteroposterior elongation of the joint on the acromial side, broadening and rounding of the distal clavicle in the anteroposterior direction, and inferior projecting osteophytes during the progression of osteoarthritis of the AC joint. Hatta et al. [4] investigated the histological features of 38 cadaveric AC joints aged between 69 and 91 years, to evaluate the localization of arthritic changes in the joints. They found the consistent findings that the lower half of the AC joint is more subject to advanced degeneration of the articular cartilage and the intra-articular disk than the upper half.

12.3 Symptoms

The most common symptom in patients with AC joint osteoarthritis is pain on the AC joint. Especially, the pain can be induced or enhanced with the arm in forward flexion, cross-body adduction, and/or internal rotation in abduction. It is known that these positions provide the narrowing of the AC joint which results in increased pressure in the joint, whereas, arthroscopic observation reveals various narrowing patterns among these positions. Anterior joint space often

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becomes narrow with arm in cross-body adduction; in contrast, posterior joint space becomes narrow with forward flexion and internal rotation in abduction. Accordingly, it is notable that painful position may change according to the location of osteoarthritic changes in the AC joint.

12.4 Diagnosis

In addition to characteristic arm positions which induce the pain as described above, the tenderness over the AC joint is helpful to detect pain from the AC joint. Several provocative tests which indicate the AC joint pathology have been advocated, such as the cross-body adduction stress test, the active compression test, the Buchberger test, and the Paxinos test. Of these, some maneuvers have been evaluated for their sensitivity and specificity (Table 12.1).

The cross-body adduction stress test is a well-known maneuver to induce AC joint pain, which was described by McLaughlin [5]. The examiner passively elevates the arm to 90° forward flexion and brings the arm in horizontal flexion. This test is considered positive if it reproduces pain at the AC joint.

The active compression test comprises two steps of the maneuver [6]. In the first maneuver, the examiner asks the patient to elevate the arm forward with full extension of the elbow and maximal pronation of the forearm. An inferiorly directed force is applied to the arm to evaluate the pain at the AC joint. In the second maneuver, the force is released, the forearm is fully supinated, and the force is applied again. The test is considered positive if the pain is induced during the first maneuver and reduced or disappeared during the second maneuver.

The Buchberger test combines inferiorly directed force to the lateral clavicle with passive forward flexion of slightly adducted and externally rotated arm [7]. For the Paxinos test, the examiner places a thumb on the posterolateral acromion and the index and/or the middle finger on the superior aspect of the mid-clavicle and then squeezes the thumb and fingers together [8]. Both tests are considered positive if the pain is induced or intensified at the AC joint.

Table 12.1 Accuracy of clinical tests

	Sensitivity (%)	Specificity (%)
Tenderness on the acromioclavicular joint	96	10
Provocative tests		
Active compression	16–100	90–97
Cross-body adduction	77	79
Paxinos test	79	50

12.5 Radiologic Assessment

Because of the high prevalence of age-related changes of the AC joint regardless of symptoms, radiologic assessment may be very difficult to make a diagnosis of AC joint osteoarthritis. Especially in plain radiographs, we should note degenerative findings including the joint narrowing, spur formation with sclerotic changes relatively consistent patterns of asymptomatic AC joint by the fourth decades. The primary aim of computed tomography is to achieve more accurate assessment of the morphology of the distal clavicle and the acromion. Magnetic resonance imaging could be helpful to detect fluid collection or reactive bone edema in the distal clavicle and acromion. Ultrasonography has been recognized as a useful diagnostic tool for AC joint pathologies [9, 10]. Especially, a dynamic provocative maneuver performed with ultrasonography can aid in detecting mild pathologies such as superior capsular bulging due to increased fluid in the AC joint [11].

12.6 Treatment

Symptomatic AC joint osteoarthritis may require conservative treatment including anti-inflammatory medications, physiotherapy, and intra-articular corticosteroid injection or surgical treatment for cases with failed conservative treatment. Since the initial reports by Mumford [12] and Gurd [13], open resection of the distal clavicle has been an

established technique for the treatment of symptomatic AC joint osteoarthritis. Arthroscopic distal clavicle resection has been recognized to provide similar results in terms of pain relief [14, 15]. A systematic review including 17 studies published from 1966 to 2008 demonstrated the arthroscopic distal clavicle resection would provide faster return to activities than the open procedure; in contrast, both procedures might result in similar long-term outcomes [16]. More recently, a database-based analysis described that the number of open procedures for the AC joint osteoarthritis had decreased among newly trained, board-eligible orthopedic surgeons [17]. They indicated that open resection could be associated with an overall higher surgical complication rate when compared with arthroscopic procedure (9.4% vs 7.6%, $P < 0.001$). Gaillard et al. [18] introduced a modified technique, bipolar AC joint resection, to gain a better visualization of the superoposterior part of the distal clavicle from the mid-lateral portal by extending a resection of the inferomedial part of the acromion.

12.7 Arthroscopic Acromioclavicular Joint Resection: Authors' Preferred Technique

The patient is in the beach chair position. In addition to the standard arthroscopic equipment, an electrical tissue ablator, a motorized burr, and a full-radius soft tissue resectors are prepared. Arthroscopic AC joint resection can be performed through two approaches; the lateral subacromial (indirect) approach and the superior (direct) approach. Because of minimal damages to the AC ligaments and the coracoacromial arch, we prefer to use the superior (direct) approach. First, an anterior portal is created just in front of the AC joint (Fig. 12.1). Through this portal, a needle is inserted into the joint to confirm the orientation of the joint space. Then, a Wissinger rod is inserted into the AC joint from the anterior portal and passed through the joint to create a posterior portal at the exit point of the rod. Through the posterior portal, an arthroscopy cannula is inserted into the AC joint along the Wissinger rod. Once the cannula is inside the joint, a standard 4.5-mm arthroscope is inserted through this cannula into the joint. The degenerated disk and proliferated synovia inside the AC joint are removed with use of the soft tissue resector inserted through the anterior portal. The electrical ablation device is also useful to remove the soft tissues and visualize the distal clavicle and the medial aspect of the acromion. Next, changing the arthroscope to the anterior portal and the soft tissue resector to the posterior portal, the debridement is continued until all the soft tissues inside the joint are removed (Fig. 12.2). It should be noted that the superior and inferior capsuloligamentous structures are completely kept intact during this procedure. After the debridement, the presence/absence of contact between the clavicle and the acromion is carefully observed both through the anterior and posterior views by moving the arm toward the three directions: forward elevation, cross-body adduction, and internal rotation in abduction. This "dynamic assessment" is considered important to determine the optimal amount and area to be resected.

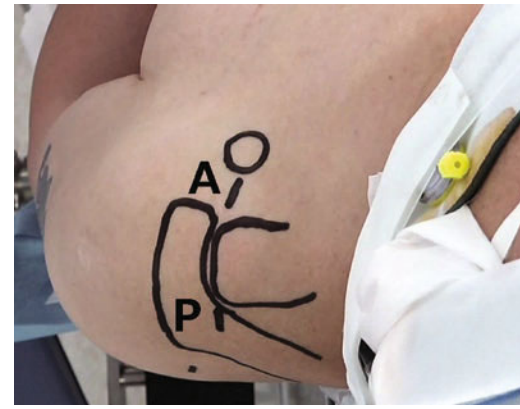

Fig. 12.1 Anterior and posterior portals. The anterior portal (A) is directly anterior to the AC joint, and the posterior portal (P) is directly posterior to the AC joint

Excision of the distal clavicle and the acromion begins with the burr through the posterior portal because this is the narrowest part of the joint. To date, several studies investigated to address the optimal amount of resection without damaging capsuloligamentous structures of the AC joint. Renfree et al. [19] investigated the

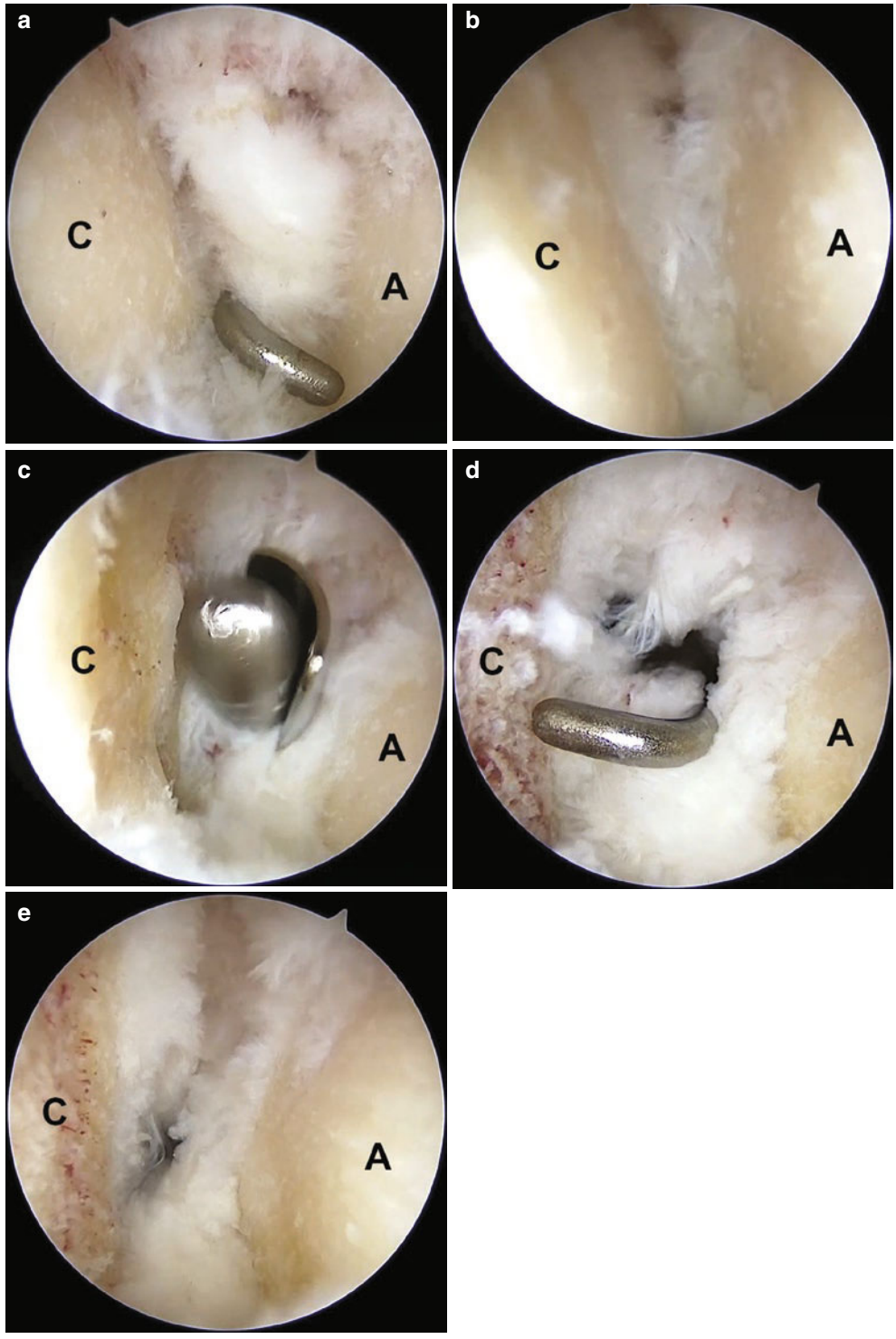

Fig. 12.2 Anterior portal view of the AC joint. (**a**) After the soft tissues were removed, the posterior joint space was measured using the probe tip (5 mm). The posterior joint space was about 3 mm. *C* clavicle, *A* acromion. (**b**) Dynamic examination with the arm in abduction and internal rotation demonstrated the narrowing of the posterior joint space. (**c**) Mechanical burr was used for bone resection on both the clavicular side and the acromion side. (**d**) As the posterior joint space was about 7 mm, the amount of bone resection was about 4 mm. (**e**) The same dynamic examination as in (**b**) showed sufficient clearance between the two bones

insertion of the superior AC ligament and suggested a safety amount of the resection on the distal clavicle less than 5.2 mm in female and 7.6 mm in male and on the acromion less than 4.7 mm in female and 8.0 mm in male. Stine and Vangsness [20] investigate the AC joint capsular insertion on the anterior, posterior, superior, and inferior edges and concluded that a safe amount of resection should be 2–3 mm of the medial acromion and 3–4 mm of the distal clavicle to avoid damaging the capsular attachments. Our goal is to achieve the loss of abutment; therefore, we gradually increase the amount of bone resection from both the clavicle and acromion until the dynamic examination revealed no more abutment between these two bones. At this point, the amount of resection is usually 3–4 mm on the clavicular side and 1–2 mm on the acromion side.

Postoperatively, the arm is kept in a sling for a week. Active motion is allowed within the range of comfort. As the pain decreases, active and passive range of motion exercise is started. After 3 weeks, muscle strengthening exercises are started.

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13 Scapulothoracic Disorders and Nonsurgical Management of the Impingement

Takayuki Muraki and Eiji Itoi

13.1 Indication of Scapular Exercises

Scapulothoracic disorders are generally manifested by abnormal scapular position or motion. Several previous studies reported differences of scapular motion during shoulder motion between patients with shoulder impingement and healthy subjects [1–10]. Frequent findings in patients with subacromial impingement are decreased scapular upward rotation, posterior tilt, and external rotation of the scapula [11, 12], whereas patients with posterosuperior impingement showed increased scapular elevation and posterior tilt [13]. However, there are no clear diagnostic criteria for "abnormal" scapulothoracic condition to be treated because of the following reasons. First, asymmetry of scapular position per se does not necessarily mean that it is pathologic because asymmetry is sometimes observed in asymptomatic subjects [14–16]. Second, characteristics of the scapular motions in patients with shoulder impingement are inconsistent among the literature. A systematic review regarding the relationship between subacromial impingement syndrome and scapular orientation has pointed out the lack of consistency in study methodologies and definition of shoulder impingement [17]. Third, it is unclear whether alterations of the scapular motion are causes or results of pain due to the impingement. Previous studies demonstrated that inducing or reducing subacromial pain affected the scapular motion [18–23]. A biomechanical study reported that reducing the posterior tilt of the scapula decreased subacromial contact pressure during glenohumeral elevation [24], which might lead to reduction of subacromial pain. Thus, reduced posterior tilt could be the result of impingement. On the other hand, it could be the cause of pain because it is the most frequent findings in patients with impingement [11]. As the scapular dyskinesis could be the cause or result of impingement, not all the scapular dyskineses in impingement patients are the indication for intervention to the scapulothoracic joint. If the alterations of the scapular motions are causes of pain due to impingement, the pain should be reduced when the altered scapular motion is corrected. In that case, correction of altered scapular motions is indicated as nonsurgical management of shoulder impingement.

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13.2 Definition of Scapular Motion

Scapular motion on the thorax consists of the scapular motion relative to the clavicle and the clavicular motion relative to the sternum.

13.2.1 Elevation/Depression

Scapular elevation and depression are superior and inferior translations of the scapula in the coronal plane, respectively. These motions are mainly produced by clavicular elevation and depression at the sternoclavicular joint.

13.2.2 Protraction/Retraction

Scapular protraction and retraction are anterior and posterior translations of the scapula in the sagittal plane, respectively. As the scapula moves on the rib cage, these motions are accompanied by internal and external rotations of the scapula, respectively. These motions are mainly produced by clavicular protraction and retraction.

13.2.3 Upward/Downward Rotation

Scapular upward/downward rotations occur around the axis perpendicular to the scapular plane. Depression and elevation of the superior angle of the scapula relative to the acromion indicate upward and downward rotations, respectively. These motions mainly occur at the acromioclavicular joint. In addition, clavicular elevation and depression usually accompany the upward and downward rotations.

13.2.4 Internal/External Rotation

Scapular internal/external rotations occur in the horizontal plane, mainly at the acromioclavicular joint. Scapular internal rotation accompanies the scapular protraction, and scapular external rotation accompanies the scapular retraction.

13.2.5 Anterior/Posterior Tilt

Anterior/posterior tilts of the scapula occur around the axis directed from the root of the scapular spine to the acromioclavicular joint.

13.3 Management Principles

First, scapular motion during painful shoulder motion should be observed. Once an altered scapular motion is detected, change of pain with correcting the scapular motion need to be examined. If a correction of the altered scapular motion reduces shoulder pain, it is a good indication of prescribing therapeutic exercises of scapular motion.

If a decreased scapular motion is the cause of pain, strengthening the agonist muscles and stretching/relaxing the antagonist muscles of the scapular motion are needed. On the other hand, if an increased scapular motion is the cause of pain, shoulder exercises focusing on relaxation of the agonist muscles need to be performed.

To obtain successful improvement of the altered scapular motion, factors affecting scapular kinematics should be managed. Poor posture of the thoracic spine, head, and shoulder can alter the scapular motions [25–27]. In addition, glenohumeral internal rotation deficit (GIRD) is associated with alternations of the scapular motions [28, 29]. If these factors are found, interventions to these factors are recommended before prescribing exercises to improve scapular dyskinesis.

Proper kinetic chain during whole-body movement is necessary for optimal shoulder motion, especially in overhead athletes. Sufficient strength, mobility, and stability of lower extremity and trunk can maximize function of the scapulothoracic joint. On the other hand, the scapulothoracic joint need to move appropriately and efficiently as a segment in kinetic chain from lower extremity or trunk. Therefore, patients need to perform scapulothoracic exercises simultaneously with leg and trunk motions simulating task-specific motion such as baseball pitching and tennis serving.

13.4 Assessment

13.4.1 Scapular Position/Motion

13.4.1.1 Visual Observation

Assessment of the scapulothoracic joint is conducted based on visual observations of scapular position/motion and comparison between involved and uninvolved sides. Three-dimensional motion analysis of the scapular motion is the most precise measurement method. However, this method is complicated and time-consuming for clinical use. Kibler [30] simply categorized a variety of altered scapular motions into three types.

Type 1 dyskinesis shows prominence of the inferior angle of the scapula representing increased anterior tilt of the scapula. Type 2 dyskinesis shows prominence of the entire medial border of the scapula representing increased scapular internal rotation. Type 3 dyskinesis shows prominence of the superior angle of the scapula representing increased scapular elevation and upward rotation. In some cases, these types are combined.

According to the previous biomechanical studies, patients with subacromial impingement tend to show types 1 and 2, whereas patients with posterosuperior impingement tend to show type 3.

13.4.1.2 Corrective Maneuvers

Corrective maneuvers of scapular motion are useful in deciding whether altered scapular motion is a cause of shoulder pain. Kibler [31] advocated scapular assistance test to determine contribution of upward rotation and posterior tilt to pain due to impingement. The examiner assists scapular upward rotation and posterior tilt by pushing the inferior medial border of the scapula laterally and upward when the patient elevates the arm (Video 13.1). Pain reduction and increased range of motion with this maneuver indicate that the test is positive, and it is most likely that the pain comes from the scapular dyskinesis.

Lewis [32] introduced the Shoulder Symptom Modification Procedure (SSMP) that systematically evaluates the influence of thoracic posture, scapular position, and humeral head position on shoulder symptom. For the assessment of the scapular position in the latest version of the SSMP, the examiner changes scapular position in three planes (elevation/depression, protraction/retraction, and anterior tilt/posterior tilt) during painful shoulder motion and then assesses changes of symptom (no change, worse, partial improvement, complete improvement) (Video 13.2) [33]. If a change of scapular position completely or partially relieves the shoulder symptom, interventions to maintain this change, such as exercises and manual techniques, should be prescribed.

13.4.2 Thoracic Posture

Although there is insufficient evidence for direct relationship between thoracic kyphosis and impingement pain [34], thoracic kyphosis can affect scapular motion. Previous studies reported that an increase in thoracic kyphosis could lead to elevation and anterior tilt of the scapula [35, 36].

Measurement of Cobb angle is a standard method for evaluating the thoracic kyphosis [26]. However, this measurement requires radiographic equipment. Instead, wall-occiput test [25] and measurement using inclinometer [27, 37], Debrunner kyphometer [38], or SpinalMouse® [39] are used as simpler clinical measures.

Similar to the assessment of the scapulothoracic joint, a corrective maneuver is useful in assessing the effect of the posture on shoulder pain. In the SSMP advocated by Lewis [33], the thoracic curvature is modified in flexion or extension of the spine during painful shoulder motion (Video 13.3). If the shoulder pain decreases with thoracic extension or flexion, intervention to the thoracic posture should be considered.

13.4.3 GIRD

The effect of the GIRD on scapular motion depends on the direction of shoulder motion. During elevation in the scapular plane, the GIRD is reported to decrease the scapular upward rotation and increase the scapular protraction [29].

Another study demonstrated an increase in anterior tilt of the scapula during internal rotation at 90° of flexion and abduction [28].

GIRD is assessed by measuring the internal rotation at 90° of shoulder abduction on both sides. Traditionally, the GIRD is positive if a deficit of internal rotation in the involved shoulder is more than 18° compared to the uninvolved side [40]. However, a systematic review suggests that the GIRD is age dependent and, thus, should be distinguished between adult and adolescent athletes [41]. In clinical practice, if a patient with GIRD shows scapular dyskinesis, we need to assess whether the dyskinesis is related to the GIRD or the pain. If the scapular dyskinesis is related to the GIRD, intervention to the GIRD should be considered before managing the altered scapular motion directly.

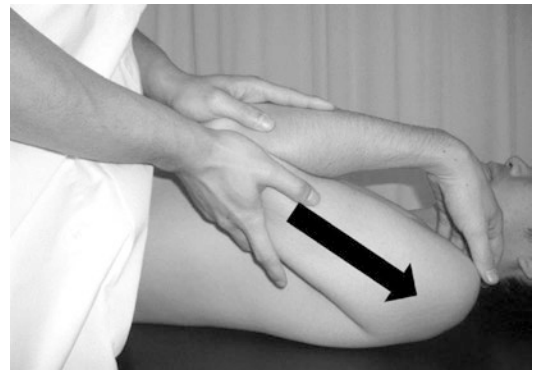

Fig. 13.1 Pectoralis minor stretching. The patient lies in supine position. The therapist flexes the patient's elbow maximally and flexes the shoulder by 30°. Then, the therapist pushes the elbow supero-posteriorly so that the origin and insertion of the pectoralis minor would be separated maximally

13.5 Management

To improve the increased scapular anterior tilt or decreased scapular posterior tilt categorized as type 1 of scapular dyskinesis, lengthening of the pectoralis minor is indicated. In addition, activating and strengthening the lower trapezius and lower serratus anterior should be included. To improve the increased scapular internal rotation or decreased scapular external rotation categorized as type 2 of scapular dyskinesis, activating and strengthening the entire serratus anterior are indicated. In cases with the increased upward rotation and elevation known as type 3 of scapular dyskinesis, inhibition of muscle activities of the upper trapezius is recommended.

13.5.1 Stretching the Pectoralis Minor

To stretch the pectoralis minor, the scapular needs to be rotated upwardly and externally as well as tilted posteriorly. Previous studies reported that posterior tilt or retraction of the scapula alone was not sufficient to stretch the pectoralis minor and that the combination of scapular posterior tilt and shoulder elevation or horizontal abduction was more effective [42, 43].

The corner stretching is an effective self-stretching technique. A patient stands near a corner wall and abducts the shoulder at 90° with 90° of external rotation so that the palm can be placed on a flat surface. From this position, the patient performs horizontal extension by rotating the trunk in the direction opposite the abducted shoulder [42].

As an alternative stretching, scapular retraction and elevation at 30° of shoulder flexion are recommended. A patient lies in a supine position and flexes the elbow of the involved arm. Then, the practitioner applies posterosuperior force to the patient's scapula by pushing the flexed elbow (Fig. 13.1) (Video 13.4) [43]. This technique is recommended for patients who cannot elevate the arm more than 90° because of shoulder pain.

13.5.2 Activating and Strengthening the Lower Trapezius

To activate and strengthen a target muscle, exercises inducing higher activity of the muscle should be selected. Several previous studies reported that antigravity shoulder flexion in the prone or quadruped position showed high-grade activity of the lower trapezius (Video 13.5) [44–46]. In addition, high electromyographic activity was observed during antigravity shoulder external rotation in the prone position [47, 48]. Because there was no significant electromyographic difference of the lower trapezius between antigravity shoulder flexion and external rotation, either of these exercises can be chosen depending on shoulder motion in which the scapular motion needs to be corrected.

13.5.3 Activating and Strengthening the Serratus Anterior

Traditionally, push-up plus exercise has been used for strengthening the serratus anterior [48]. Currently, several modifications to the push-up plus exercise are used. Regarding the exercise position, all modifications including knee push-up plus, elbow push-up plus, and wall push-up plus result in lower muscle activities of the serratus anterior compared to the muscle activity during standard push-up plus [49]. Regarding the surface condition, push-up plus on a stable surface appears to induce higher muscle activity of the serratus anterior rather than an unstable surface [50, 51]. Regarding the hand position width, higher muscle activity of the serratus anterior during push-up plus is obtained with the hand position of shoulder width compared to the hand positions of wider and narrower widths [52].

Open kinetic chain exercises for the serratus anterior should be considered as well. Serratus punch exercise induces higher muscle activity of the serratus anterior compared to push-up plus exercise [53] (Fig. 13.2) (Video 13.6). Diagonal exercise with a combination of shoulder flexion, horizontal flexion, and external rotation also expects to provide high activity of the serratus anterior [54].

13.5.4 Inhibiting Muscle Activities of the Upper Trapezius

To correct increased upward rotation and elevation of the scapula, scapulothoracic exercises with minimal activation of the upper trapezius are recommended. Side-lying external rotation, side-lying forward flexion, and prone horizontal abduction with external rotation can promote the activity of the lower trapezius while minimizing activity of the upper trapezius [55]. In order to keep the balance of the serratus anterior and upper trapezius, standard push-up plus on stable surface with hand positions of shoulder width is an effective exercise [49–52].

13.5.5 Management of Other Factors

For thoracic postural correction, exercises and manual technique to extend thoracic spine are generally prescribed. Taping to reduce thoracic kyphosis is also an alternative method. A previ-

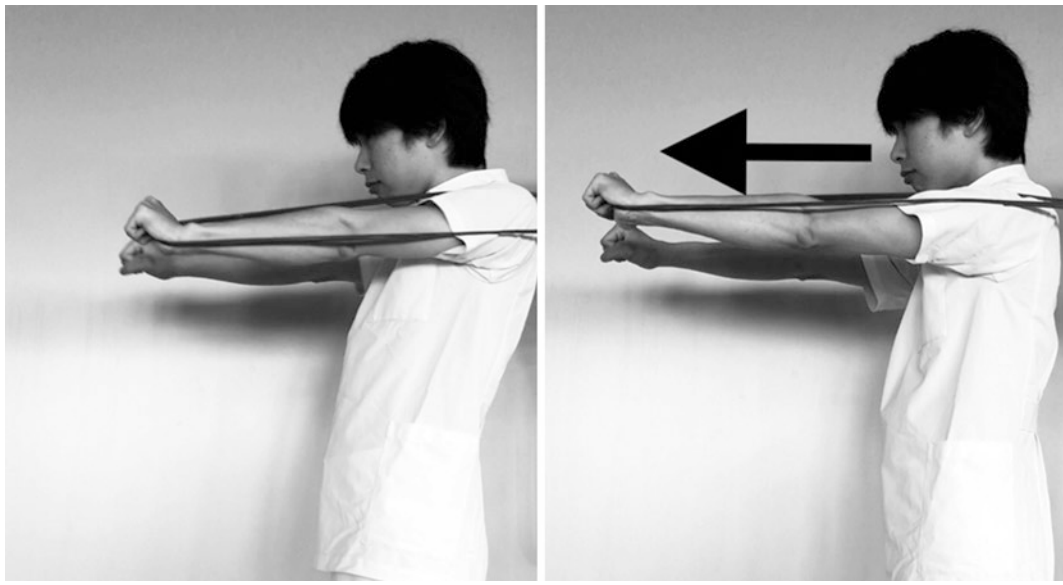

Fig. 13.2 Serratus punch exercise. The patient flexes both shoulders up to 90° with the elbows extended in standing position. While the patient grasping a rubber band with the involved hand (left hand) and the therapist pulling the rubber band from behind, the patient retracts the scapulae bilaterally and then protracts them maximally. To keep the neutral rotation of the trunk, the patient needs to perform symmetric motion of bilateral scapulae

ous study reported the efficacy of taping applied bilaterally from Th1 to Th12 [56].

For improvement of GIRD, the sleeper stretch is widely used [57–59]. In this stretch, a patient lies in the decubitus position on the involved side with 90° of shoulder flexion and then rotates the shoulder internally.

13.6 Tips, Tricks, and Pitfalls

In early phase of nonsurgical management of the scapulothoracic disorder, exercise should be performed under control of joint motion and loading. Isometric exercise in closed kinetic chain manner is safer and easier than open kinetic chain exercises when starting the scapular muscle activation exercises. If dysfunction exists in the proximal segments of the kinetic chain, such as the trunk and hip joint, these segments should be managed before starting scapular motion exercise [60].

Once activating the scapular muscles is successfully obtained, strengthening of these muscles needs to be encouraged with gradual increase in the intensity of loading. Dynamic exercise using open kinetic chain can be included as well. As a dynamic exercise, lawn mower exercise was introduced [61] (Fig. 13.3) (Video 13.7). This exercise requires large joint motion at multiple segments, leading to greater activity of the lower trapezius compared to isometric exercise. Care should be taken when inadequate motion and/or weakness in any segment of the kinetic chain is observed.

If the goal of the management is to return to play, high-intensity and plyometric exercise should be considered. It is important to assess whether adequate kinetic chain is maintained with increase of loading.

Fig. 13.3 Lawn mower exercise. The patient begins this exercise with a contralateral leg stepped forward and with a flexed and rotated trunk toward the contralateral side with the hand in front of the stepped leg. Then the patient rotates and extends the trunk while retracting the scapula

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Part III

RC in the Middle Ages (Age 30–50)

The Philosophy of Arthroscopic Rotator Cuff Repair

14

Stephen S. Burkhart and Robert U. Hartzler

In the 1980s, only a handful of orthopedic surgeons were performing shoulder arthroscopy, and those surgeons were directing their efforts primarily toward instability. Arthroscopic rotator cuff repair lagged behind due to two factors: (1) visualization in the subacromial "potential space" was difficult and usually unsatisfactory and (2) there were no good ways to arthroscopically fix the torn cuff tendons to the bone. The first problem was overcome in 1984 when Dr. Harvard Ellman discovered that he could reproducibly create a subacromial "virtual space" in which he could see well enough to do an arthroscopic acromioplasty [1, 2]. The second problem (tendon fixation) was a lingering conundrum until the introduction of suture anchors to the market in 1991. Since that time, the pace of scientific and technological advancement in the field of arthroscopic rotator cuff repair has accelerated to the point that the paradigm shift from open to arthroscopic cuff repair has occurred [3]. Few of us who listened to Dr. Rockwood [4] rail in the 1980s and 1990s about the arthroscope being "the instrument of the devil" would have predicted that the standard of care for rotator cuff tears in 2019 would be arthroscopic repair [5–7]. Gandhi was right when he said, "First they ignore you. Then they laugh at you. Then they fight you. Then you win."

14.1 Primary Goals of Arthroscopic Rotator Cuff Repair

From the beginning, the overriding goal of arthroscopic cuff repair was secure anatomic restoration of the cuff without damaging important adjacent structures such as the deltoid muscle. Preservation of a normal deltoid has always been a major advantage of arthroscopic rotator cuff surgery.

Furthermore, as our abilities to arthroscopically treat even large and massive cuff tears have improved, our focus has increasingly centered on joint preservation. Although some authors advocate the use of reverse total shoulder arthroplasty (rTSA) for treatment of massive irreparable cuff tears [8], we have been achieving equally good and even better results—with a low rate of complications—in these patients by performing superior capsular reconstruction (SCR) with dermal allograft [9]. Joint preservation remains our foremost goal in active patients with irreparable cuff tears, yet no glenohumeral arthritis.

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14.2 Is the Tear Repairable?

Prior to 2000, when authors referred to an irreparable cuff tear, they meant that it was operatively irreparable. That is, the surgeon tried to repair the tear but was not able to. In such cases, we would perform partial repair, and we reported good results overall with this approach [10].

Sometime around 2000, certain surgeons began to use the term "irreparable" in a different way. Specifically, they said that they could predict if a tear was irreparable or if it would not perform well functionally, even if it was repairable. The first article to claim predictability of repair offered this claim with no supporting data [11]. It was only the author's opinion that patients with Goutallier grade 3 or 4 changes in the supraspinatus or infraspinatus were irreparable. Then other authors referenced this article, and before long the opinion had become dogma for many surgeons. But not for all.

We agree that severe fatty infiltration (>75%) of the infraspinatus or supraspinatus is a negative prognostic sign for function after rotator cuff repair. However, we have shown that patients with up to 75% fatty infiltration generally do quite well with arthroscopic cuff repair [12]. We have also shown that pseudoparalysis is often reversible, even in patients with grade 3 or grade 4 Goutallier changes [13, 14].

Other authors have suggested that cuff tears are not repairable if the acromiohumeral interval (AHI) is <7 mm [15]. However, we have found that most patients with AHI <7 mm are repairable and do well after repair [13, 16].

The issue of being able to predict the repairability of a cuff tear is an important one, particularly in view of the fact that some authors are now suggesting that rTSA be performed in many patients with "irreparable" cuff tears (i.e., the tears are predicted to be irreparable). However, since we believe that "predictability criteria" are not accurate, it follows that many patients are not being offered a joint-preserving option (cuff repair or SCR) that likely would have been successful for them [17].

14.3 The Burden of Craft: Principles of Arthroscopic Rotator Cuff Repair

Surgery is a craft. So surgeons are, by definition, craftsmen. But the craft of arthroscopic cuff repair is a very difficult one, and the mastery of that craft requires study, practice, patience, tenacity, and creativity. Nonetheless, by practicing that craft, the surgeon assumes the burden of that craft, which is to provide the patient with the best procedure for his or her problem. Even now, journal articles [18] and podium speakers recommend for surgeons to "do what's best in your hands." We take issue with that dogma. The implied pact, the fiduciary relationship, that the surgeon has with the patient is to do what's best for the patient, even and especially if that conflicts with what is in the surgeon's best interest (e.g., "what's best in that particular surgeon's hands"). Particularly for challenging elective cases, if the surgeon cannot skillfully perform the procedure that is in the best interest of the patient, his burden of craft demands that he refer the patient to a surgeon who can do so.

There are a number of general principles that can aid the surgeon in achieving the best possible rotator cuff repair:

1. *Subacromial visualization*. Arthroscopy can provide unparalleled access to the shoulder, but not without cost: the surgeon must take the time and effort to prepare the subacromial space for visualization. Only after a thorough bursectomy with exposure of the tendons and bony landmarks will the surgeon be able to perform technically sound rotator cuff repairs.
2. *Tear pattern recognition*. It is important to distinguish among crescent tears, L-shaped and reverse-L tears, U-shaped tears, and massive retracted tears [19]. One must always remember that the tear pattern is also the repair pattern.
3. *Recognition of all components of the tear*. Subscapularis tears continue to be missed frequently. It is also important to recognize occult tears (e.g., subscapularis tears into the

medial sidewall of the bicipital groove; interstitial tears of the supraspinatus and infraspinatus) as well as associated pathology (e.g., biceps instability/subluxation).

4. *Mobilization of retracted tears*. Retracted subscapularis tears can have their excursion improved by doing a three-sided release [20]. Anterior and posterior interval slides should be considered and used appropriately for retracted tears of the supraspinatus and infraspinatus [21, 22].
5. *Bone bed preparation*. Proper bone bed preparation is essential, as the blood supply for tendon healing comes from the bone. All soft tissue must be removed from the tuberosity bone bed, and two to three bone vents for marrow access should be created.
6. *Footprint reconstruction.* We believe that most tears, if there is no loss of tendon length, are best treated by linked double row constructs [23].
7. *Proper tensioning of the muscle-tendon unit.* Sutures from the medial row anchors should be placed approximately 2 to 3 mm lateral to the muscle-tendon junction, as this is the anatomic location of the medial margin of the cuff footprint.
8. *Optimize fixation of poor-quality tendon*. For short tendons with tissue loss, or for poor-quality tendons, consider reinforced suturing techniques such as the load-sharing rip-stop technique [24, 25].
9. *What is the endpoint of fixation (i.e., when is fixation good enough)?* Surgeons know a strong construct when they see it. Stop when it looks perfect. Perfect is good enough.
10. *What if the tear is not repairable?* If there is no glenohumeral arthritis, do partial repair plus SCR.

14.4 Conclusion

The vast majority of rotator cuff tears can be repaired arthroscopically [17]. Adherence to basic principles will lead to predictably strong repairs. For irreparable cuff tears in active patients, joint preservation should be a guiding principle. In such patients, the surgeon should consider arthroscopic SCR.

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Biology of Rotator Cuff Healing

15

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15.1 Introduction

Rotator cuff tears are the most common source of shoulder pain and dysfunction in adults worldwide. It is estimated that 30–40% of the current population over the age of 60 will suffer a full-thickness rotator cuff tear [1]. Due to the enormity of this population, significant research efforts have been undertaken to identify strategies for prevention, treatment, and rehabilitation of rotator cuff tears. The rate of recurrence of rotator cuff tears, estimated to range from 5% to 85%, is also a significant factor to consider when assessing the overall burden that these injuries impart upon healthcare systems. The majority of recurrent tears occur in the first 3 months following primary repair, and this high rate of recurrence is primarily attributed to poor healing [2]. Despite ever-improving biomechanics of fixation, biological failure following rotator cuff repair remains a significant burden on healthcare systems worldwide.

Research efforts that evaluate aspects of rotator cuff tear pathology and treatment range from studies of microscopic molecular signals that affect tendon healing to macroscopic analyses of surgical techniques that yield superior healing and improved functional outcomes. To complicate the matter, studies that compare healing with patient outcomes do not always identify a direct correlation between the former and the latter [3]. The next great milestone in the treatment of rotator cuff tendon tears will likely be the amalgamation of a greater understanding of the complexities of rotator cuff healing with the vast array of current data regarding preoperative, surgical, and postoperative management. The goal for this chapter is to present a concise review of the biology of the rotator cuff, factors that affect pathology and healing, and clinical interventions that optimize both healing and functional outcome.

15.2 Native Biology

The rotator cuff is a complex of flat tendons, comprised of the supraspinatus, infraspinatus, teres minor, and subscapularis tendons. Like other tendons, the primary composition of each rotator cuff tendon is water (55% wet weight) and type I collagen (85% dry weight). The described triple helical arrangement of collagen with cross-linking is crucial to the mechanical strength of the tissue and its ability to facilitate tensile loads. The proteoglycan component of the tendon structure plays an important role in establishing the viscoelastic properties necessary for normal motion. Tenocytes function to establish the extracellular matrix while also synthesizing collagen and proteoglycans to maintain structure

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[4, 5]. Tenocytes have been shown to respond to mechanical loading and regulate chemotactic mediators under stress [5].

The rotator cuff has two important anatomical junctions, the myotendinous junction and the bone-tendon junction. The myotendinous junction is composed of interdigitations of end sarcomeres at the *Z* line, which splint and give rise to myofilament bundles that insert directly onto collagen fibrils. The bone-to-tendon interface, the enthesis, is characterized by a four-layer transition from the tendon to the bone: the tendon, fibrocartilage, mineralized fibrocartilage, and bone. This design is typical of anatomical areas where the tendon-to-bone apparatus transmits high tensile loads, such as the rotator cuff and Achilles tendon insertion sites.

15.3 Normal Tendon Healing

There are three described phases of tendon healing. Following repair, the inflammation phase is initiated. The inflammation phase predominates for the first 7 days of healing and is most importantly characterized by platelet deposition of fibrin and fibronectin as well as the release of growth factors to recruit monocytes and macrophages. Macrophages phagocytose cell debris and release cytokines that activate myofibroblasts to initiate scar formation [6]. During the final stages of the inflammatory phase, tenocytes begin to migrate to the injury site, and the synthesis of type III collagen begins. During the early inflammatory phase, muscle cells enter a catabolic state, and retraction, degeneration, and atrophy occur [7].

Following the inflammation phase is the proliferation phase of tendon healing. The proliferative phase begins approximately 48 h after insult and predominates approximately from 1 to 6 weeks after injury. The proliferation phase is characterized by deposition of highly disorganized, vascularized scar tissue. The synthesis of type III collagen peaks during the proliferative phase, and cellularity remains high.

The remodeling phase of tendon healing predominates approximately 6 weeks after injury and is characterized by a gradual decrease in cellularity and vascularity. The primary goal of the remodeling phase is the reorientation of the tissue. The predominate type III collagen is replaced with type I collagen. Despite the significant increase in type I collagen synthesis during remodeling, studies show that healed rotator cuff tendons continue to express a higher concentration of type III collagen than uninjured tendons. Animal models have shown that after rotator cuff tear and subsequent healing, the tendon-bone interface does not regain its normal histological configuration. Of critical concern from a biological perspective is the phenomenon of apoptosis, the process of programmed cell death. Tenocyte apoptosis has been noted in tissue studies of torn rotator cuff tendon [8]. Degenerative changes and muscle atrophy are well described features of rotator cuff tears. Recent studies attribute this phenomenon to the muscle remaining unloaded and retracted. In this setting, myogenic precursor cells may be directed toward adipogenic pathways, producing the infiltrative fatty changes commonly encountered after rotator cuff tear [6, 9, 10].

When addressing the healing process of the rotator cuff tendon, it is important to evaluate the primary tissues involved at the site of repair. The healing interface of rotator cuff tears often requires healing of the tendon to bone. Unlike the process of tendon-to-tendon healing, tendon-to-bone healing occurs via the generation of a fibrovascular scar. The structure, composition, and biomechanical properties of this tissue are not of equivalent quality to the original fibrocartilaginous tissue [10–12]. Many studies have demonstrated that this tissue often remains an order of magnitude weaker than the preceding, healthy tissue. This diminished strength is attributed to the more disorganized arrangement of collagen fibers and failure to reconstitute a true fibrocartilaginous transition zone (Figs. 15.1, 15.2, 15.3, 15.4).

Another important consideration in healing at the tendon-to-bone interface is bone loss. Biomechanical studies have demonstrated diminished load to failure values in models with diminished bone density. As delay to repair of chronic retracted rotator cuff tears leads to predictable osteopenic changes in the greater tuberosity in accordance with Wolff's law, decreased pullout

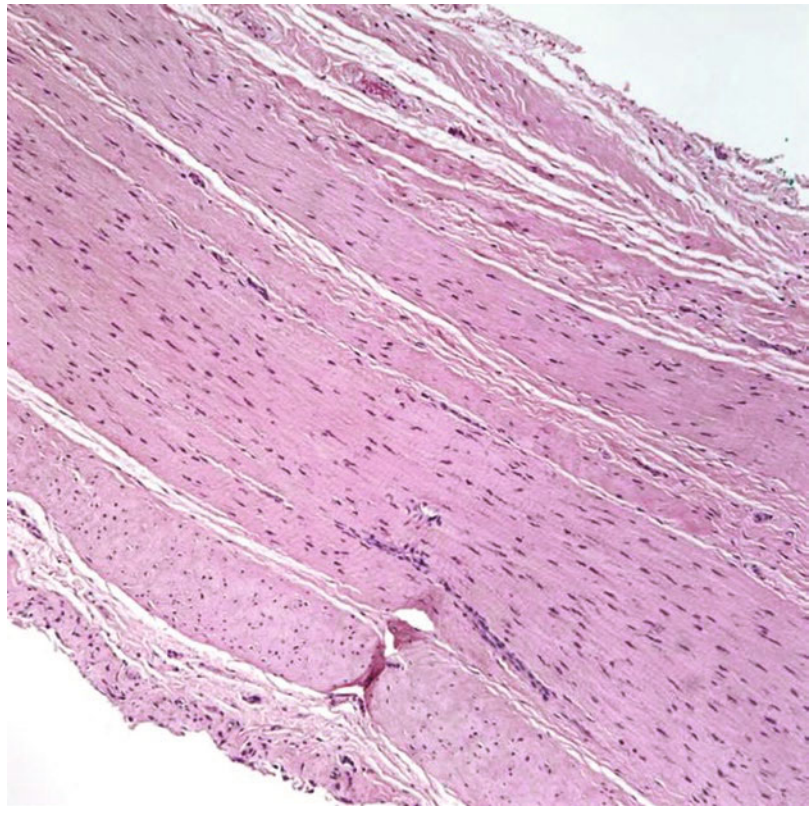

Fig. 15.1 This photomicrograph depicts the normal histological alignment of the cells and collagen from a supraspinatus tendon biopsy specimen

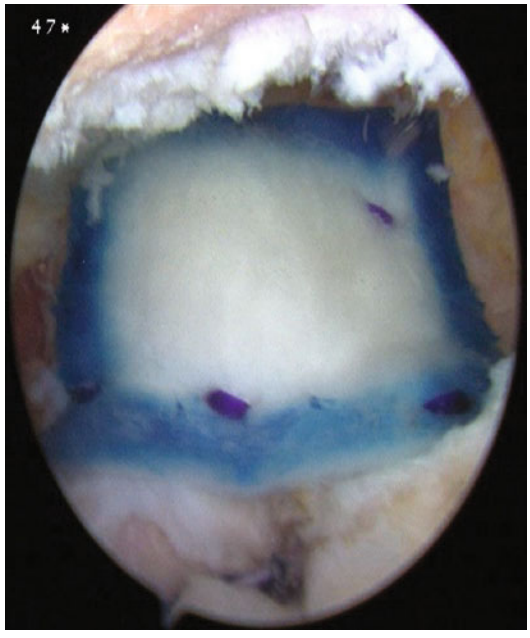

Fig. 15.2 An arthroscopic image which shows biologic patch augmentation of a rotator cuff repair

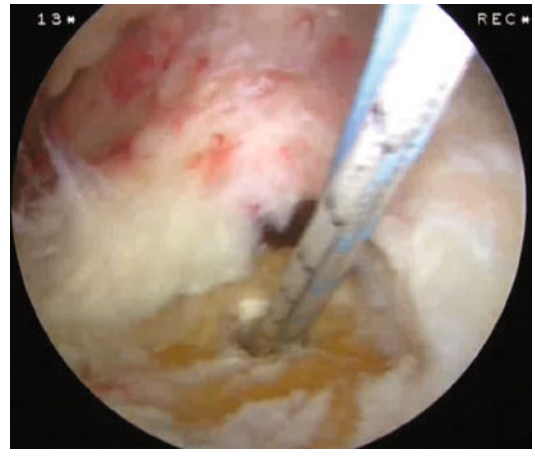

Fig. 15.3 In this view from the lateral portal, one can see the central, open core of a vented suture anchor inserted into the medial aspect of the greater tuberosity with marrow elements leaking out along the suture

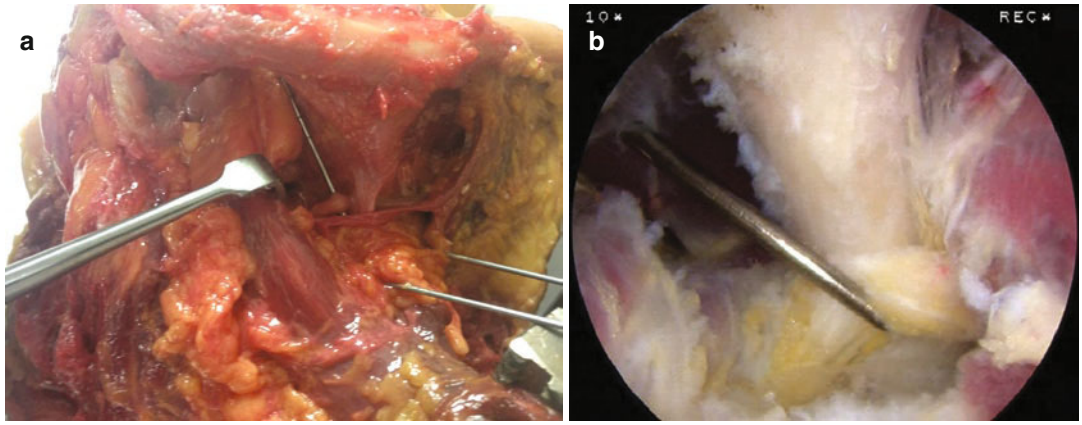

Fig. 15.4 In this open dissection, the suprascapular nerve can be seen passing under the suprascapular ligament (**a**). The second image (**b**) shows the suprascapular nerve after decompression in the spinoglenoid notch

strength of anchors and sutures used for surgical repair is a well-documented feature of this pathologic state. As discussed, chronic rotator cuff tears are complicated by variable degrees of tendon retraction, fatty infiltration, and atrophy of the rotator cuff muscles. These factors have all been shown to alter the healing response and limit the success of rotator cuff tendon repairs. The physiologic mechanisms that are proposed to contribute to increased failure rates are a lack of normal inflammatory response and its subsequent consequences and poor healing potential of degenerative tissue.

15.4 Biological and Biomechanical Factors of Rotator Cuff Healing

The fact that most patients who present with rotator cuff tears have no notable traumatic history indicates that the inherent tendon-to-bone junction is pathologic. A multitude of intrinsic and extrinsic factors have been attributed to initial rotator cuff injury and poor healing following repair. Most of the identified intrinsic factors are known age-related changes to the rotator cuff. Age-related factors such as disorientation of collagen fibers, increased cellularity, altered cell shape, and biomechanical changes are commonly identified in tissue samples from animal and cadaveric studies of rotator cuff tears [13]. The intra-articular location of the rotator cuff also presents a challenge for tendon healing. Studies demonstrate that the increased levels of matrix metalloproteases and inflammatory cytokines in synovial fluid impede tendon-to-bone healing and are often elevated in rotator cuff tears. Fibrinolytic enzymes within synovial fluid inhibit blood clot formation, which decreases the potential for a bridging scaffold across the repair site. The subacromial bursa in patients with rotator cuff tears contains high levels of pro-inflammatory and cyclooxygenase enzymes that contribute to collagen breakdown. The confluence of these factors creates a hostile healing environment that must be understood and, if possible, mitigated by the clinician.

The most studied extrinsic factors affecting rotator cuff healing are blood supply, tendon compression, repetitive microtrauma, and tension at the repair site. Studies evaluating blood supply of the rotator cuff demonstrate diminished capillary density adjacent to the tear relative to the healthy cuff. It is proposed that this decreased vascularity reduces progenitor cell recruitment to the area of pathology, which limits healing capacity [11]. In addition, the concentration of mesenchymal stem cells at the tendon-bone interface is indirectly correlated with the size of tear, time to repair, and degree of fatty infiltration. It is unclear if this finding is the product of chronic cuff tear or a risk

factor for development of cuff tear [12]. One must appreciate that diminished blood supply to the repair site can create a detrimental cascade that creates a hostile environment for tendon healing. The anatomy of the shoulder has been extensively examined with regard to rotator cuff tendon compression. A swathe of literature suggests that the presence of a type III acromion increases the likelihood of having a large or massive rotator cuff tear and is directly correlated with failed nonoperative healing, but there is now substantial data that disputes these findings [14].

15.5 Surgical Considerations

The primary goal of orthopedic surgeons is to preserve normal functional anatomy or reconstitute the normal functional anatomy after pathologic event. In the surgical treatment of rotator cuff tears, it is important to focus efforts on obtaining appropriate anatomical alignment. The surgeon should always ensure that the humeral head remains located at the glenoid and avoid over-tensioning at the repair site. The use of obliquely oriented sutures to minimize tension has been well-documented.

Many surgical strategies have been proposed to overcome or minimize the factors associated with poor tendon healing. The medial aspect of the subacromial bursa provides essential blood supply to the rotator cuff tendon, and its preservation allows access to the inflammatory factors required for healing. The lateral bursa is considered pathologic and has been shown to be a considerable source of pain. Both the medial and lateral bursa have a high cellular content, which may contribute to healing. Current recommendations call for preservation of normal bursa but excision of pathologic bursa [15].

Appropriate preparation of the greater tuberosity is essential to maximize tendon-to-bone healing potential. The widely studied "crimson duvet" technique, in which microfracture of the greater tuberosity is performed to create a bed of marrow-derived blood with pluripotent stem cells upon which the rotator cuff will lie, is a staple of rotator cuff repair. It is important that these trephination holes are directed into the marrow to allow stem cell access to the tear. The use of vented anchors allows access of bone marrow-derived stems cells to the rotator cuff. Randomized, prospective studies have shown significantly enhanced healing at the repair sites in patients who received vented suture anchors versus nonvented anchors [16].

Acromion type, assessed on scapular *Y*-view, has been described as follows: type 1, flat; type 2, curved; and type 3, hooked. The hooked acromion (type 3) is estimated to be present in approximately 10% of the general population as well as a majority of patients with large rotator cuff tears. Recent studies have shown that increased lateral projection of the acromion as measured on AP x-ray is associated with rotator cuff rupture. The routine use of acromioplasty during arthroscopic rotator cuff repair remains a source of debate among surgeons. A meta-analysis of patients undergoing acromioplasty failed to show any benefit with regard to successful tendon healing [17]. Acromioplasty should be considered in patients with anterior osteophytes and lateral projection, as these patients have been shown evidence of improved outcomes following excision. It may be important to preserve the coracoacromial arch in cases of massive tears, in which the CA arch provides superior stability to prevent humeral head escape [14, 17].

Preservation and release of an entrapped suprascapular nerve may contribute to a successful rotator cuff repair in patients with muscular atrophy. Preoperative imaging and intraoperative assessment for compression at the suprascapular notch, supraspinatus fossa, and spinoglenoid notch must be emphasized, especially in tears with grade 3 or 4 atrophy and revision rotator cuff repairs with significant medial retraction and atrophy. Suprascapular nerve compression is associated with rapid atrophy of the cuff and increased pain following repair. Outcome studies suggest the potential for significant benefit from arthroscopic suprascapular nerve release in patients undergoing revision arthroscopic rotator cuff repair [18, 19].

Another important surgical consideration is superior capsule reconstruction. In patients with

large, complete supraspinatus tears with retraction medial to the glenoid rim, superior capsule reconstruction may be utilized to hold down the humeral head within the glenoid. With the humeral head located, the deltoid and rotator cuff can be biomechanically optimized.

In large and massive rotator cuff tears, the use of scaffolds has been shown to increase healing rates. Multiple studies appear to indicate that scaffolds offer a biomechanical advantage during the healing process by redistributing some component of tension from the tendon repair site [20–22]. A variety of scaffold options exist, from synthetic to allograft to xenograft, all of which require further study [22]. Bio-inductive collagen scaffolds continue to produce promising outcomes in the lab and clinical settings, and innovative operative techniques have been described for their implementation [20, 23, 24].

15.6 Non-operative Considerations

Research regarding the use of platelet-rich plasma (PRP) has been indeterminate in delineating a clear benefit to tendon healing in the clinical setting. In vitro studies have shown that this preparation, which consists of a platelet concentration greater than serum and numerous growth factors including TGF-beta1, platelet-derived growth factor, VEGF, and IGF-1, promotes healing. Due to the variable preparations and application methods available, no conclusive evidence has been discerned. This area of study continues to show significant potential, especially in patients with large rotator cuff tears. Several studies have noted improved vascularity at the repair site on postoperative ultrasound and improved patient outcome scores. Meta-analyses of PRP in rotator cuff tears have failed to identify significant differences in clinical outcomes [25].

Numerous studies have proposed the utilization of growth factors to promote rotator cuff healing. The unique characteristics of the many studied growth factors and cytokines that appeal to surgeons and researchers are promotion of angiogenesis, cellular recruitment, and induction of proliferation and differentiation of cells associated with tissue repair and regeneration. It is estimated that approximately 1500 identified cytokines have a potential role in the process of tendon healing, which presents a significant challenge for researchers working to identify the correct composition for a therapeutic regimen. The clinical benefit of isolated growth factors appears to be limited, as the process is regulated by many factors in combination [26, 27]. More research is needed to understand the complexities of these cell signaling molecules, the associated growth factors, and how to appropriately apply this knowledge to the clinical setting.

Postoperatively, the use of an abduction pillow sling to minimize tension at the repair site and place the shoulder in an optimal position for perfusion is routinely utilized by many surgeons, but data has failed to show conclusive results with regard to improved healing. Cryotherapy, also routinely used in the acute postoperative setting following rotator cuff repair, has been shown to be associated with diminished pain scores, reduced narcotic requirements, improved sleep, and improved ability to participate in therapy programs but has yielded mixed results with regard to potential healing [28]. It should be considered that any postoperative protocol that results in diminished pain could potentially offer improved outcomes due to allowing for better adherence to therapy protocols.

15.7 Conclusion

This chapter represents an overview of the recognized factors that contribute to rotator cuff pathology, obstacles that impede rotator cuff healing, and strategies to improve healing potential. As the literature suggests, these factors are numerous, and many are not entirely understood. With so many variables affecting rotator cuff healing, it is important for the orthopedic surgeon to focus on the aspects he or she can control. Precise surgical planning, preservation of blood supply, anatomical restoration, reliable but not excessive suture repair, and surgical techniques such as trephination, the use of vented suture anchors, superior

capsular reconstruction, and suprascapular nerve release are all vital tools in achieving a well-healed, functional rotator cuff repair.

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16 Philosophy on Repair In Situ vs Completing and Repair of the Partial Rotator Cuff Tear

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16.1 Introduction

Diagnosis and treatment of partial-thickness rotator cuff tears remain challenging. While not completely established, recent advances in the understanding of partial-thickness rotator cuff tears have clarified treatment options to a degree, and high-level data is becoming available to direct the surgeon regarding treatment.

16.2 Anatomy, Examination, and Imaging

Partial rotator cuff tears can be divided into articular side, bursal side, and interstitial tears. The physical examination of the patient with a partial-thickness rotator cuff tear is indistinguishable from that of impingement. In fact, Neer originally lumped these two together as type II impingement [1] feeling these had equivalent treatment, probably true in the open shoulder era. Pain with abduction, forward flexion, and a variety of positive impingement signs are the hallmark of both diagnoses.

Imaging partial rotator cuff tears remains challenging. Arthrograms are useful only in articular-side tears. Ultrasound cannot often differentiate partial from complete tears [2, 3]. MRI scanning remains challenging, especially at a community level. Our study [4] showed that:

1. Only 65% of the scans could be definitively interpreted.
2. Correlation of MRI reports of partial tear to observed arthroscopic findings was poor. Only 17 of 80 patients were correctly diagnosed (true positive 22%, false positive 78%).
3. Isolated radiologic interpretation of partial-thickness rotator cuff tear based on non-specific increased signal on T1 and T2 images is not an indication for surgery.
4. Lidocaine impingement test preoperatively and clinical exam are far more important than MRI.
5. MRI with contrast may improve these results [5] but not always [6].

This data is summarized in Table 16.1. Given the low sensitivity and specificity of imaging for partial rotator cuff tears, initial diagnosis of a partial rotator cuff tear leading to aggressive initial surgical treatment does not seem indicated. Duralde et al. similarly noted MRI to be accurate in less than 40% of cases of partial rotator cuff tear [8].

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Table 16.1 Correlation of the radiologic diagnosis of "partial rotator cuff tear" with the preoperative lidocaine impingement test and arthrogram result [7]

Surgical diagnosis	*n*	Lidocaine test positive	Arthrogram positive	Treatment
Partial tear MRI no tear Lidocaine neg	10	0/10	0/3	Diagnostic arthroscopy 8 Chondroplasty 2
Partial tear MRI-no tear Lidocaine pos	28	28/28	0/2	Removal calcium 8 Acromioplasty 28 AC resection 5 Biceps tenodesis 3
Partial tear MIR partial tear Partial tear MRI complete tear	17 25	11/14 22/25	0/10 8/10	Arthroscopic partial repair 14 Biceps tenodesis 3 Arthroscopic repair
Total	80	74	25	

16.3 Indications and Techniques

Initial conservative management of the suspected partial-thickness rotator cuff tear is still the first step in treatment. Neer in his landmark work regarding rotator cuff disease recommended a year of conservative treatment for type II impingement [1]. Breazeale and Craig report 40% successful response to conservative management of partial articular side tears [9]. Morrison's review [10] as well and McConville and Ianotti [11] confirmed this concept. As delayed treatment does not appear to offer inferior outcomes to acute repair of partial-thickness rotator cuff tears [12], the concept of initial conservative treatment appears well validated.

Treatment options for those patients who fail conservative management have been clarified in recent years. Early success was documented with debridement [13] and debridement and acromioplasty [14] but subsequent studies failed to duplicate the results of these early results [8, 11, 15–19]. It is now generally established that rotator cuff tears greater than 50% of the substance of the rotator cuff insertion will do better with repair than debridement either with or without acromioplasty, with an 18% early reoperation rate with debridement and acromioplasty [18, 19]. Acromioplasty alone has clearly been shown to not delay progression of partial- to full-thickness rotator cuff tears. Kartus et al. [20] showed in a long-term clinical and ultrasound evaluation that followed 26 patients with partial rotator cuff tears treated with acromioplasty alone that 9 of 26 progressed from partial to full tear at a follow-up mean 101 months. Interestingly 12 of 26 had pain in the other shoulder. They noted that "it appears that an arthroscopic acromioplasty and cuff debridement does not protect the rotator cuff…" [20].

One problem has been how to establish which partial tears are at or greater than 50% at surgery. Bursal side cuff tears are relatively easy for the surgeon to assess the depth of the tear simply by visualizing the tear from the bursal side. Articular side tears have been more challenging. While staining the cuff tissue with methylene blue, the so-called "color test" of Fukuda [21] or palpation around a marking suture as described by Snyder et al. [22] has been described; the most reliable technique to assess the degree of tearing has been the amount of exposed footprint visible from the joint side of the tear arthroscopically. Curtis et al. [23] and Ruotulo et al. [24] both presented data to show that the rotator cuff footprint averaged 12 mm in width. Thus, if greater than 7 mm of footprint was exposed between the articular surface of the humerus and the insertion of the remaining rotator cuff tendon, the tear was at 50% thickness and warranted repair (Fig. 16.1). This approach was further validated by Lo and Burkhart [17]. While more advanced age has been suggested as an indication for more liberal use of debridement rather than repair, this did not prove true in our study [18] as failure rates with

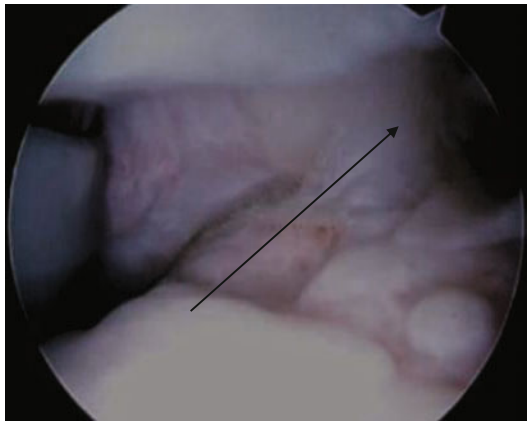

Fig. 16.1 View of uncovered rotator cuff footprint from the posterior aspect of the glenohumeral joint of the right shoulder (arrow). Uncovered footprint of greater than 7 mm indicates a high-grade partial-thickness tear which warrants repair

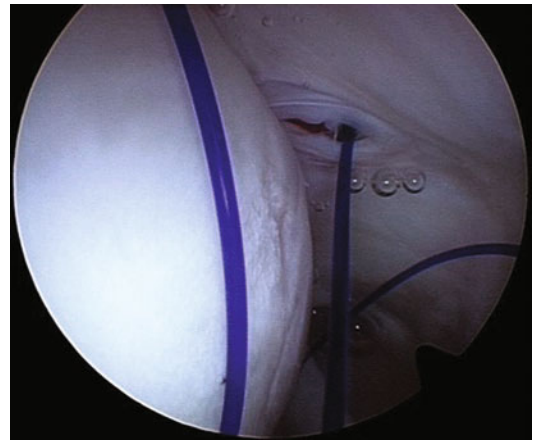

Fig. 16.2 PDS marking suture through articular partial-thickness rotator cuff tear according to the technique of Snyder et al. [22], posterior aspect of the glenohumeral joint of the right shoulder. Inspection and palpation of residual tendon from the bursal side of the tear can allow assessment of the quality of the residual tendon

debridement were similar regardless of the age of the patient.

Operative technique is similar to that of full-thickness rotator cuff repair. Standard arthroscopic portals and complete visualization of the glenohumeral joint are mandatory to avoid missing other associated pathology. For articular side tears, once the depth of the tear has been determined, the marking suture technique of Snyder et al. is useful to allow the surgeon to correlate the area of greatest damage on the articular side with the adjacent bursal side of the tendon [22] (Fig. 16.2). Bursal-side tears can be repaired using the same techniques as small full-thickness tears. Small tears of this nature are generally amenable to single-row repair. Acromioplasty is increasingly felt to be optional [25] with rotator cuff surgery of any type.

A continued source of discussion is the preferred technique for repairing articular-side tears. Two techniques have been proposed: (1) completing the tear and repairing as one would for a small complete tear or (2) in situ repair, leaving the bursal component of the rotator cuff intact. Proponents of in situ repair [17, 22, 26] note that the length of the tendon is automatically maintained and that the remaining tendon is not violated. Proponents of completing the tear point to the ease of execution and ability to perform double-row repair if desired, with excellent short-term results [27]. Completing the tear also avoids difficulties with anchor placement, visualization, and the need to switch back and forth between the bursa and glenohumeral joint for visualization. The technique of completing the tear has been subsequently supported by Deutsch [16], Kamath et al. [28], and Porat et al. [29], noting comparable good results and high rates of healing with this technique compared to published results of in situ repair. Prospective, randomized studies are now available comparing the two techniques. Franchesci et al. [30] and Castagna et al. [31] noted in their prospective, randomized studies equivalent results with either technique. Shin [32] noted that while there were slightly less retears with transtendon repair (0/24 vs 2/24), transtendon repairs were more likely to become stiff and took longer to be pain-free. Kim et al. [33] noted that transtendon repair showed similar results to completing the tear, with slightly more retears in the transtendon group. The equivalence of completing the tear to in situ repair has also been recently confirmed in the two systematic reviews on this topic by Katthagan et al. [34] and Ono et al. [35].

More recently research has been directed at the quality of the remaining intact residual tendon

in the setting of partial rotator cuff tears. Yamakado [36] biopsied the residual tendon in partial rotator cuff tears and found the tissue abnormal and of poor quality. Lo and Burkhart similarly commented that "if the tendon is thin or of poor quality, we complete the tear." [17]. This appears to give further credence to the technique of completing the tear. Given the poor quality of the residual tendon, Schlegel et al. recommended reinforcing the partial tear with a graft [37]. At 1-year follow-up in this prospective study, the bioinductive collagen implant, polylactic acid (PLA) tendon staples, and polyetheretherketone bone staple combination showed only 1 patient failed to heal in 33 patients [37]. No control data was provided in this preliminary study.

16.4 Specific Points in Rehabilitation

Rehabilitation has generally been thought to be consistent with that of small rotator cuff repairs in general. Early range of motion is most likely not detrimental.

16.5 Results

While retears with either in situ repair or tear completion have been reported to be as high as 18%, the meta-analysis of Ono et al. showed that 98.2% healed in the transtendon group and 93.9% healed in the tear completion group [35]. Furthermore, this review noted that even patients with a rotator cuff tear on postoperative imaging generally had excellent clinical results. While some studies have shown inferior results with repair of bursal side partial tears to articular side tears [33], other surgeons have failed to confirm any difference in outcome [38]. Xiao et al. showed excellent results with repair of both type II and type III bursal side rotator cuff tears [39]. Although virtually all studies show low rates of retearing with either in situ repair or completing the tear, it should be understood that progression of rotator cuff disease may be unavoidable due to age-related apoptosis of the tenocytes [40]. Overall, results of repair of partial-thickness tears have generally been excellent.

16.6 Complications and How to Avoid Them

The most common complication in the management of partial rotator cuff tears is undertreatment. The temptation to limit treatment of high-grade partial tears to debridement only should be avoided. The only reported complication in the literature regarding repair of partial rotator cuff tears is adhesive capsulitis, occurring in approximately 10% of cases [35], all of which had good ultimate functional outcomes. Complications such as infection, hardware failure, bleeding, and neurologic injury should all be at or below the incidence rates quoted for repairs of small rotator cuff tears in general.

16.7 Conclusions

The treatment of arthroscopic partial-thickness rotator cuff tears has shown dramatic evolution in the last three decades. Initial conservative management is appropriate for all partial-thickness tears. Current treatment favors repair versus debridement of high-grade partial-thickness tears. Acromioplasty has proven to be optional in most cases of rotator cuff repair in general. While in situ repair continues to have advocates, outcomes in several prospective randomized studies have been equivalent to completing the tear, and completing the tear is technically easier and allows excision of the residual tendon which appears to be of histopathological poor quality.

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Bursal-Side Partial-Thickness Rotator Cuff Tears

17

Kevin Shea and Colin Pavano

17.1 Introduction

Partial-thickness tears of the rotator cuff, in particular, the supraspinatus, are a common finding in patients with symptomatic rotator cuff disease. Codman [1] was the first to describe these tears and termed the articular-side tears "rim rents." He documented some degree of rotator cuff tearing, primarily in the supraspinatus tendon, in up to 20% of autopsy specimens studied. Recognition of the spectrum of partial-thickness tears grew with the routine use of arthroscopy to perform surgical procedures in the shoulder. Ellman [2], Snyder [3], Esch [4], and others described various partial tears, bursal, articular, and interstitial. While partial articular-side rotator cuff tears (PASTA lesions) have received the most attention in the literature, bursal-side tears are also frequent sources of shoulder pain requiring treatment. This chapter will outline the anatomy, pathomechanics, and current treatment of these types of partial rotator cuff tears.

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17.2 Anatomy and Pathomechanics

In order to understand partial rotator cuff tears, it is first important to understand the microanatomy of the rotator cuff tendon, and in particular, the supraspinatus tendon. In general, most tendons, e.g., the patellar tendon, are formed by rows of parallel collagen fibers, all aligned in the direction of the applied force. Histologic sections usually show parallel fiber orientation that is the same regardless of the area of tendon examined. In contrast, the fiber arrangement of the supraspinatus tendon is multiplanar, reflecting the complex loading of the rotator cuff. Clarke and Harryman [5] showed that the supraspinatus tendon is actually composed of five distinct layers, each with its own distinct arrangement of collagen fibers, as is shown in Fig. 17.1. Layers 2 and 3 are the thickest and likely carry most of the applied load. Fibers in layer 2 are oriented in the classic alignment, parallel to the line of applied supraspinatus muscle force generation, but the fibers of layer 3 are smaller and more loosely packed and lack specific orientation, reflecting more complex loading, likely in the transverse (anterior-posterior) axis. Differential movement between these load-bearing soft-tissue planes, in particular between layers 2 and 3, creates the potential shear failure between these layers.

Fukuda [6] published a series of histologic whole block specimens from 66 operated partial-thickness tears. These sections of bursal-side

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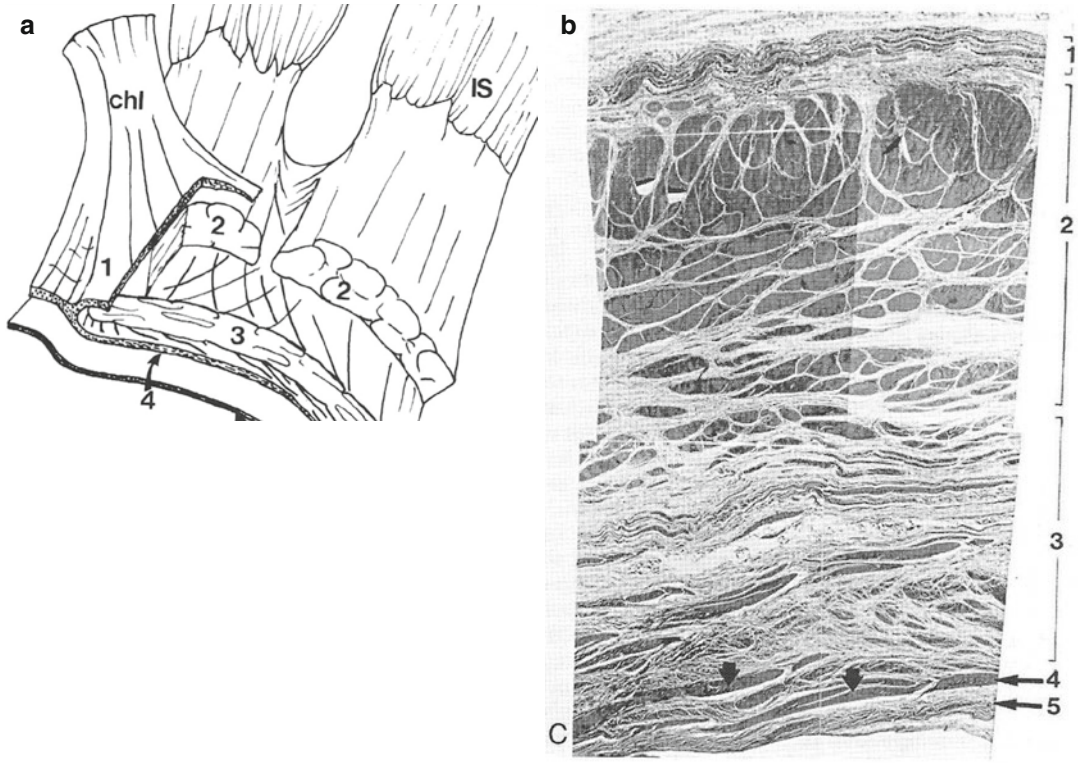

Fig. 17.1 (**a**) illustrates the multilayer organization of the rotator cuff tendon. Layers 2 and 3 are thought to transmit most of the load between the muscle and bone. Partial-thickness tears delaminate in the plane in between these layers. (**b**) is a stained and enlarged cross section through the rotator cuff tendon. The cross sections of layers 2 and 3 in particular show that the collagen bundles are oriented in different planes. Reprinted from Clark JM, Harryman III, DT. Tendon, Ligament and Capsule of the Rotator Cuff. JBJS Am 1992; 74-A:713–725

tears demonstrate that the articular portion of the cuff tendon remains attached while the bursal-side avulses and a delamination occurs through the tendon. Though not specifically stated, the delamination seen in these specimens likely occurs in the shear plane described by Clarke and Harryman.

Recent biomechanical studies have described possible mechanisms for the development of bursal-side rotator cuff tears. Tensile properties of both bursal- and articular-side fibers are studied at various sites in the supraspinatus tendon. Bursal-side samples were noted to be significantly stiffer than articular-side samples when loaded transverse to the line of muscle action [7]. In another study, creating a bursal-side partial tear decreased the midsubstance strain in sheep infraspinatus tendons as compassed to intact specimens immediately, while articular-side partial tears had little effect on the resultant midsubstance strain until a 66% defect was created compared to intact loaded specimens [8]. Finally, partial bursal tears created in the anterior portion of the tendon resulted increased strain in the posterior portion of the tendon in direct proportion to the depth of the tear [9].

Taken together, these studies support the theory that repetitive contractions of the supraspinatus tendon may result in shear failure of the tendon due to a combination of shear stresses at the interface between layers 2 and 3 combined with a mismatch in material properties between the bursal- and articular-side fibers.

Defects in the bursal side of the tendon, due to impingement or other degenerative processes, may result in the initial disruption of the bursal tendon surface, and a bursal-side tear may propagate anterior to posterior and along the intratendinous plane as the system seeks to

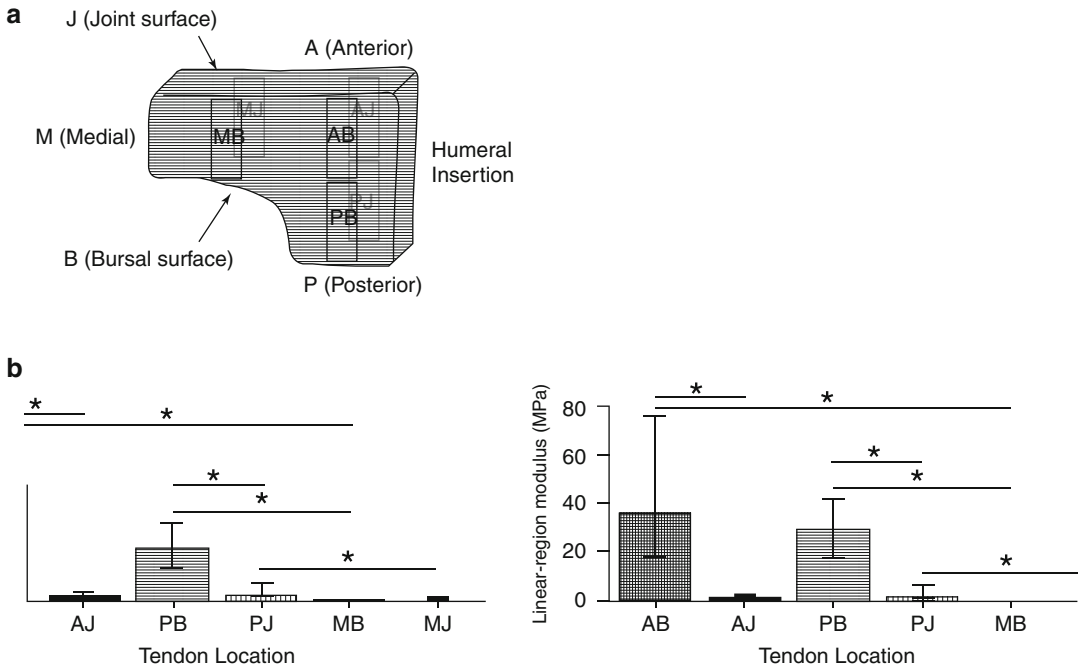

Fig. 17.2 (**a**) is a schematic drawing of a human supraspinatus tendon illustrating six separate regions that were individually harvested and tensile properties evaluated. (**b**) documents the mean modulus of each of these regions, demonstrating that the bursal surface is significantly stiffer than the articular surface. Reprinted from Lake SP, Miller KS, Elliott DM, Soslowsky LJ. Tensile properties and fiber alignment of human supraspinatus tendon in the transverse direction demonstrate inhomogeneity, nonlinearity and regional isotropy. J Biomech 2010;43:727–32

minimize the strain in the loaded tendon. Increased strain at the tear edge may result in further tearing and may be a source of clinical pain. Tears greater than 50% thickness in particular resulted in nonlinear increases in strain.

17.3 Clinical Presentation

Symptomatic bursal-side tears of the supraspinatus present similar to other rotator cuff syndromes. The shoulder pain increases gradually and usually does not start with a single event. In the author's experience, bursal-side tears often are much more painful than even full-thickness tears causing the patient to seek medical care more rapidly.

The physical examination is characterized by pain with motion, positive impingement signs, and pain with maneuvers that activate the supraspinatus such as the "empty can" or "full can signs." Weakness in elevation is rare, as there is not a complete tear, but may be difficult to assess secondary to pain. Extreme loss of motion, in particular, external rotation, is unusual and may be a clinical sign of developing frozen shoulder (Fig. 17.2).

17.4 Imaging

Plain radiographs are rarely helpful. If conservative measures fail to alleviate the pain, MRI is usually diagnostic. Bursal-side and interstitial tears are best seen on the T2 FS or STIR images (see Fig. 17.3). The tears are often less than 1 cm in the coronal plane and may be missed on the sagittal views. The entire imaging series should be viewed to develop a better understanding of the size and extent of tearing. As these tears are not full-thickness, fatty infiltration of the muscle belly rarely is seen.

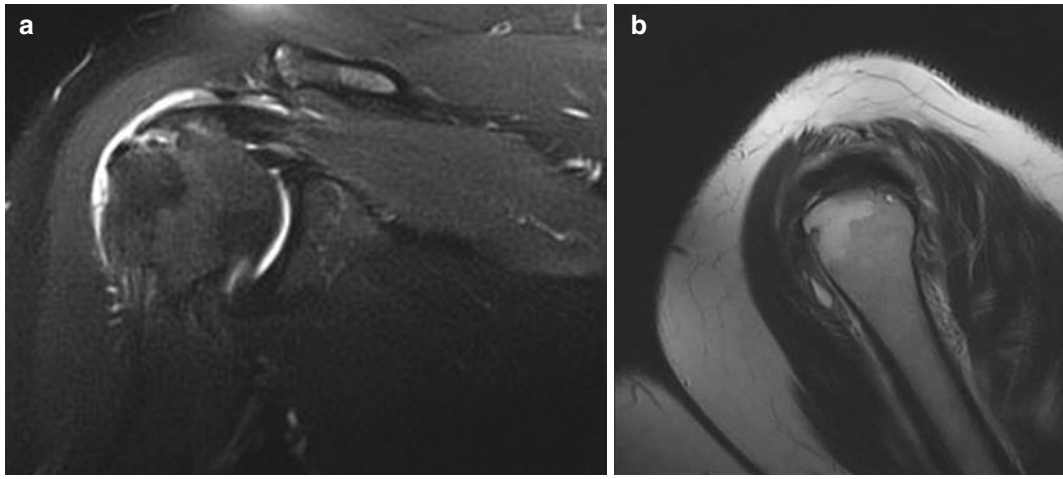

Fig. 17.3 Sagittal (**a**) and coronal (**b**) T2 STIR MR images of a typical bursal-side rotator cuff tear. The tear begins just posterior to the long-head biceps tendon and propagates posteriorly (**a**). The fluid signal is seen between the tendon tissue and bone, but the fluid signal does not communicate with the joint space (**b**)

CT scans are not useful, even with intra-articular dye, as these tears do not communicate with the joint surface. Ultrasonography can detect bursal and interstitial tears, but an extremely skilled ultrasonographer is required as the tears are often small and difficult to assess.

17.5 Non-operative Treatment

In general, treatment should start with activity modification, physical therapy, and later a corticosteroid injection, as with other rotator cuff syndromes. An MRI is usually obtained after a failure of non-operative management but may be obtained sooner according to the magnitude of the pain. In the author's experience, bursal tears in particular are often resistant to conservative measures. Once a bursal-side supraspinatus tear is identified, operative treatment is usually recommended. Spontaneous healing of bursal-side tears is unlikely to occur [10].

17.6 Surgical Treatment and Results

The recognition and treatment of bursal tears have evolved along with the science of shoulder arthroscopy in general. Codman [1] did describe operative repair of these tears, when he identified them surgically, but little more was written about them until shoulder arthroscopy came into common practice. Arthroscopic debridement alone, similar to the recommended treatment for low-grade partial articular-side tears (PASTA lesions), failed to relieve the pain in most cases [11].

Arthroscopic repair has proven to result in satisfactory outcomes in most series. Ranalletta et al. [12] recommend repair of the bursal flap without acromioplasty. All other published series state that acromioplasty is essential to a satisfactory outcome. Some authors recommend repairing only the bursal-side flap [13–15], while others convert the partial tear to a full-thickness tear and repair it [16, 17].

17.7 Author's Preferred Technique

Surgery is performed in the beach chair position with a mechanical arm holder. A standard arthroscopic examination of the intra-articular space is performed, and biceps tenotomy/tenodesis is performed as clinically indicated.

The arthroscope is inserted into the subacromial space, and a complete bursectomy and acromioplasty are performed to expose the tear. The tear is always very anterior, just posterior to the biceps and rotator interval. In most cases the

shoulder needs to be externally rotated to expose the tear. The standard posterior viewing portal may fail to give an adequate view of the tear, and a posterior lateral viewing portal is necessary (see Fig. 17.4a–d).

The bursal edge is debrided. We prefer to convert the tear to a full-thickness tear to avoid overtensioning the repair. This can be performed with an elevator, a shaver, or an RF device. A single cannula is inserted directly over the tear, and an anchor is inserted into the exposed footprint near the tendon free edge. Anterior and posterior portals are created. All suture limbs are then retrieved and passed into the posterior portal. In this manner, sutures rarely become tangled.

We prefer to pass the sutures using a crescent hook and suture shuttling device, in this case #2 PDS suture, as the mechanical suture passing devices are often too bulky in small tear settings. The suture hook is passed through the lateral cannula and under the tendon flap. The hook then pierces the tendon, and the shuttle is delivered into the anterior cannula. Another arthroscopic device such as a loop grasper can be inserted through the

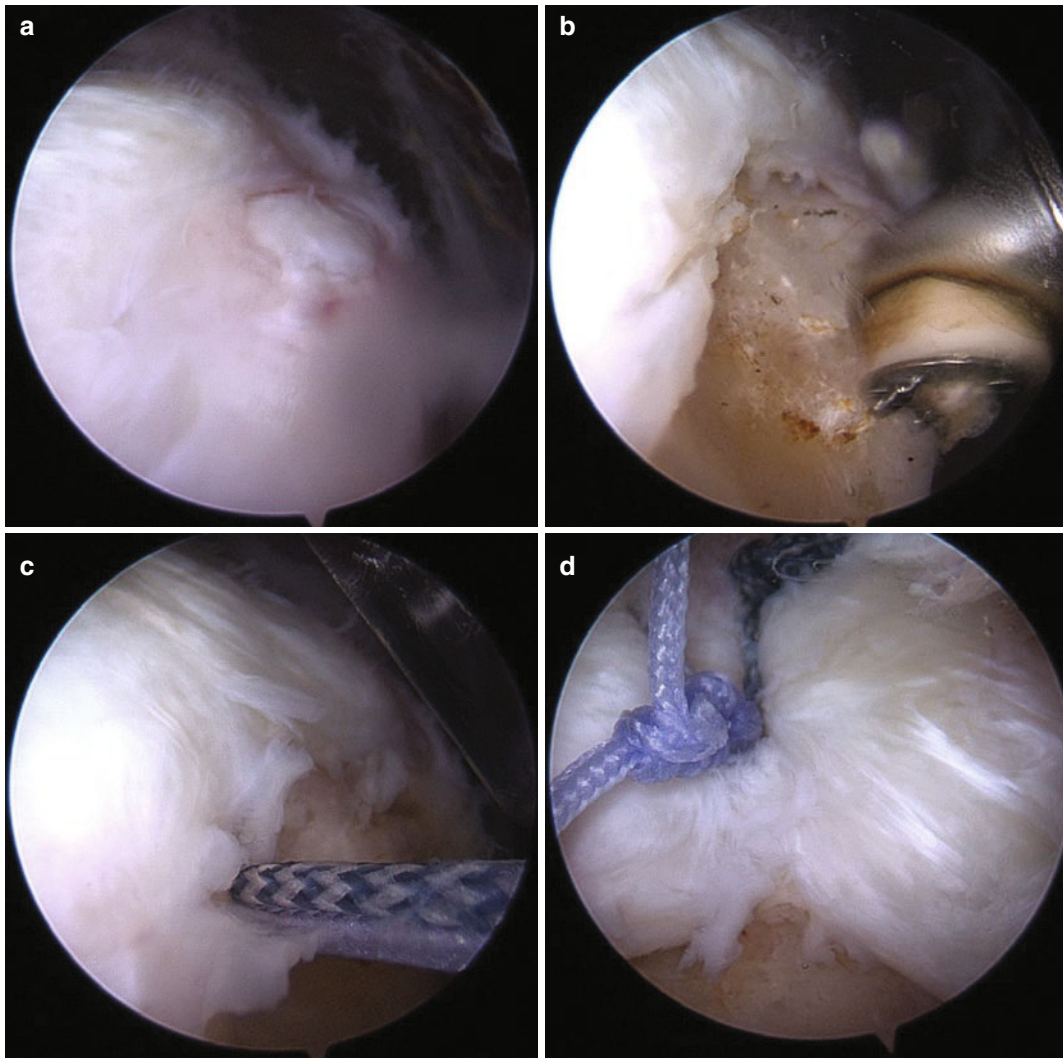

Fig. 17.4 (**a**) shows the typical appearance of a bursal-side tear. The upper flap is retracted, while the articular flap remains attached to the foot print. (**b**) the articular flap is dissected from the footprint with a radiofrequency device creating a full-thickness tear. (**c**) an anchor has been placed in the footprint at the edge of the tendon free edge and all sutures shuttled out the posterior portal. (**d**) two simple sutures have been used to complete the repair

posterior portal to exert downward pressure on the tendon for ease of passing the hook.

One limb of one suture (in the posterior portal) is shuttled into the lateral cannula. It is tied to the suture shuttle and then passed through the tendon and out the anterior portal. The other limb of this suture is retrieved into the anterior portal as well, keeping the limbs together for later. The process is repeated. Two simple sutures are usually sufficient. The suture limbs are then retrieved into the cannula and tied completing the repair.

The shoulder is placed in a sling for 4 weeks. Because the tear is small and the fixation usually very tight, pendulum exercises and active-assisted external rotation exercises can be started immediately to reduce the chance of stiffness. Standard rotator cuff rehabilitation protocols are then used.

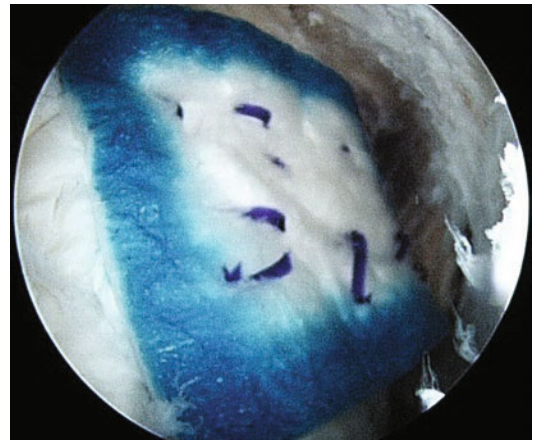

Fig. 17.5 Arthroscopic view of a collagen biomatrix (Rotation Medical, New Jersey) applied to the bursal surface of the supraspinatus tendon to promote healing. See text for details. Courtesy of FH Savoie, MD

17.8 Results

There are few studies that look at the outcomes of bursal-side rotator cuff repair treatment alone. Most series include both articular-side and bursal-side tears together. Ranalletta [12] reported an average improvement in Constant score from 42.5 to 86.1 in 74 patients treated with arthroscopic repair alone. Aydin [16] reported an average improvement in the Constant score from 38.9 to 89.2 at 2 years and 87.8 at 5 years in 29 patients, average age 55 years, with tear completion, repair, and acromioplasty. In the author's experience, most patients improve and are satisfied with their surgical results. The incidence of postoperative stiffness or re-tearing is very low.

17.9 Emerging Techniques

Recent studies have suggested that partial rotator cuff tears may not possess the ability to heal due to high shear in the complex loading environment discussed above. A novel option is to apply a highly porous collagen biomatrix patch to increase tendon thickness and reduce local shear concentration [18]. Early results with applying the patch to partial rotator cuff tears have demonstrated tendon healing and increased thickness of the tendon on MRI at 1 year (see Fig. 17.5). Further studies will be needed to investigate how this technology can be used in the future.

17.10 Summary

Bursal-side rotator cuff tears can be a source of shoulder pain. Complex tendon anatomy and resultant shear forces may play a role in their development and propagation. MRI can identify most bursal-side tears. Arthroscopic repair combined with acromioplasty results in favorable outcomes in most cases.

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Single-Row Repair

18

Stephen C. Weber

18.1 Introduction

Decreasing the re-tear rate associated with rotator cuff repair has been a major focus of the orthopedic literature for the last two decades. While some of the literature has focused on improving the biologic milieu, much of the literature has been on improving the mechanics of the construct attaching the tendon to the bone. Much of this literature has focused on the time-zero strength of the attached tendon. More recently, the biologic response to these constructs, clinical outcomes, and re-tear rates for rotator cuff repair using these differing techniques has become available. This chapter highlights the results of this voluminous literature.

18.2 Literature Summary

In response to high failure rates leading to poor outcomes with open rotator cuff repair [1] and similar early results of all-arthroscopic repair in 2004 [2], it was recognized that improvements in fixation techniques might be necessary. Apreleva et al. in an early paper noted that none of the standard techniques available at the time reproduced the rotator cuff footprint [3]. This 2002 paper inspired Lo and Burkhart to describe in a technical note one of the first descriptions of arthroscopic double-row repair in 2003 [4]. Fealy et al. [5] described one of the first clinical series of double-row repair using a mini-open technique. Another early attempt to improve on traditional single-row repair was Waltrip et al. [6]. This 2003 paper was one of the first to describe a "double-layer repair" with biomechanical data to show improved fixation strength over traditional single-row repair. Interest in double-row techniques exploded in the second half of 2000, with numerous variations and techniques described. The clinical study that most focused attention on this issue was the 2005 study of Sugaya et al. [7] in which they first described his classification of postoperative imaging of rotator cuff repairs. His classification highlights the challenge of interpreting postoperative MRI scans. This level 4 retrospective cohort study of 80 shoulders noted no difference in clinical outcomes but a statistical difference in MRI appearance of recurrent rotator cuff tears. This was followed by his 2007 publication in JBJS [8], in which they described a prospective outcome study of 106 patients using double-row repair. While the re-tear rate was 5% for small to medium tears, it was 40% for large and massive tears using double row.

This pioneering work inspired a plethora of studies regarding double-row repair. A summary of biomechanical studies and non-randomized clinical trials is shown in Table 18.1. A summary

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Table 18.1 Results of biomechanical studies and non-randomized clinical studies (from Pedowitz et al. [9])

Biomechanical studies and non-randomized clinical studies	
Better with double row	No difference DR versus SR
Waltrip, AJSM 2003 [6]	
Cyclic load, double row> single row	
Meier, ORS 2005 [10]	
Cycles to 10 mm gap	
Rodosky, AANA 2005 [11]	Rodosky AANA 2005
Footprint area	Stiffness or ultimate load
Mazzocca, AJSM 2005 [12]	Mazzocca, AJSM 2005
Footprint area	Displacement or load to failure
Tuoheti, AJSM 2005 [13]	
Contact area, force versus single row	
Sugaya, Arthroscopy [7] 2005 [7]	Sugaya, Arthroscopy 2005
Better MR appearance, double row	Clinical outcome same as single row
Kim, AJSM 2006 [14]	
Decreased gap, formation, stiffness	
Ma, JBJS 2006 [15]	Ma, JBJS 2006 [15]
Stronger vs single and Mason-Allen	Same as massive cuff stitch
	Mahar, Arthroscopy 2007 [16]. No biomechanical difference between single versus double row
Smith, JBJS 2006 [17]	
Gap less, failure load higher than single row	
Charousset, AJSM [18] 2007 [18]	Charousset, AJSM 2007 [18] no clinical difference versus single-row repair
Better "anatomic" healing on CT arthrography vs single-row repair	
Baums, Knee Surg Sports Traum Arth 222,008 [19]	
[19] Better dual than single with Mason-Allen sutures 2008	
Ozbaydar, JBJS (Br) 2008 [20] better healing with double than single row in rabbit tendon repairs	~
Hepp, Arch Orthop Trauma Surg 2008 [21] Double layer, double-row repair	
Nelson, Arthroscopy 2008 [22] better surface area with double row	Nelson, Arthroscopy 2008 [22] single- and double-row repairs biomechanically similar
Domb, JBJS 2008 [23] less gap with double row, repair tension adjusted between groups	
	Senna Rev. Bras Ortop 2018 [24] no difference in outcome scores

of the current systematic reviews and meta-analysis and level 1 and 2 randomized controlled trials (RCTs) is shown in Table 18.2. Impressively, this topic has inspired 20 meta-analyses and systematic reviews, including 1 systematic review and meta-analysis of just the level 1 studies [36], and 1 paper summarizing all the meta-analyses [39]. Many of these have surprisingly differing conclusions, given essentially the same techniques of systematic review and meta-analysis.

It can be seen that the majority of studies supported improved mechanical properties of the repair construct at time zero with some type of double-row fixation. Equally clear is the absence of any improvement in clinical outcomes or patient-reported outcomes (PROs) with the exception of the meta-analysis of Xu et al. [42] and the study of Carbonel et al. [50]. There remains considerable disagreement over any improvement in re-tear rates with double-row constructs. Millett et al. [36] in a meta-analysis of the available level 1 studies regarding single versus double row showed that while partial and complete tears are increased with single-row techniques, confirmed complete re-tears are equivalent between techniques ($p = 0.953$). Given the challenges associ-

Table 18.2 Systematic reviews, meta-analyses, and level 1and 2 randomized clinical studies

Systematic reviews and meta-analyses	
Studies demonstrating difference	Studies showing no difference
	Reardon, Arthroscopy [25] 2007 [25]
	No evidence of Wall, JSES 2009 [26] no clinical difference
	DR vs SR based upon systematic review
	Nho, Arthroscopy 2010 [27] no clinical outcome difference based upon best available evidence
Duquin, AJSM 2010 [28] meta-analysis: Lower rate rate of re-tears on imaging for DR in tears cm	
Dines, JAAOS 2010 [29] better biomechanical properties with double row (in general)	Dines, JAAOS 2010 [29] no demonstrated difference in clinical outcomes with double-row repair
Saridakis, JBJS 2010 [30] possible advantage of DR for larger tears (based upon Park AJSM 2008) no clinical	Saridakis, JBJS 2010 [30] in general, no clear clinical advantage DR repair (systematic review)
	Papalia, Sports Med Arthr 2011 [31] minimal differences DR, clinical or functional ratings
	Prasathaporn, Arthroscopy 2011 [32] no difference with DR function, satisfaction, return to work
Zhang PLOS 2013 [33] better clinical and radiographic results in large tears with DR	
	Sheibani-Rad Arthroscopy 2013 [34] no difference in clinical outcomes
	Perser Sports Health 2011 [35] no difference in clinical or radiographic results
Millett JSES 2014 [36] more partial and complete tears with single row	Millett JSES 2014 [36] no difference in complete re-tears or clinical outcomes DR repair
Chen Arthroscopy 2013 [37] less re-tears with DR repair med to large tears	
Mascarenhas J Arth 2014 [38] better tendon integrity with DR repair	
Spiegl Open Orthop J 2016 [39] increased re-tear rate with single row	Spiegl Open Orthop J 2016 [39] equivalent clinical outcomes
Hein Archive Orthop 2009 [40] increased re-tear in single-row versus DR or suture bridge	
	DeHaan AJSM 2012 [41] no difference in clinical outcomes or re-tear rates
Xu JSES 2014 [42] increased re-tear rate and improved ASES scores with double row	
	Trappey JSES 2011 [43] no difference
	Ying Orthop Surg 2014 [44]
Level 1 and level 2 randomized clinical studies	
Studies demonstrating difference	*Studies showing no difference*
	Francheschi, AJSM 2007 [45] no clinical outcome difference versus single-row repair
	Burks, AJSM 2009 [46] no clinical outcome difference versus single-row repair
	Grasso, Arthroscopy 2009 [47] no clinical outcome difference versus single-row repair
Gartsman 2013 [48] significant increase in re-tear rate with single row	
	Koh Arthroscopy 2011 [49] no significant difference
Carbonel Int Orthop 2012 [50] significant improved outcomes with DR tears >3 cm	Carbonel Int Orthop 2012 [50] no difference in re-tear rates
	Nicholas Orthop J Sports Med 2016 [51] no difference clinical outcomes

(continued)

Table 18.2 (continued)

Systematic reviews and meta-analyses	
Studies demonstrating difference	Studies showing no difference
Lapner, JBJS 2012 [52] increased re-tear single row	Lapner et al. JBJS 2012 [52] no difference in clinical outcomes
	Aydin, JSES 2010 [53] no clinical outcome difference, small to medium cuff tears
Ma, Arthroscopy 2012 [54] better strength strstrength with double-row cuff repair in tears>3 cm	Ma, Arthroscopy 2012 [54] no difference in·clinical outcome scores or radiographic healing rates

ated with the postoperative imaging of partial-thickness tears on MRI, the equivalence of complete re-tears with single- and double-row techniques may be the most relevant. Similarly Spiegl et al. [39] in their summary of meta-analyses noted that "No clinical differences are seen between single-row and double-row repair for small and medium rotator cuff tears after a short-term follow-up period with a higher re-tear rate following single-row repairs. There seems to be a trend to superior results with double-row repair in large to massive tear sizes." Six of eight cited meta-analyses in this study were felt to show superior results for double-row repair for tears greater than 3 cm. The challenges associated with interpreting meta-analyses in general was well summarized by Faulkner et al.'s [55] editorial regarding the meta-analysis of Xu et al. [42]. Faulkner et al. document issues with the number of suture, anchor placement, method of diagnosis, and using statistical significance rather than meaningful clinically important difference (MCID) to imply superiority in this meta-analysis and largely refuted the conclusions of Xu that double row is superior looking at the same data.

Balanced against the purported advantages of double row are potential significant downsides of double-row techniques. Double-row techniques address time-zero strength, but do not address the biology of the repair, and may actually harm the biology. Faulkner et al. document that the importance of marrow venting in improving rotator cuff healing [55] is a factor of significance at least equal to the number of rows. Snyder et al. covered this topic using their coined phrase "Crimson Duvet" [56] where they point out that the biology of the repair site and vascularity are perhaps at least as if not more important than time-zero strength. These and other biologic issues are well reviewed by Charles et al. [57]. Accousti et al. showed that there was a significant decrease in localized perfusion of the rotator cuff after the medial and lateral rows of a double-row repair were tied [58], an issue that Snyder et al. point out in their discussion of providing vascular channels in the repair using a single-row technique [56]. The challenges of revision of double-row repair are numerous, not the least of which is dealing with multiple residual imbedded anchors. Perhaps the most worrisome revision issue is the medial re-tear or type 2 failure. This was initially reported by Trantalis et al. [59]. Yamakado [60] noted medial re-tears in a further four cases and noted significant challenges with re-repair. Cho et al. [61] reported that type 2 failures occur in 74.1% of DR re-tears compared with 26.3% of SR re-tears. There are few salvage options for type 2 failures.

Perhaps the most challenging part of reviewing this topic is understanding exactly what "single row" and "double row" entails. Single-row simple mattress and single suture repairs are not comparable to single-row constructs with double- and triple-loaded anchors or additional rip-stop sutures. Barber et al. showed that the number of sutures and not the number of rows may be the most important variable [62] as did Jost et al. [63] A mechanical study performed by Lorbach et al. [64] showed that a single-row triple-loaded anchor construct provided equivalent footprint coverage to a double-row suture bridge repair with equal load to failure and cyclic displacement for all tear sizes. Triple-loaded anchors were recently shown in a prospective, randomized study to be completely equivalent to a double-row construct both in clinical outcomes and healing rates [65]. Making sense of the literature that compares multiple types of both single- and

double-row constructs is difficult indeed. Comparing single-row techniques of historic interest to current double-row techniques is certainly "apples to oranges" and offers little useful information for decision-making.

Perhaps the least controversial comparison between single-row and double-row repair is cost. The implant costs associated with double-row repair in the United States generally exceed the reimbursement for the procedure in an outpatient setting, making it commercially unfeasible. Faulkner et al. [55] note that doubling the number of anchors given that 20% of the US population may have a rotator cuff tear could yield an increased cost of $31.4 billion to repair these tears. Genuario et al. [66] did a cost-effectiveness analysis and noted that double-row repair was not cost-effective even for large (>3 cm) tears. Lapner et al. [67] and Huang [68] both felt that double-row repair was more cost-effective but used failure rates of single-row techniques of historic interest to justify the increased cost of double-row repair. The role of implant companies in promoting double-row repair to improve their own bottom line is unclear, but the science of double-row repair does not seem to conclusively support its cost-effectiveness.

18.3 Conclusion

Overall, single- and double-row rotator cuff repairs are equivalent in terms of clinical outcome based on PROs in virtually all currently available studies. While re-tear rates remain elusive, the rates of complete re-tears with single-row and double-row repair remain similar in all studies. Given the increased risks associated with revision of double-row repairs and the cost, it is difficult at this time to make a convincing case for double-row repair.

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19 Delaminated Tears of the Rotator Cuff: The Rationale and Techniques for the Double-Row Repair

Enrique Salas, Guillermo Arce, and Gustavo Matheus

19.1 Introduction

The rotator cuff is constituted by the tendons of the supraspinatus, infraspinatus, and teres minor muscles, and it has more than one layer. Delamination represents a horizontal separation of the tendon layers in the setting of a ruptured rotator cuff. Histologically, delamination occurs between two layers of collagen fibers with a different fiber orientation [1].

Although delamination is frequently observed during arthroscopic surgery (38–82% of the cases), only a few reports describe the layers involved and the retraction patterns of the delaminated cuff tendon. In addition, there is a lack of well-founded recommendations regarding the most appropriate surgical technique to anatomically repair these cases [2].

The physical exam of patients who suffer from rotator cuff tears does not vary if the tear is delaminated or not. Standard magnetic resonance imaging (MRI) usually does not demonstrate the tendons delamination, while MRI with either intra-articular or intravenous contrast injection enables differentiation between both types of tears.

In 2001, Sonnabend et al. [1] first reported a laminated lesion in a patient with rotator cuff tear injury, while Boileau et al. described the healing of the supraspinatus following arthroscopic repair. Their findings demonstrated that tendon recovery was poorer in case of subscapularis or infraspinatus delamination [3].

According to Sang-Won Cha et al. [4], comprehension of the delamination process and the retraction patterns allows for an anatomical balanced repair of each layer.

In occasions where two tendon layers are found at the rotator cuff tear site, the upper layer is recognized as the supraspinatus or the infraspinatus and the lower part of the horizontal tear as the superior glenohumeral capsule. A surgical technique entailing independent repair of the infraspinatus and the articular capsule was described by Mochizuki et al. [2]. The objective is to restore the static function of the capsule and the dynamic function of the rotator cuff. By doing so, the technique may lead to better clinical outcomes [5].

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19.2 Imaging: Findings and Classifications

Contrast MRI of the shoulder represents the best imaging study for the identification of delaminated tears. The sensitivity and specificity for the detection of delaminated tears with this technique are 92% and 94%, respectively [6]. Recently, an MRI classification for this type of tears has been described (Table 19.1) [6].

Cha et al. classified tears according to the lesion pattern of the delamination (Table 19.2) [4]

Table 19.1 Choo, Kim et al. radiological classification for partial or complete delaminated tears

Type 1	Completely delaminated rotator cuff tears
1a	The deep or articular layer is more medially retracted than the superficial or bursal layer, with or without the horizontal image
1b	The superficial or bursal layer is more medially retracted than the deep or articular layer, with or without the horizontal image
1c	The superficial or bursal layer is equally retracted than the deep or articular layer, with or without the horizontal image
Type 2	**Partially delaminated rotator cuff tears**
2a	The delamination is only of the deep or articular layer and medially retracted; the superficial or bursal layer is normally inserted, with or without the horizontal image
2b	The delamination is only of the superficial or bursal layer and medially retracted; the deep or articular layer is normally inserted, with or without the horizontal image
2c	The delamination is interstitial; it is between layers both deep or articular layer and superficial or bursal layer

Table 19.2 Tear pattern of delaminated rotator cuff tears. Himchan classification

Type D	The observed pattern retraction of the deep layer
D1	Supraspinatus and infraspinatus lesion, with posterior-medial retraction
D2	Supraspinatus lesion, anterior medial retraction
Type S	**The observed pattern for the superficial layer**
S1	The lesion is more infraspinatus than supraspinatus with posterior-medial retraction
S2	The lesion is more supraspinatus than infraspinatus, with anterior medial retraction
S3	The lesion is equal for the infraspinatus and the supraspinatus, with retraction anteriorly and posteromedially

19.3 Surgical Treatment

Currently described arthroscopic techniques must be tailored to each specific injury pattern. We depict below the most commonly used:

19.3.1 Technique by Suyaga et al. [7]

The authors reported two alternative techniques:

19.3.1.1 Dual-Layer Double-Row (DLDR)

- To perform the DLDR, the surgeon repairs the deep and superficial layer separately based on the direction of the tear and the retraction pattern of each layer.
- One or two anchors at 0–5 mm articular margins are inserted. The articular surface of the deep layer and the superior capsule are taken, and after delivering the sutures through the tissue, a knot is tied.
- One to three anchors are inserted at the lateral margin of the greater tuberosity to fix the superficial or bursal layer.

19.3.1.2 Dual Layer Suture Bridge (DLSB)

DLSB technique is assumed to be an effective surgical method if the tear retraction pattern of both (deep and superficial) layers runs in the same direction.

Place two anchors at the medial row. Penetrate the articular surface of the deep layer and the superior capsule with a mattress stitch. Make a knot. Do not cut the tied suture limbs.

Pass the medial row tied sutures through the superficial layer. Place a knotless anchor at the lateral part of greater tuberosity to complete the suture bridge configuration.

19.3.2 Technique by Mochizuki et al. [2]

The deep layer is treated as the articular capsule. It is pulled laterally across the glenoid and fixed at the articular edge of the great tuberosity.

The superficial layer is treated as the infraspinatus. It is pulled anterolaterally up to the edge of the bicipital groove and stabilizes with an anchor.

19.3.3 Technique by Burkhart et al. [8]

Load-sharing ripstop (LSRS) is described to improve fixation strength in delaminated cuff tears associated with poor tissue quality. A 2-mm suture tape is placed in anterior-posterior direction as an inverted mattress stitch in the rotator cuff.

Medial row sutures coming from two anchors are passed through the deep and superficial layers of the cuff medial to the tape. First, the ends of the tape are fixed to the greater tuberosity with a knotless anchor. Lastly, the medial row sutures are tied.

19.3.4 Technique by Mori et al. [5], Triple Row (Picture 19.1)

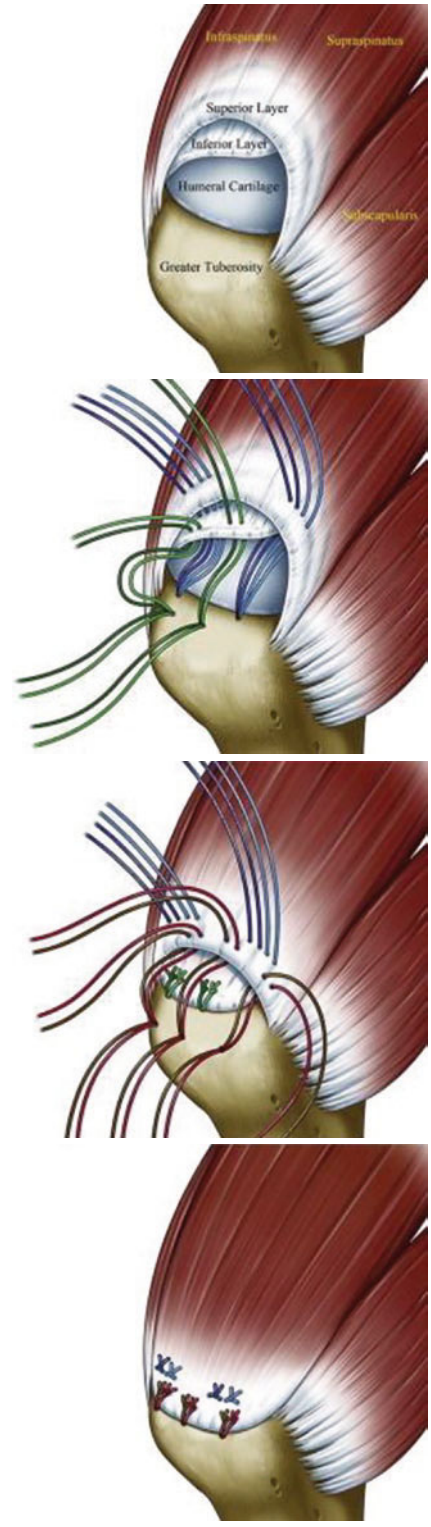
Medial row sutures are passed through the inferior (articular side) and superior (bursal side) layers in a mattress fashion.

Lamina-specific lateral-row simple sutures are passed through the inferior layer.

Lateral-row simple sutures are passed through the superior layer.

19.4 Rehabilitation

The rehabilitation program depends on the tissue quality and the fixation strength. Commonly, after a period of immobilization of 4 weeks, a gentle passive motion with a stable scapula is recommended for at least 8 weeks.



Picture 19.1 Scheme of tripe-row delaminated rotator cuff repair. Courtesy of: Mori, Funakoshi, Yamashita. Arthroscopy Techniques 2014

19.5 Discussion

Several studies have consistently shown a horizontal split between the different layers of a teared rotator cuff, with a delamination rate of 71%. Such rate did not vary by gender, age, handedness, worker compensation status, or tear size. MacDougal [9] stated that the presence of delamination did not influence the total Western Ontario Rotator Cuff score or physical symptoms subsection score either preoperatively or at 2 years following arthroscopic repair. However, other studies have shown that the presence of cuff delamination increases procedural risk and impairs long-term outcome.

Although contrast MRI can't detect cuff delamination and help typify them, its use in every single patient with shoulder pain appears excessive, increasing health cost. In contrast, arthroscopic examination remains the best way to determine the various retraction patterns of delamination [6, 10–12].

Regarding the infraspinatus muscle, it is critical to recognize its precise insertion site at the top of the greater tuberosity, its layers, and its retraction patterns. Such data enable the restoration of native insertions sites and natural biomechanics which will ultimately lead to better clinical results.

Kim et al. [13] compared double-layer double-row repair versus conventional en masse repair in patients with delaminated cuff tears. Although both techniques shared similar range of motion and functional scores, double-layer double-row repair lead to lower visual analog scale score for pain. Meanwhile, on a recent systematic review including ten papers [14], the authors found no clear difference in clinical outcomes among single-row, double-row, or triple-row techniques in patients with delaminated tears except for an improvement in short-term structural integrity with double-row technique. However, many of the abovementioned publications studies did not report the precise tear pattern orientation, its reinsertion site, as well as technical details regarding the double- row technique. Therefore, the role of double- and triple-row fixation techniques still needs to be tested on a standardized fashion and with longer follow-up.

19.6 Final Thoughts

Delaminated rotator cuff tears are relatively common during arthroscopy. The deep or articular layer seems to be part of the superior capsule, whereas the upper or bursal layer arises from the infraspinatus. The surgical goal is to recognize the tear patterns and the retraction of each layer to reduce and repair the different layers appropriately. Further research is needed to really know if these new ways to approach these tears will lead to better clinical outcomes.

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Double Row Rotator Cuff Transosseous Equivalent Repair

20

Gonzalo Samitier and Emilio Calvo

20.1 Indications

Numerous biomechanical studies have demonstrated improved tendon to bone contact, increased footprint coverage, decreased gap formation, and increased mechanical strength with double-row configurations [1–5]. These favorable biomechanical properties are thought to improve the healing process allowing an accelerated physical therapy. However, clinical evidence comparing the efficacy of single-row versus double-row repair has been inconsistent. Whereas some studies report no clinical differences [6, 7], others have shown significantly improved subjective, objective, or radiologic outcomes and decreased re-tear rate after double-row repair, especially for larger tears [8, 9].

The authors reserve initial nonsurgical treatment for those patients with chronic symptomatic tears that never tried conservative measures and those who remain asymptomatic, regardless of the size of the injury, as long as they have no pseudoparalysis; cuff tears tend to progress overtime and become more difficult to repair. Thus we do recommend to the patients with complete tears and relatively young age to do not delay consultation or surgery if symptoms and/or limitation return [10, 11]. For large tears in acute traumatic setting, we will offer surgery primarily in most cases.

Our non-operative approach consists of guided physical therapy to keep a strong force couple. It is very common for these patients to have one or more subacromial corticosteroid injections along the process trying to reduce the inflammatory response and pain. We also favor conservative treatment for symptomatic low-demand elderly population, patients who are not willing to have surgery, and/or patients who are medically inadequate.

20.2 Operative Principles

We usually recommend surgical treatment if conservative measures showed to be not effective over 8–12 weeks.

20.2.1 Strategy

Single-row repair is reserved for small full-thickness tears and partial articular-sided tears with preserved lateral footprint. For midsize,

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large, and massive mobile reparable rotator cuff tears, the authors choose transosseous equivalent (TOE) double-row suture bridge technique mostly with medial-row tying. Described by Park et al. in 2006, the TOE double-row technique has demonstrated greater tendon to bone contact area and higher load to failure compared with other double-row configurations [12–15]. We favor medial-row knot tying over knotless repairs especially in delaminated tears where anatomic independent layer repair is intended using the lasso-loop technique. Previous studies have shown better biomechanical properties after medial knot tying performed as part of a TOE suture bridge construct compared with all-knotless constructs [16–19]; nevertheless, knotless repairs have also shown clinical success in the past [20, 21]. We may favor a suture/tape speed bridge configuration, without medial knot tying for midsize complete crescent-type tears. Millett et al. in a recent research demonstrated excellent outcomes at 2 years with either knotted suture bridging or knotless tape bridging transosseous equivalent double-row rotator cuff repair for full-thickness supraspinatus tendon tears; the repair technique did not affect the final functional outcomes, although patients with medial knotless repairs using tape were less likely to have a full-thickness rotator cuff re-tear [22].

Type II re-tears, at the level of the muscle tendon unit, with medial-row knot tying seem to be an increasing finding in recent studies [23, 24]; in order to avoid this complication, we tend to separate the couples of threads piercing the cuff and avoid over-tensioning or tying knots through the musculotendinous junction [25].

For the massive, immobile, and irreparable tear in relatively young population, tendon transfers have been recommended, but also preliminary clinical outcomes of superior capsular reconstruction have been encouraging [26–28]. For symptomatic massive irreparable tears in elderly patients with or without signs of rotator cuff arthropathy and/or pseudoparalysis, we opt for reverse total shoulder arthroplasty, given the predictable good outcomes in regard to pain and functionality [29].

20.3 Preoperative Information: Managing Patient Expectations

A complete medical history of the patient and a full physical exam with an adequate imaging study are important to build a convenient preoperative plan. In revision cases, the main factors related to failure should also be examined as history of trauma, complete reports about previous surgical procedures as detailed as possible, smoking habits, and whether early aggressive motion or strengthening contributed to structural failure. Rotator cuff repair is an elective surgery that requires careful preoperative evaluation and discussion of treatment expectations, risks, and benefits. Overall, repairs of rotator cuff tears have been shown to lead to good-to-excellent outcomes in most patients, with significant improvement in the mean scores on self-assessment questionnaires, however, multiple factors, including age, gender, smoking, larger tear size, poor tendon quality, fatty degeneration, workers' compensation status, and healing potential of the rotator cuff repair, have been shown to be associated with less favorable outcomes after rotator cuff repair [30, 31]. The patient must be advised of potential surgery- and anesthesia-related issues; postoperative timing should be discussed; and the recovery process after rotator cuff repair, especially in regard to motion and strength, is usually slow and occasionally can't be reversed back to normal [32].

20.4 Operative Technique

Double-row transosseous equivalent suture bridge repair.

The double-row TOE suture bridge rotator cuff repair preserves the suture limbs of the medial row and "bridges" them over the footprint insertion to a distal-lateral row of knotless suture anchors; medial and lateral suture anchors are "linked" where the interconnecting suture compresses the tendon over its footprint (Fig. 20.1).

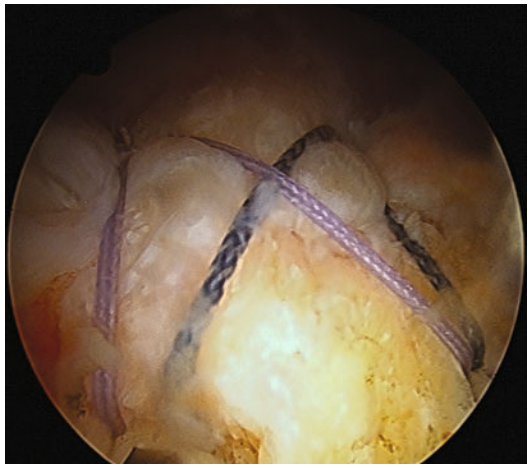

Fig. 20.1 Double-row configuration

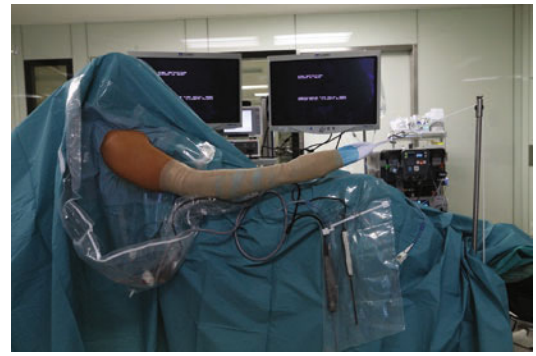

Fig. 20.2 Patient positioning for arthroscopic rotator cuff repair. Forward flexion is very helpful in creating enough space for repairing posterosuperior rotator cuff tears

20.4.1 Positioning and Preparation

Anesthesia is carried out following a standardized protocol based on a single-shot interscalenic 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). Isolated regional anesthesia is reserved for those with increased risk of complications with general anesthesia. Antibiotic prophylaxis (2 g cefazolin or 1 g vancomycin as alternative for patients with β-lactam allergy) is administered 30 min before surgery. Rotator cuff tear repair can be performed either on the lateral decubitus or beach chair positions (BCP) with the arm forward flexed and 3–4 kg of traction. We find beach position more ergonomic and easier to work in the subacromial space, the surgeon stands in front of the shoulder facing the shoulder positioned in its anatomic position, the left and right hands can be used to insert instruments alternatively through anterior or posterior portals, and the arm can be moved easily facilitating the rotator cuff repair. It is important to adequately pad the heels, hand, and forearm and to set up the head centered maintaining a neutral position of the neck with no rotation (Fig. 20.2). 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 neutral position using straps to prevent any lateralization of the patient during the procedure.

The operative extremity is prescrubbed with chlorhexidine solution, and once the patient is properly positioned, definitive sterile preparation and draping is performed. At the conclusion, the surgical team should change gloves and conduct a final preincision time-out.

Controlled hypotension and muscular relaxation is desirable as it may allow better visualization, decrease blood loss [33], and reduce operative time which secondarily can affect the quality of the repair and patient safety. Because of the risk for neurological ischemic events, caution should be exercised with hypotensive anesthesia in the BCP; elderly patients, hypertensive patients with poor control, and patients with BMI > 34, diabetes mellitus, obstructive sleep apnea, and previous history of stroke are considered high-risk population [34]. 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 (FMS®; DePuy, Mitek, Raynham, Massachusetts). The pump is usually set up initially to start at 80/90 mm Hg.

20.4.2 Surgical Technique

20.4.2.1 Posterosuperior Double-Row Rotator Cuff Repair

Although numerous descriptions were made on where portals for rotator cuff reconstruction should be precisely located, we recommend establishing liberally as many portals as needed after testing the appropriate position and direction of the portal with a spinal needle. A precise anatomic knowledge is necessary to avoid injury of neurovascular structures. Typically three to six arthroscopic portals are established. These portals are placed posteriorly, posterolaterally, laterally, anterolaterally, and anteroinferiorly (Fig. 20.3). For anchor insertion it is often necessary for a more medialized lateral portal close to the lateral edge of the acromion to have an adequate entry angle. The anterior portal, lateral to the coracoid process, is often used to repair subscapularis tears. The Neviaser portal, medial and posterior to the acromioclavicular joint, can be helpful for suture passing when the tear is not accessible from anterior or posterior portals, but in the beach chair position, the patient's head can restrict the movement of instruments (Fig. 20.4). The authors do not routinely use cannulas for arthroscopic rotator cuff repair.

After sterile preparation and draping, a slightly superiorly placed posterior viewing portal is developed, 10 mm inferior to the scapular spine, in line with the glenohumeral joint. Then, for instrumentation, an anteroinferior portal is made using in outside-in manner a 20-gauge needle, and intra-articular diagnostic arthroscopy is subsequently performed. During the joint exam, the size of the rotator cuff tear is assessed along with the subscapularis tendon, long head of the biceps, bicipital entry groove, glenohumeral articular surface, and labrum. A decision is made at this point to treat or not associated intra-articular injuries if any.

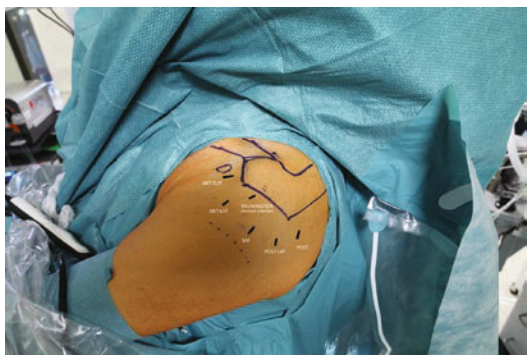

Fig. 20.3 Portals recommended for arthroscopic rotator cuff repair

Then the camera is removed from the joint, and the trocar and the camera sheath are repositioned into the subacromial space through the same posterior portal. The tip of the blunt trocar should palpate the coracoacromial ligament and rest lateral to it; this area is normally free of the posterior bursa and facilitates to establish the lateral portal. The camera is introduced, and the subdeltoid space is filled with saline solution. The 20-gauge needle is again used (and hereafter for other portals) to establish the lateral portal approximately 3–4 cm lateral to the lateral edge of the acromion in line with its midportion or slightly posterior. The lateral portal is used to enter the arthroscopic shaver or the radiofrequency device in order to clear the subacromial bursa, reactive synovitis, and subdeltoid adhesions facilitating the subsequent rotator cuff repair. In our practice we only perform subacromial decompression if signs of subacromial impingement are identified or when extra room is needed to proceed with the rotator cuff repair. In these scenarios, the anterolateral acromion is identified, the coracoacromial ligament is resected, and a 4.5 mm burr is used to perform the acromioplasty. If resection of the acromioclavicular is needed, it is performed at this moment in time utilizing the same anterior portal used for joint inspection but directing our instruments in line with the AC joint; the camera can be positioned in the posterior or lateral portal indifferently. If any intervention to the long head of the biceps tendon is necessary (either tenotomy or tenodesis), it should be performed prior to the rotator cuff tear repair to prevent any interference with the reconstruction.

We recommend placing the camera in any of the more lateral portals for visualization. In this position it provides an optimal angle for a

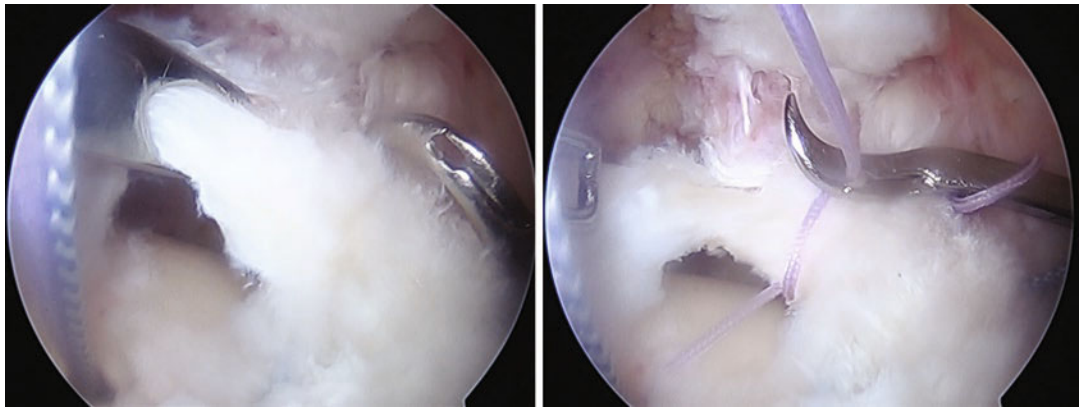

Fig. 20.4 Lasso-loop stitch used for double-layer double-row rotator cuff tear repair

complete evaluation of the configuration of the rotator cuff tear and furnishes an ample visualization of the anterior aspect of the subscapularis, which facilitates its repair if needed. Once bursectomy is completed, retraction can be tested from anterior or posterior portals using an arthroscopic forceps. The accessory lateral portals are often used for instrumentation and completion of the rotator cuff release. According to the configuration of the tear, at any time, those accessories anterolateral or posterolateral portals can be created to assist the instrumentation. It is very important to understand correctly the tear configuration to plan the repair. While crescent-shaped tears are repaired to the footprint reducing the tendon medial to lateral, in L-shaped and reverse L-shaped tears, it is very important to identify the apex of the tear that should be reduced to the corresponding edge of the footprint.

At this point, tendon releases are performed; for larger immobile rotator cuff tears, the objective is to achieve a tension-free repair of the rotator cuff, so the tendons move easily in line with the direction of the retraction to the footprint; the technique employed includes resection of the coracohumeral and superior glenohumeral ligaments, resection of the rotator interval to the base of the coracoid, and a release between the undersurface of the rotator cuff and the glenoid labrum and neck. An interval slide technique in between supra- /infraspinatus, as suggested by Burkhart et al., can additionally be performed if needed [35]; our experience with the rotator interval slide technique has been limited, but we failed to find any benefit to improve rotator cuff healing as other authors [36]; it is important also to do not separate the anterior supraspinatus tendon attachment to the coracohumeral ligament and the subscapularis, the so-called comma sign by Burkhart, as this compromises the strength of the distal tendon and helps greatly in the reduction of the supraspinatus once the subscapularis is in place. Traction sutures may also be helpful in exposing adhesions to the rotator cuff during the release, managing tendons during the repair, and relieving tension during the knot tying.

Once adequate release has been achieved, reduction of the cuff over the greater tuberosity is attempted using a grasping instrument or the aforementioned traction sutures. At this time it is important to check the tension and confirm the viability to perform a double-row repair. The greater tuberosity is gently decorticated with a burr or shaver. In most double-row constructions, two double-threaded (4.5 or 5.5 mm Healix Advance® Depuy Mitek, Raynham, Massachusetts, USA) anchors are placed medially at the junction of the articular surface and the greater tuberosity. Pilot holes can be performed using a punch in the majority of patients, but a tap can be needed depending on the quality of the bone. Typically, anchors can be placed from the anterolateral portal, but it is not uncommon to use a more medialized lateral portal for adequate insertion angle of 45°. The posterolateral and

anterolateral portals are utilized to pierce the tendon using a hook self-retrieving device (Cleverhook® Depuy Mitek, Raynham, Massachusetts, USA) in a horizontal mattress pattern depending on the configuration and size of the tear. In some cases a suture passer grasp (Scorpio® Arthrex, Naples, FL) or a shuttle relay device (Suturelasso® Arthrex, Naples, FL) is preferable to minimize tissue damage during the suture passage. When all the sutures from each anchor are passed through the rotator cuff, they should be clamped together outside of the skin in order to optimize suture management. The sutures pairs coming from the same anchor are grasped together before proceeding to the knot tying of the medial row. Both limbs of one suture in each anchor are preserved without cutting and will be used for the lateral row. Once all mattress repair sutures of the medial-row anchors have been placed and tied, the goal is to link these anchors with the lateral row. First we select the best portal to insert our anterior and posterior lateral-row anchor; it is usually the anterolateral portal. One limb from each single knot tied medially is retrieved and loaded into the eyelet of a knotless anchor (4.75-mm Healix Advance Knotless® Depuy Mitek, Raynham, Massachusetts, USA). While some tension is applied to the threads, the anchor is then placed just lateral to the bursal rotator cuff footprint on the greater tuberosity. The remaining limbs are gathered again from the same portal, loaded, and placed in a similar fashion to complete the TOE repair. Cortical bone in the lateral footprint of the footprint is usually weaker, and it is advisable to do not bury the anchors in this area.

Occasionally for small- and medium-sized non-delaminated tears, we may load single-tape suture in two medial-row knotless anchors in order to reproduce the double-row transosseous equivalent-type configuration as described initially from Park et al. [12].

When a delaminated, double-layer, rotator cuff tear is present, we often use the technique of the lasso-loop stitch for the deep lamina, as described by Lafosse et al., to bring it down effectively to the native medial footprint [37]. With this technique, it is important to ensure that both the superficial and deep tendon possess appropriate mobility for anatomic repair by pulling it to the ideal insertion for each layer independently. In order to perform the lasso-loop stitch, the retrieval hook (Cleverhook® Depuy Mitek, Raynham, Massachusetts, USA) is passed through the lateral edge of the deep layer of the tear to retrieve one suture from the anchor; when the suture is partially pulled through, it makes a loop, and then the curved tip of the device must enter through the loop and retrieve the free end of the same suture forming the loop pulling it outside of the shoulder. The free end of the thread doing the lasso loop is then passed through the superficial layer. The other thread from the anchor is passed in a conventional manner through both layers of the tear without creating the loop. The lasso-loop technique permits by pulling from the non-loop thread, using it as the post during knot tying, to approximate better the deep layer to the anatomic footprint (Fig. 20.4).

20.4.2.2 Anterosuperior Double-Row Rotator Cuff Repair

Double-row fixation of the subscapularis is challenging because of the small anterior space overlying the subscapularis. Whereas the subacromial space allows freedom of movement, the limited subcoracoid space makes visualization, instrument manipulation, and knot tying more difficult. Denard et al. first described the technique for double-row subscapularis repair [38]. The same principles described for posterosuperior rotator cuff repair are followed for subscapularis repair. For type I to III subscapularis tears, using a single-row configuration with 1 or 2 4.5 mm double-loaded anchors seems sufficient; we reserve double-row repair for the largest subscapularis tendon tears, types IV and V, based on Lafosse's classification of subscapularis tears [39].

The patient is placed in the beach chair position, combined anesthesia is used, and the camera is kept in the posterior portal to proceed with the repair from the intra-articular site in most cases; for the types IV and V and most retracted tears with multiple adhesions, we may move the camera to a more lateral or anterolateral portal in

order to improve visualization when performing the extensive circumferential release of the subscapularis required for these tears. Because most tears begin at the upper articular surface, a bare lesser tuberosity footprint is indicative of a tear. Sometimes the footprint is difficult to identify, and placing the arm in abduction and internal rotation helps to visualize the subscapularis footprint.

An anterior portal is established for instrumentation and anchor placement. This portal begins somewhat more medial than the typical anterior portal and is created to enter the glenohumeral joint just lateral to the coracoid. A 4.5 mm shaver and a 90° radio-frequency system device are used to create a window in the rotator interval just superior to the subscapularis tendon. The medial sling of the biceps and the superior glenohumeral ligament should be preserved laterally. The subscapularis tendon is then released; and a shaver or a burr inserted through the anterior or an anterosuperolateral portal is used to abrade gently the lesser tuberosity bone bed. For the medial row, anchors then inserted at the border between the cartilage and bone through an anterior portal lateral to the coracoid process. Medialization of the footprint can be necessary in cases with severe subscapularis retraction. Sutures are retrieved through the accessory anterolateral portal, and then a suture-passing device passed through the anterior portal pierces the tendon anteriorly to retrieve the sutures sequentially. Once the sutures are tied, lateral-row fixation is then accomplished with the suture tails from the medial row and an additional knotless anchor (4.75-mm Healix Advance Knotless® Depuy Mitek, Raynham, Massachusetts, USA).

20.5 Postoperative Management

We perform most of our cuff repairs as an outpatient procedure except for those patients who are not medically suitable. A single-shot brachial plexus block performed as previously described results in a great analgesic effect for at least 10 h. Before discharge, patients are instructed to start taking oral medication at home regularly from about 6 h after surgery (while the block is still working). Postoperative analgesia after discharge consists of an oral nonsteroidal anti-inflammatory (NSAID) agent (ibuprofen, 600 mg/8 h) combined with acetaminophen 1000 mg/8 h. Patients are instructed to receive oral tramadol 50 mg/12 h as a rescue medication if the combination of ibuprofen and acetaminophen is not enough to control the pain. After 48 h from surgery, patients are recommended to reduce doses as soon as the pain subsides; cold therapy commenced 3 h after surgery and is used 15 min at a time every 2 h to control pain and swelling. NSAID intake is limited postoperatively because of the potential side effects and the known adverse impact on tissue healing and bone metabolism [40, 41].

20.6 Follow-Up Treatment

The postoperative rehabilitation program is critical for success after RC repair. There is no agreement about the best timing to start rehabilitation postoperatively. While some authors have reported better results after accelerated rehabilitation, other studies have warned about the risk of re-tearing [42]. Two perspective, randomized studies comparing early versus delayed physical therapy after rotator cuff tear repair registered not significant different outcomes [43, 44].

In our practice, early passive exercises after RC repair to prevent initial postoperative shoulder stiffness are allowed for small- to midsize stable repairs. We delay physical therapy until the sixth week in patients with large to massive tears, as well as those patients with poor tissue quality; research from Parson et al. found that ROM restriction did not predispose to stiffness at 1 year [45]. In selected patients with high risk for shoulder stiffness (coexisting calcific tendinitis, adhesive capsulitis, PASTA-type repair, concomitant labral repair, and single-tendon RC repair), early rehabilitation is advised; Koo and Burkhart [46] demonstrated that those patients are high risk of developing limited ROM and qualify for an accelerated rehabilitation program.

20.7 Tips, Tricks, and Pitfalls

- Use additional portals as needed for suture management, cuff release, or anchor placement.
- For visualization, avoid excessive water extravasation and turbulence, plugging temporarily the portals with a needle cup or a urinary catheter plug.
- Identify the tear pattern and do work in your cuff release as described.
- Use temporary traction sutures to improve your release and facilitate suture passing.
- Medialize the footprint if needed using a motorized burr.
- Be aware that most of the larger rotator cuff tears are delaminated at the level of the supra and mostly the infraspinatus tendon to include the inferior layer in your repair.
- Do not bury the anchors in the lateral row; cortical bone is weaker in this area.
- Use the adequate tap or punch depending on the quality of the bone and be aware of the presence of previous bone cysts in the humeral head.
- If you are not using cannulas, always shuttle the involved two sutures out together; take out any other suture in that portal before tying.
- During TOE repairs, separate enough the couples of threads and avoid over-tensioning the medial-row knot tying.
- Do not tie knots through the musculotendinous junction.

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21 Classification of Subscapularis Tears and Correlation with Physical Exam

Michelle X. Xiao, Rebecca A. Carr, and Geoffrey D. Abrams

21.1 Background

The subscapularis is an important contributor to normal shoulder function. It receives innervation from the upper and lower subscapular nerves (C5, C6, C7) and originates on the subscapular fossa of the scapula and inserts on the lesser tuberosity of the humerus. It is the sole anterior rotator cuff muscle-tendon unit and acts to internally rotate and adduct the humerus as well as provide anterior stability to the glenohumeral joint [1]. Along with the other rotator cuff muscles, the subscapularis provides an important dynamic force couple to keep the humeral head centered upon the glenoid, allowing for shoulder stability and proper kinematics [2]. In addition, the superolateral aspect of the subscapularis tendon is confluent with the superior glenohumeral and coracohumeral ligaments, forming a pulley that stabilizes the long head of the biceps tendon.

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Historically, the presence of subscapularis tears was thought to be low. In 1934, Codman reported a 3.5% rate of subscapularis tears in a series of 200 patients with rotator cuff tears [3]. Warner et al. reported a subscapularis tear rate of 4.6% in another series of 407 patients who had supraspinatus and infraspinatus tears and underwent open rotator cuff repair [4]. More recently, however, with the increased use of arthroscopic approaches for rotator cuff repair, subscapularis tears have been increasingly recognized. Arai et al. noted a prevalence of 27% in a series of patients with supraspinatus tears [5], while Barth et al. found a prevalence of 29% [6]. A more recent series, which also proposed a detailed tear classification system, noted an incidence of over 50% [7]. Isolated subscapularis tears remain less common, occurring in approximately 5% of patients undergoing rotator cuff repair [8] and are usually associated with traumatic injury to the shoulder [9, 10]. Subscapularis tears are often associated with biceps tendon pathology given their close anatomic relationship [11, 12].

21.2 Classification of Subscapularis Tears

Multiple classification systems have been reported for subscapularis tears based on arthroscopic findings. However, there is no universally accepted classification system. Tears are

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generally classified as partial thickness or full thickness, and the degree of tendon retraction also guides classification. Fox et al. first reported an arthroscopic technique for subscapularis repair using a classification system comprised of four types [13]. Type 1 tears were partial thickness tears of the subscapularis, type 2 were full-thickness tears of the upper 25% of the tendon, type 3 were full-thickness tears of the upper 50% of the tendon, and type 4 consisted of complete subscapularis tendon rupture.

Lafosse et al. proposed a classification system for subscapularis tears to differentiate repairable and non-repairable tears [8]. A type I tear consists of a partial lesion localized to the superior third of the subscapularis tendon. The superficial fibers of the subscapularis remain intact, as type I tears only affect the deep fibers and do not exhibit tendon retraction. Type II tears involve complete ruptures of both the superficial and deep fibers of the subscapularis localized to the superior third of the tendon. Type III tears are complete tears of the upper two-thirds of the tendon. Type IV tears are complete ruptures of the entire tendon without anterior displacement of the humeral head on the glenoid. These tears have a Goutallier score of less than three, whereas Type V tears consists of complete tears of the subscapularis tendon with humeral head subluxation and coracoid impingement and a Goutallier score greater than or equal to three [8]. Garavaglia et al. expanded on the Lafosse classification by subdividing Type I tears into two subgroups. Grade 1a tears were described as having minor fraying at the insertion site, whereas grade 1b tears involved partial tearing of the deep fibers at the subscapularis insertion on the lesser tuberosity of the humerus [14].

A more recent classification system was formulated based on the three-dimensional subscapularis footprint anatomy found in a cadaveric study consisting of four facets on the lesser tuberosity [7]. A type I tear consisted of a leading edge tear with fraying or longitudinal split of the tendon. Type IIa tears have less than 50% detachment from the first facet, while type IIb tears have greater than 50% detachment from the first facet. Type III included complete thickness tears of the first facet. Type IV comprised of complete thickness tearing off the first and second facets and medial retraction of the entire tendinous portion of the subscapularis insertion. Type V consisted of complete tearing, including the muscular portion at the inferior lesser tuberosity facet [7].

21.3 Correlation of Physical Exam with Subscapularis Tears

There are three predominant special tests for the diagnosis of subscapularis pathology: belly-press, lift-off, and bear-hug tests. Some physicians also utilize the internal rotation lag sign. All of these tests involve active internal rotation of the shoulder in varying degrees of shoulder flexion. The lift-off test places the dorsum of the hand in the lumbar region so that the humerus is internally rotated and extended [10]. A positive test occurs when the patient is unable to further internally rotate the humerus, indicted by an inability to lift the hand off the back. The internal rotation lag sign is evaluated with the arm in the same starting position as the lift-off test [15]. However, in this test the arm is held at near maximal internal rotation (hand off of the back), and the patient is asked to maintain this position. A positive test occurs when the arm drifts into external rotation (hand nears the back), with the magnitude measured in degrees.

When the patient is not able to perform either of the above tests due to discomfort, the belly-press test is may be used by having the patient press the palm of their hand into their abdomen [9]. The test is considered positive when the elbow drops in a posterior direction, internal rotation is lost, and pressure is exerted by extension of the shoulder and flexion of the wrist. More recently, the bear-hug test has also been described [6]. In this test, the palm of the involved side is placed on the opposite shoulder. The patient is asked to hold this position as the examiner tries to pull the patient's hand from the shoulder. The test is considered positive when the patient is not able to resist the examiner and the hand lifts from the shoulder or when there is weakness as compared to the contralateral (unaffected) side.

All of these tests were compared in an investigation by Yoon et al. who performed preoperative isokinetic testing in over 300 patients undergoing rotator cuff repair [16]. They reported that for detecting any tear of the subscapularis, the belly-press was the most sensitive (28%), while the lift-off was the most specific (100%). For differentiating a full-thickness tear from a partial tear, the most sensitive test was the belly-press test (57%) while the most specific was the lift-off test (97%). Furthermore, a positive lift-off test best correlated with loss of internal rotation strength.

21.4 Conclusion

Recognition of subscapularis tears has increased with the wide adoption of arthroscopic techniques for the treatment of shoulder pathologies. More advanced classification systems delineate between partial and full-thickness tears as well as the amount of tendon torn from the lesser tuberosity. Physical exam maneuvers have good specificity but lack significant sensitivity, in the detection of subscapularis tears.

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Single-Row Subscapularis Repair: The Intra-articular Technique

22

Michelle X. Xiao, Rebecca A. Carr, and Geoffrey D. Abrams

22.1 Management of Subscapularis Tears

Non-operative treatment is undertaken for small, degenerative (non-traumatic) tears of the subscapularis in the older or less physically active individuals. Physical therapy may be utilized, with rehabilitation protocols focusing on rotator cuff and scapular strengthening exercises. Corticosteroid injections and anti-inflammatory medication may also be utilized.

Operative treatment is pursued for all acute subscapularis tears, smaller tears that have failed conservative treatment, larger degenerative tears, as well as all tears visualized arthroscopically, whether they were identified on pre-operative MRI or not. While open repair is an option, it is almost always possible to achieve adequate mobilization and secure fixation of the tendon through arthroscopic techniques. The author uses the beach-chair position with an arm holder for all subscapularis and rotator cuff repairs, although the lateral decubitus position is also an option. After a standard posterior viewing portal and anterior working portal are established, a diagnostic arthroscopy is performed.

Evaluation of the subscapularis insertion and less tuberosity can be difficult, but a few techniques can help to improve visualization. Internal rotation of the arm as well as a posteriorly directed force on the humerus (posterior lever push [1]) can bring the tuberosity into view (Fig. 22.1a, b). A 70-degree arthroscope should be available if increased visualization of the footprint be needed. Lastly, since swelling can impede visualization and working space in the anterior aspect of the shoulder, it is recommended that subscapularis repair be performed first prior to other interventions.

Given the close anatomic relationship of the biceps tendon and pulley to the subscapularis, there is often concomitant pathology. Arai et al. reported that of all biceps tendon lesions, 76% were associated with a subscapularis tear and all unstable biceps tendons also had subscapularis tears [2]. Another investigation found that a subscapularis tear was significantly associated with biceps tendon lesions [3]. Because of this, and particularly in older patients with degenerative tears, a biceps tenodesis or tenotomy is often

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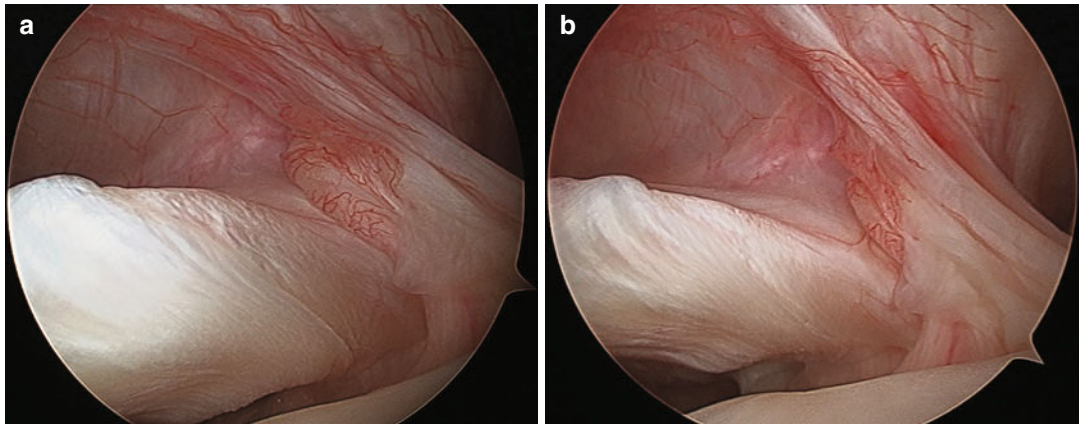

Fig. 22.1 (**a**, **b**) Arthroscopic images from the posterior viewing portal demonstrating an upper boarder tear of the subscapularis (**a**) before and (**b**) after a posterior lever push. The posteriorly directed force on the humerus allows the subscapularis tendon to lift away from the lesser tuberosity, revealing the true extent of the pathology

performed, especially in light of evidence that tenodesis for tenotomy was associated with improved subjective and objective results in a cohort of patients undergoing subscapularis repair [4].

Once the extent and anatomy of the subscapularis tear has been identified, the surgical construct can be determined. A distinction is made between partial thickness tears (Fig. 22.2a), small full-thickness tears (Fig. 22.2b), and large full-thickness tears with retraction (Fig. 22.2c). A similar but slightly more detailed classification system which divides the subscapularis insertion on the lesser tuberosity into four distinct facets has been proposed [5]. In general, the author utilizes a single-anchor construct for partial thickness tears, while a double-row construct is used for small and large full-thickness tears. In the author's experience, and in agreement with previously published literature [6], most chronic and retracted subscapularis tears can be repaired arthroscopically given appropriate mobilization techniques. Denard et al. have also shown that medialization of the lesser tuberosity footprint by as much as 7 mm does not result in negative clinical consequences [7].

Following the assessment of the tear pattern and mobility, an additional anterosuperolateral working portal is created off the edge of the anterolateral acromion using outside-in technique. The portal should be mostly aligned with the subscapularis tendon. The exception to this has been in the setting of isolated partial thickness tears where a coracoplasty is not required and a single-anchor repair is planned. In this circumstance, the author does not create additional anterosuperolateral portal so as to remove the possibility of damage to the anterior aspect of the supraspinatus tendon. For these cases, a larger cannula may be exchanged for the initial smaller cannula placed anteriorly. After preparation of the footprint, a free suture is passed in mattress fashion through the superolateral border of the tendon using a suture-passing device (Fig. 22.3a). The two suture limbs (exiting the anterior aspect of the tendon) are then placed through the eyelet of a knotless suture anchor and secured to the superolateral aspect of the lesser tuberosity footprint for repair of the partial thickness tear (Fig. 22.3b, c).

22.2 Postoperative Rehabilitation

Postoperatively, patients are placed in a sling for 6 weeks. No weight bearing is allowed during this time. Active motion of the elbow, wrist, and hand is encouraged. In the case of partial thickness repairs, external rotation is allowed to 30°. Forward flexion is limited to 90° and abduction to 60°. At 6 weeks, passive stretching is allowed

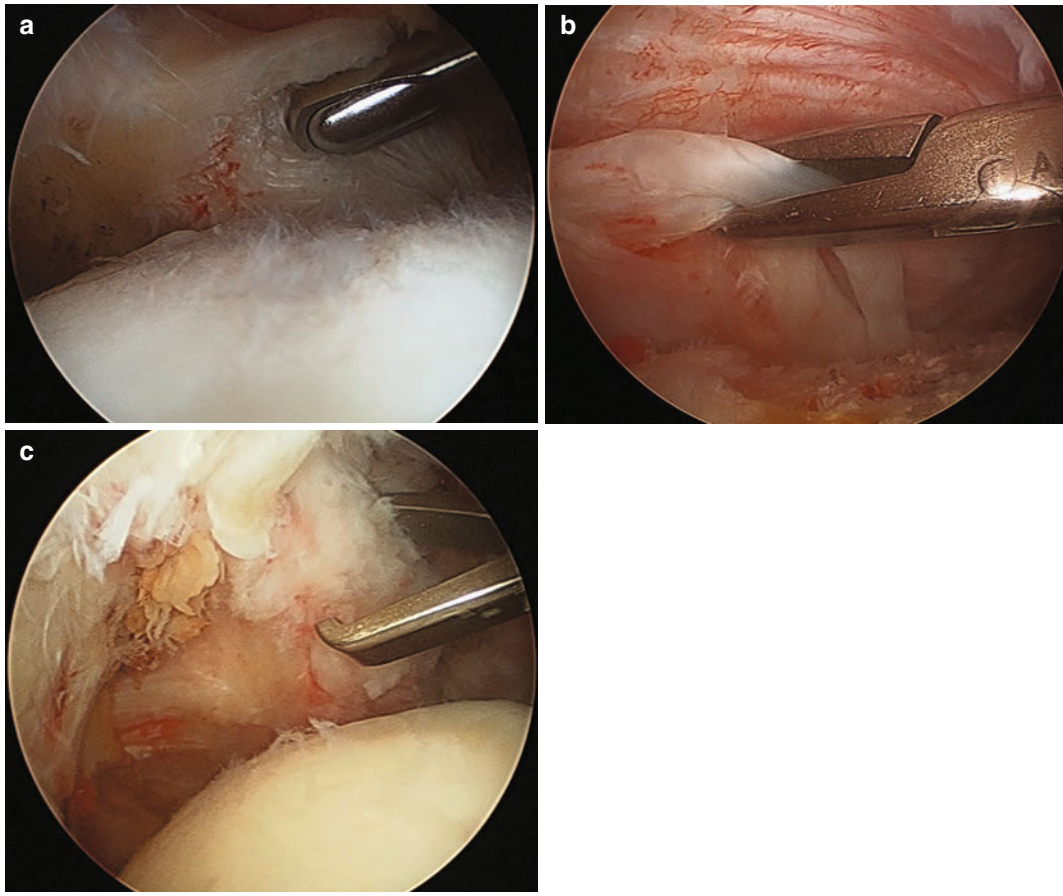

Fig. 22.2 (**a**–**c**) Arthroscopic images from the posterior portal of three different left shoulders demonstrating (**a**) partial thickness, (**b**) small full-thickness, and (**c**) large and retracted full-thickness tears of the subscapularis

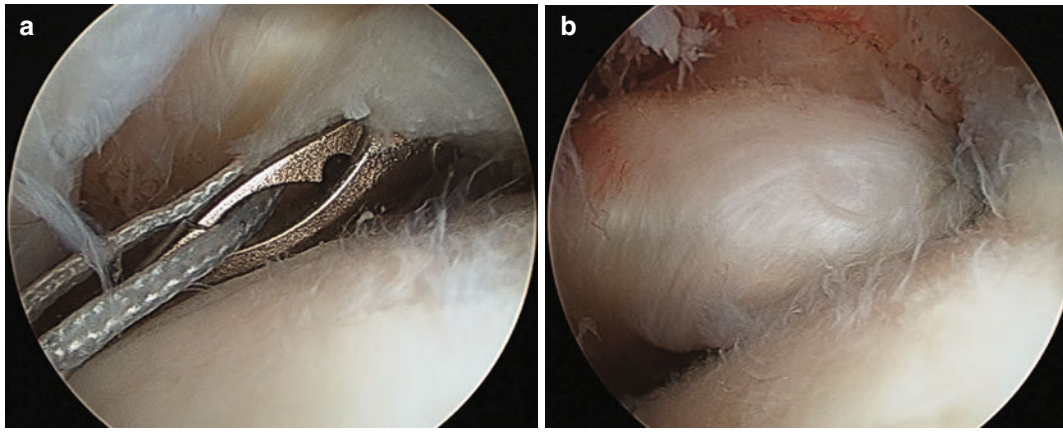

Fig. 22.3 (**a**–**c**) Arthroscopic images as viewed from the posterior portal demonstrating the steps for repair of a partial thickness upper border subscapularis tear utilizing single anterior working portal. In this series (**a**), the free end of the sutures are passed in mattress fashion through the superolateral border of the tendon using a suture-passing device. The two suture limbs are then placed through the eyelet of a knotless suture anchor, and (**b**) the anchor hole is created. The final construct demonstrates (**c**) secure fixation of the tendon to the superolateral aspect of the lesser tuberosity footprint

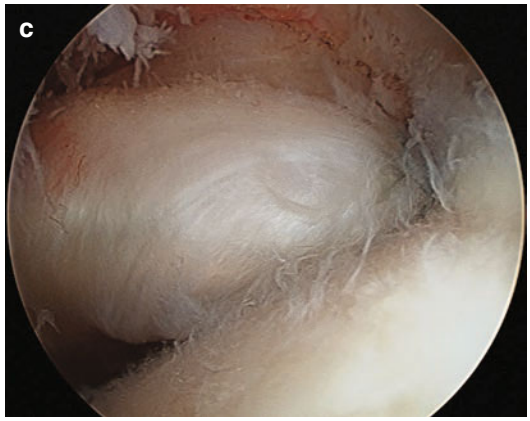

Fig. 22.3 (continued)

as well as progression to active range of motion. Strengthening is deferred until 3 months postoperatively.

22.3 Conclusion

Conservative treatment is pursued for small chronic tears in older patients, while operative management is the mainstay of treatment for all other categories. Most subscapularis tears can be repaired arthroscopically. For isolated partial thickness subscapularis tears, a single-row construct is preferred.

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Double-Row Subscapularis Repair: The US Perspective

23

Michelle X. Xiao, Rebecca A. Carr, and Geoffrey D. Abrams

23.1 Double Row Subscapularis Repair

For full-thickness tears, and especially for retracted tears, mobilization of the tendon is required, and an additional anterosuperolateral portal is created. Working through this portal, the coracoid tip is identified, paying careful attention to the presence of nearby neurovascular structures, and a window in the rotator interval can be created to give access to the anterior aspect of the tendon. The tip and posterolateral base of the coracoid is skeletonized, proving for and giving access to anterior and superior releases. The need for coracoplasty can be determined at this time. Posterior releases can be achieved using a blunt elevator inserted between the subscapularis and anterior glenoid neck. In chronic and retracted tears, the "comma sign," a convergence of the superior glenohumeral ligament and coracohumeral ligament, can aid in identification of the superolateral aspect of the torn tendon (Fig. 23.1) [1]. This tissue can hold a traction stitch to aid in releases and mobilization of the tendon and should be preserved in the final repair.

The author's preferred construct for a full-thickness tear is a double-row knotless repair (Fig. 23.2). Ide et al. reported on a group of patients undergoing subscapularis repairs using either a single-row or double-row technique [2]. While they found that the clinical outcomes for these 61 patients were comparable, subscapularis function and abduction strength were improved in the double-row group, and there was a trend toward a lower failure rate in this same group. Similarly, Saltzman et al. performed a systematic review of subscapularis repairs and reported a lower incidence of re-tearing in patients treated with double-row versus single-row constructs [3]. Furthermore, the mean change from pre-op to post-op in the total Constant score and the range of motion, activities of daily living, and strength sub-scales were greater in the double-row versus single-row group [3].

For smaller full-thickness tears, a single anchor is placed at the medial aspect of the exposed footprint. For larger tears where more of the footprint is exposed, an inferior and superior

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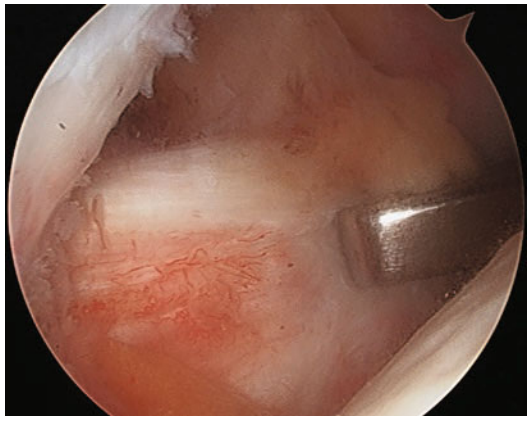

Fig. 23.1 An arthroscopic image from the posterior viewing portal demonstrating a chronic and retracted subscapularis tear. The grasper is placed through the anterosuperolateral portal and is pulling lateral traction on the tendon, demonstrating the "comma sign," representing the convergence of the superior glenohumeral ligament and coracohumeral ligament attached to the superolateral border of the tendon

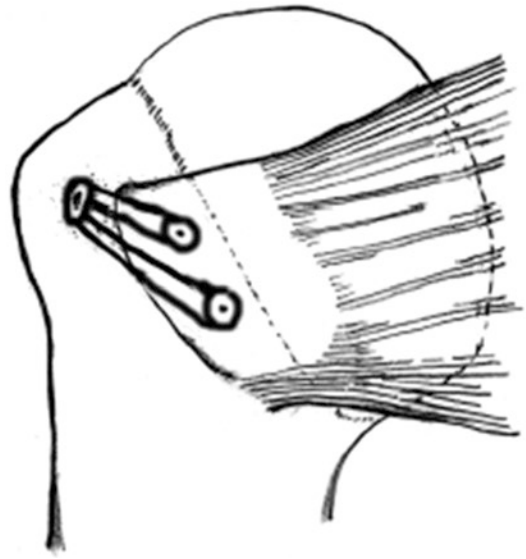

Fig. 23.2 Schematic drawing of the authors preferred method for double-row repair of the large, full-thickness subscapularis repair. (Adapted from Ide J, Karasugi T, Okamoto N, Taniwaki T, Oka K, Mizuta H. Functional and structural comparisons of the arthroscopic knotless double-row suture bridge and single-row repair for anterosuperior rotator cuff tears. J Shoulder Elbow Surg. 2015 Oct;24(10):1544-54)

anchor is placed. The anterior portal may need to be adjusted, or a new anterior portal can be created using outside-in technique to allow for appropriate angle for anchor placement. With the use of a grasper or traction stitch through the anterosuperolateral portal to place tension on the subscapularis, a suture-passing device is utilized to pass each suture limb, from inferior to superior, through the tendon in a mattress configuration. Each limb is then secured with a single knotless anchor to the superolateral aspect of the lesser tuberosity footprint. As mentioned, nearly all subscapularis repairs, even with significant fatty infiltration, are able to be repaired with appropriate releases with or without footprint medialization. In the truly irreparable tears, pectoralis major transfer remains an option [4, 5]; however latissimus dorsi transfers have also demonstrated good results and are becoming a more accepted approach [6].

23.2 Conclusion

In the senior author's experience, a double-row construct is chosen when repairing full-thickness subscapular tears. While repair techniques and construct configurations may vary, there is some evidence for decreased re-tear rates and improved clinical outcomes in double-row as compared to single-row repair of larger full-thickness subscapularis tears.

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Double-Row Subscapularis Repair: The German Perspective

24

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24.1 Introduction

The function of the subscapularis (SSC) muscle is important for a proper centration of the glenohumeral joint. Therefore, a sufficient treatment is key for successful management of rotator cuff lesions [1]. There are various options for the surgical approach of SSC tendon lesions, which have been recently developed further. However, partial re-tears and progressive muscle atrophy especially at the superior aspect of the SSC were reported [1–4]. This is caused by a higher muscle activity of the upper portion of the SSC, which is generated as a result of the independent innervation of the upper and lower SSC [5].

Due to the footprint anatomy with its twofold humeral insertion including a strong superior tendinous insertion and an almost muscular inferior insertion, an anatomical reconstruction can be challenging [6]. In this context, the importance of the superior lateral edge of the SSC tendon has to be underlined representing the initial tear site. Therefore, the term "leading edge" was established [7] correlating with the usually used classifications of Lafosse et al. [3] and Fox and Romeo [8].

24.2 Indication and Treatment Strategy

The main indication for subscapularis repair is a symptomatic tear of the subscapularis tendon. Considering the commonly used classification of Fox and Romeo [8], we suggest a graduated approach (Fig. 24.1). In case of an SSC lesion grade 1 according to Fox and Romeo, a debridement may be adequate showing better results compared to a reconstruction [9]. SSC tendon tears grade ≥2 according to Fox and Romeo require a reconstruction. Therefore, it is necessary to focus on the importance of the "leading edge" representing the initial tear site. In order to prevent tear progression, we recommend a double-row technique placing a superolateral anchor. Following our staged treatment strategy, SSC tears grade 3 and 4 require the placement of three and four anchors, respectively, to ensure coverage of the native footprint and protection of the leading edge.

24.3 Preoperative Assessment

Prior to the clinical examination, a detailed exploration of the patients' symptoms (e.g., pain, functional deficits), duration of the complaints, and presence of an initiating trauma (external rotation with the arm in adduction position) is necessary.

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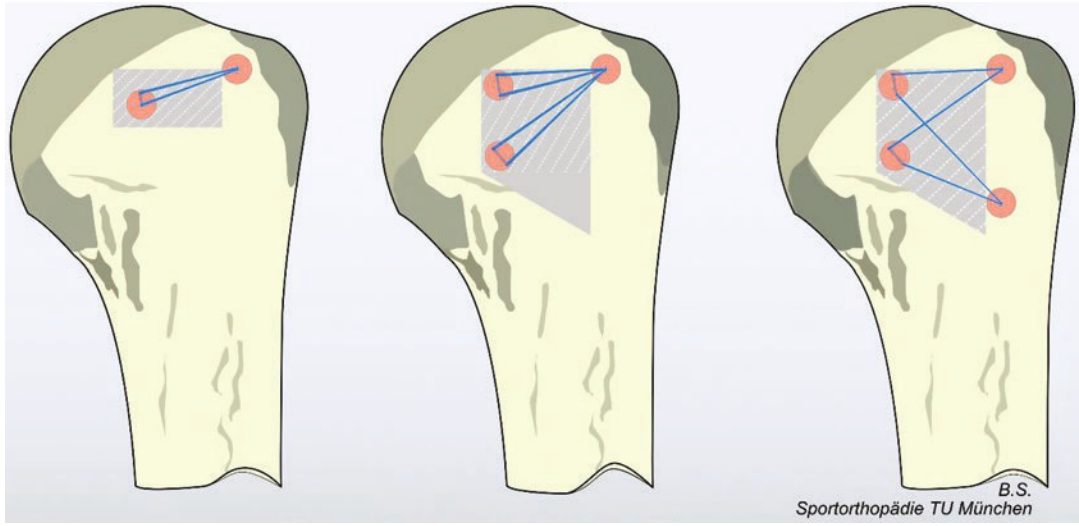

Fig. 24.1 Reconstruction techniques considering the classification according to Fox and Romeo. (**a**) Fox and Romeo II, hybrid double-row technique; (**b**) Fox and Romeo III, double-row technique; (**c**) Fox and Romeo IV, double-row SpeedBridge technique

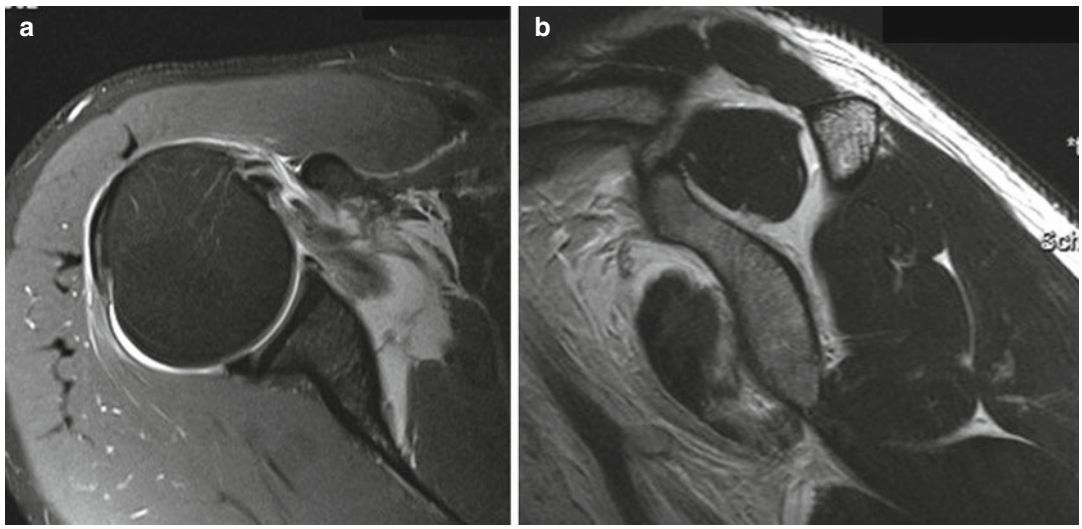

Fig. 24.2 MRI scan SSC tear Fox/Romeo III: (**a**) axial view, (**b**) parasagittal view

The clinical examination should include documentation of active and passive range of motion (increased passive external rotation) as well as functional tests (internal rotation against resistance, internal rotation lag sign, lift-off test, belly-press test, bear-hug test). In addition, concomitant pathologies (esp. instability of the LHB tendon, lesion of the pulley system) have to be considered.

A series of three shoulder X-rays (true a.-p., y-view, axial) should be performed to evaluate bony conditions and centering of the humeral head. An MRI is essential to assess tear morphology and size as well as tendon retraction, muscle atrophy, and fatty infiltration (Fig. 24.2). Furthermore, concomitant pathologies can be excluded.

24.4 Operative Technique

24.4.1 Positioning and Preparation

The patient should be positioned in upper body elevation of 60° with hip flexion of 45–60° and knee flexion of 30° (beach-chair position). It is recommended to fix the arm in a movable arm holder in slight abduction and elevation (Fig. 24.3).

24.4.2 Technique

Initially, a diagnostic arthroscopy using the posterior standard portal (Fig. 24.4, *A*) is performed. Usually, the subscapularis refixation requires an additional anterosuperior (Fig. 24.4, *G*) and anterolateral portal (Fig. 24.4, *F*) placed in an outside-in-technique (Fig. 24.4).

Using the anterolateral portal, the reposition of the subscapularis tendon is examined with a holding forceps. A temporary traction suture (PDS or FiberWire) is placed using a perforation instrument and then positioned outside the cannula through the anterolateral portal (Fig. 24.5).

Subsequently, the tendon is mobilized medially with a shaver or electric instrument. A circumferential adhesiolysis to the coracoid base and the MGHL is performed, while the tendon is kept under tension. Therefore, it is recommended to change the camera to the anterolateral portal or 70°. It is important to preserve the axillary nerve and artery as well as the musculocutaneous nerve and lateral cord of the brachial plexus. To achieve a tension-free refixation, a release of the subscapularis tendon (ventral until below the coracoid as well as between the muscular part and glenoid) is required. In older patients, the MGHL may be cut for a better tendon mobilization [10, 11].

Once the tendon has been sufficiently mobilized, the footprint at the tuberculum minus is vitalized. Depending on tear size, a varying amount of suture anchors is needed. In case of tears ≥ grade 2 according to Fox and Romeo, the double-row technique is necessary for a biomechanically better reconstruction and coverage of

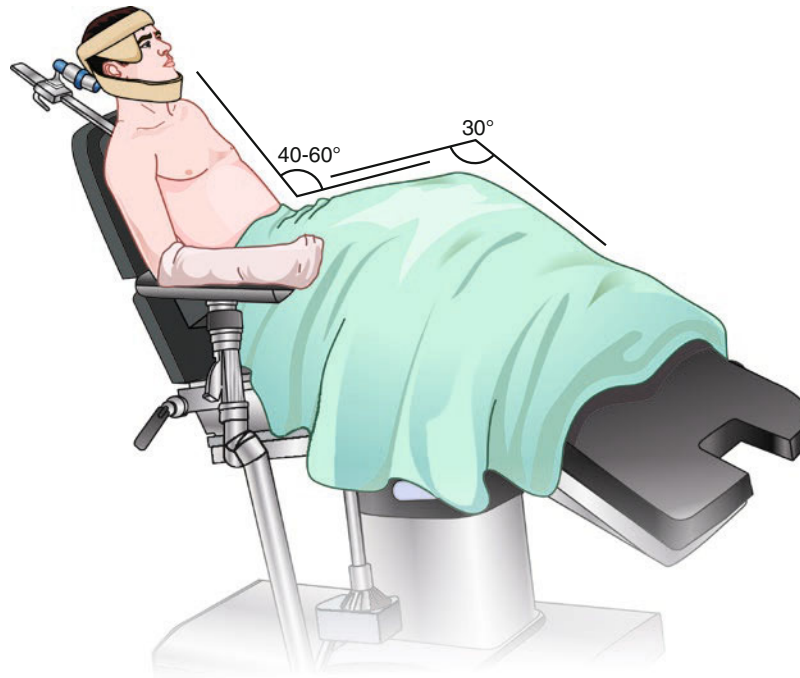

Fig. 24.3 Beach-chair position

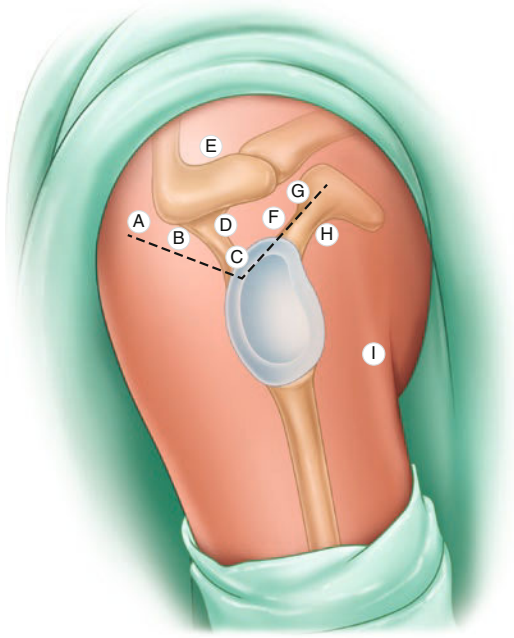

Fig. 24.4 Arthroscopic portals: *A* posterior standard portal, *B* posterolateral portal, *C* deep lateral portal, *D* high lateral portal, *E* Neviaser portal, *F* anterolateral portal, *G* anterosuperior portal, *H* anteroinferior portal, *I* deep anteroinferior portal

the almost trapezoid humeral footprint (State of Nevada!).

From our perspective, we recommend using 4.75 mm anchors to perform the double-row repair. Alternatively, all-suture anchors can be used for the reconstruction of the medial row. The hybrid double-row repair of a subscapularis tear grade 2 according to Fox and Romeo requires two anchors. The first anchor is loaded with a fibertape and placed on the caudal tear edge exactly lateral to the cartilage margin within the native footprint. Each tape has to be shuttled through the tendon separately using a suture lasso. One of the limbs of the fibertape is now shuttled back through the tendon on the superior lateral edge, whereas the other limb is passed over the tendon edge. Then, both limbs are passed through the

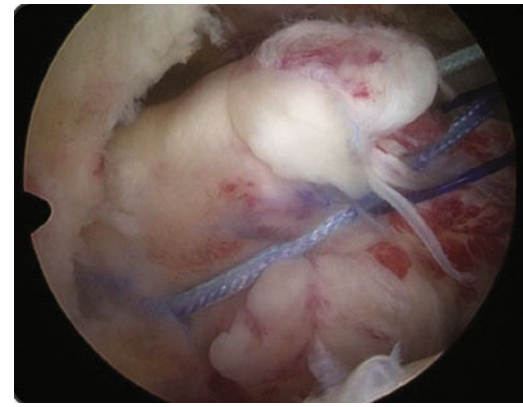

Fig. 24.5 Temporary traction suture

eyelet of the second anchor and tightened before fixation. Now the protruding ends of the fibertapes have to be cut (Fig. 24.6).

In case of a tear grade 3 according to Fox and Romeo, we suggest three anchors to ensure a sufficient fixation using a double-row technique. The first two anchors are each loaded with a fibertape and placed exactly lateral to the cartilage margin. Starting at the caudal aspect of the defect with the first anchor, the second anchor has to be placed more cranially. Each tape has to be shuttled through the tendon separately. Subsequently, all tape limbs are passed through the eyelet of the third anchor and tightened before fixation (Fig. 24.7).

To perform the repair of a grade 4 lesion according to Fox and Romeo, we suggest a double row including four anchors. The second anchor of the lateral row is placed caudally to the superolateral anchor within the native footprint. One limb of each fibertape of the first two anchors is now passed through the eyelet of the third and fourth anchor and tightened before fixation.

Ensuring a leading edge fixation, we recommend to place the lateral row as a superolateral anchor out of the native footprint close to the entrance of the bicipital groove. The fibertapes stretched over the tendon pressing it against the footprint create a large contact area between the tendon and bone.

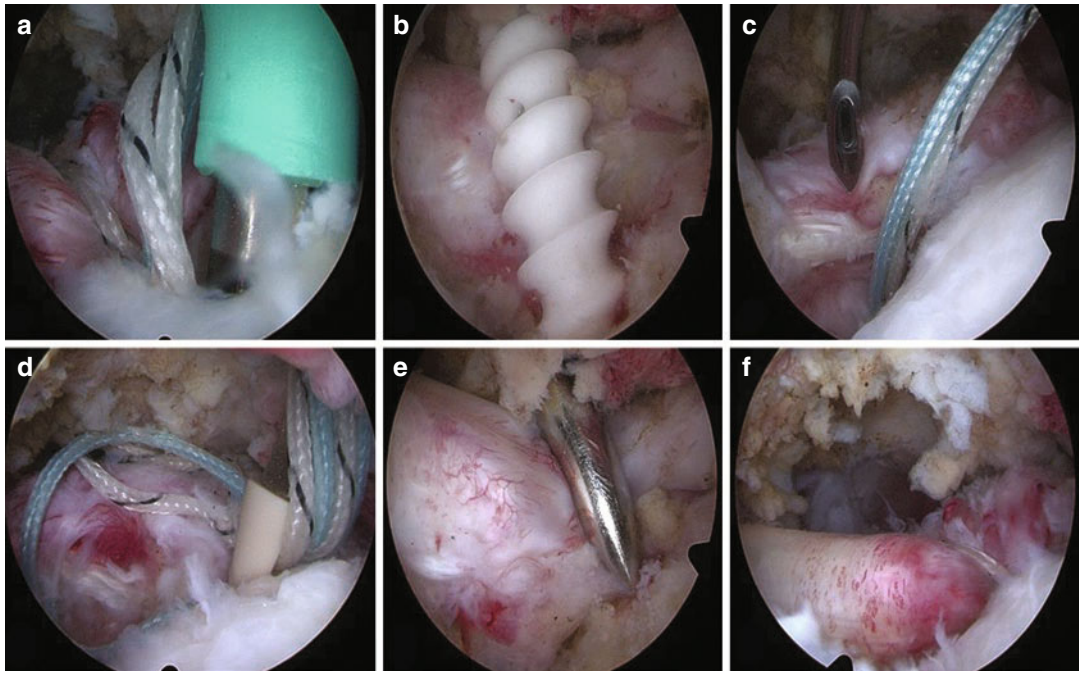

Fig. 24.6 (**a**–**f**) Hybrid double-row technique

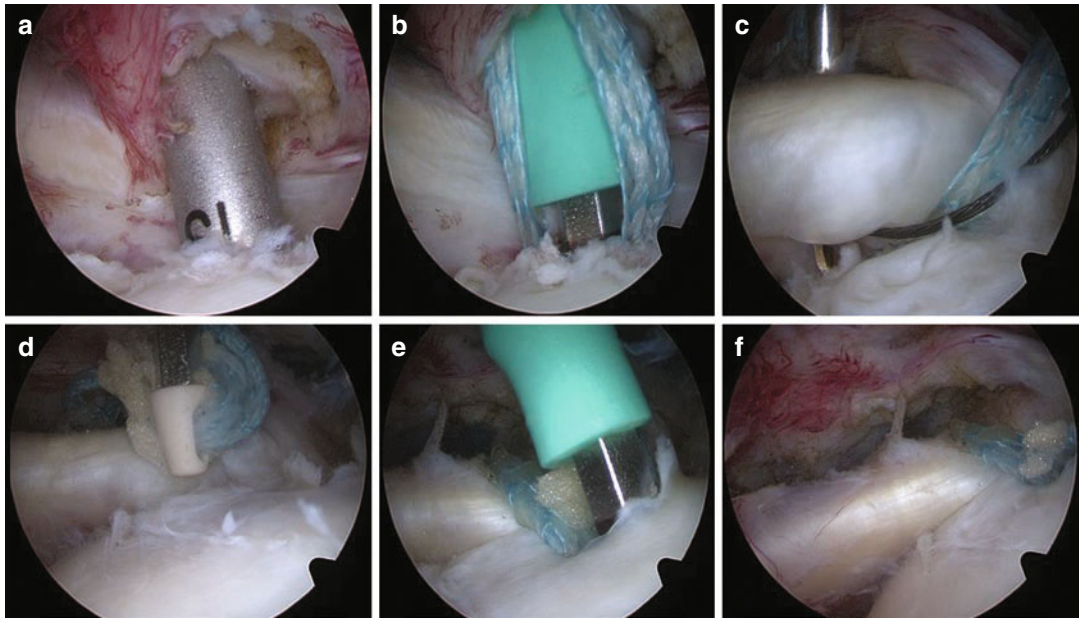

Fig. 24.7 (**a**–**f**) Double-row technique

24.5 Postoperative Management

A shoulder abduction brace should be mounted in 15° abduction and internal rotation during anesthesia in the operating room. The control of peripheral circulation, motor function, and sensitivity is important. Additionally, a postoperative X-ray control should be performed.

24.6 Follow-Up Treatment

It is recommended to wear a shoulder abduction brace in 15° abduction for 4–6 weeks. For the 1–3 postoperative week, the range of motion is limited to only passive abduction/adduction 90°/30°/0°, flexion/extension 90°/30°/0°, and 0° external rotation. For the 4–6 week, passive abduction/adduction and flexion/extension are free with active-assisted abduction and flexion of up to 90°. From 7 weeks on, a free active-assisted motion is allowed and from 9 weeks on a free active motion.

24.7 Tips, Tricks, and Pitfalls

If the caudal margin of the tear cannot be detected arthroscopically, one may have to change to an open procedure. While performing the diagnostic arthroscopy, concomitant lesions of the long head of the biceps tendon and the pulley system have to be excluded. The functionality of the pulley system is examined dynamically in internal and external rotation of the upper arm. Due to medial subluxation or luxation, an instability of the LHB tendon jeopardizes a sufficient subscapularis refixation and therefore has to be priorly addressed with a tenotomy or tenodesis.

In case of a torn pulley system, residual fibers form scar tissue, which sticks together with the superolateral margin of the subscapularis tendon ("comma sign") [12]. This should not be misinterpreted as an intact tendon insertion but helps to catch and mobilize the subscapularis tendon.

For an exact evaluation of the humeral insertion of the subscapularis tendon, the patient's arm has to be positioned in slight abduction and internal rotation.

In case of a massive rotator cuff tear, it is recommended to start with the SSC reconstruction. With increasing duration of surgery, the insight of the already tight anterior joint compartment between coracoid and humeral head decreases due to tissue swelling making SSC mobilization and refixation more difficult.

In order to cover, restore, and protect the leading edge of the subscapularis muscle and therefore prevent tear progression, it is recommended to place a superolateral anchor out of the native footprint right next to the entrance of the bicipital groove.

24.8 Outcomes

The long-term results of isolated arthroscopic subscapularis repairs are excellent showing significant clinical improvements and enduring tendon integrity [13]. Even though single- and double-row SSC repairs both achieve comparable good clinical results with low revision rates and safe fixation, there is a lower number of re-tears if a double-row reconstruction is performed [14–16]. However, reduced SSC muscle strength may still be present in the long term, and early surgical treatment seems to be a relevant factor achieving substantial improvement of shoulder function [13]. This long-term strength deficit often correlates with atrophy especially of the upper third of the SSC [17]. Considering the importance of the SSC leading edge [7], the placement of a superolateral anchor may ensure coverage, restoration, and protection of this area.

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The Anatomy of the Biceps Pulley

25

Giovanni Di Giacomo, Alberto Costantini, Andrea De Vita, Nicola de Gasperis, and Luigi Piscitelli

25.1 Introduction

The long head of the biceps (LHB) tendon has been the subject of numerous studies for years, to study its anatomy, function, and pathology. The interest in biceps pathology and its treatment has increased in recent times.

The long head of the biceps brachii is the proverbial stepchild of the shoulder. Kessell and Watson [1] described the tendon as "somewhat of a maverick, easy to inculpate but difficult to condemn." Lippman [2] linked the long head of the biceps to the appendix: "An unimportant vestigial structure unless something goes wrong with it." At various times in history, surgeons have tenodesed, translocated, pulled through drill holes in the humeral head, debrided with an arthroscope, and tenotomized this tendon. Still others have worshipped at the altar of the biceps, keeping it sacrosanct, contending that it must be there for a reason, even if it is unclear what exactly that reason is or ever was.

Recently, some authors have demonstrated the clinical importance of instability of the tendon and the association with pulley lesions and partial tears of the subscapularis and supraspinatus tendons; moreover the biceps tendon pathology is an important cause of pain, and ignoring the biceps tendon may reduce the clinical outcome for these patients.

25.2 Anatomy of the Pulley

The superior glenohumeral ligament SGHL and the coracohumeral ligament (CHL) contribute to the "biceps pulley" [3]. A lesion of these ligaments leads to the instability of the biceps. The biceps pulley or "sling" is a capsuloligamentous complex that acts to stabilize the long head of the biceps tendon in the bicipital groove. This complex is composed of the superior glenohumeral ligament, the coracohumeral ligament, and the distal attachment of the subscapularis tendon. It is located within the rotator interval between the anterior edge of the supraspinatus tendon and the superior edge of the subscapularis tendon.

There are two pulleys: one *medial,* formed by the coracohumeral ligament, the superior glenohumeral ligament, and the superior border of the subscapularis, and the *lateral one formed* by the anterior border of the supraspinatus and the rotator cable (Fig. 25.1) [4].

The rotator interval is an integral part of the rotator cuff and capsule and is distinguishable only by sharp dissection. The most important retaining structure in this area is the portion of the shoulder capsule thickened by the coracohumeral ligament (CHL) and the edges of the

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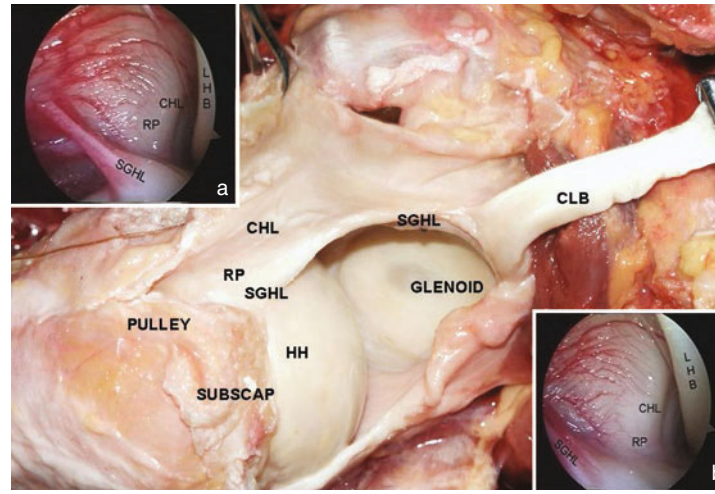

Fig 25.1 A diagram of the biceps pulley. The coracohumeral ligament (CHL) creates the reflection pulley, which encloses the long head of the biceps at the entrance of the intertubercular groove (from shoulder.co.uk)

subscapularis and supraspinatus tendons; this part of the capsule bridges the tuberosities in the uppermost portion of the bicipital groove. This portion of the capsule is the first and foremost obstacle to medial dislocation of the tendon.

Aalto et al. [5] found in his series that in cases of dislocation of the long head of the biceps, this portion of the capsule was always stretched or torn.

The CHL is the most superficial capsular structure of the rotator interval. It blends with the fibers of the subscapularis and supraspinatus tendons at their insertions. The coracohumeral ligament has a broad, thin origin on the coracoid along the lateral border. As the ligament passes laterally, it divides into two main bands. One band inserts onto the anterior edge of the supraspinatus tendon and the greater tuberosity. The other band inserts onto the superior border of the subscapularis, the transverse humeral ligament, and the lesser tuberosity (Fig. 25.2).

The coracohumeral ligament has extensions that envelop the cuff tendons and blend into the superficial and deep layers of the supraspinatus and subscapularis tendons and the articular capsule. These extensions reinforce the capsule in the rotator interval at the border of the tendinous cuff. The coracohumeral ligament is superficial to the shoulder capsule and overlies the biceps tendon.

The superior glenohumeral ligament (SGHL) is the second structure stabilizing the biceps in the rotator interval. It arises from the labrum adjacent to the supraglenoid tubercle, inserts onto

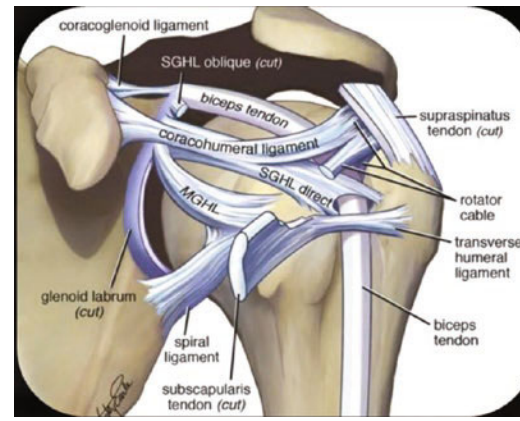

Fig. 25.2 Schematic diagram showing the interrelationship of the coracohumeral ligament, superior glenohumeral ligament, and long biceps tendon at several planes in the rotator interval

the superior lateral portion of the lesser tuberosity, and blends into the medial aspect of the coracohumeral ligament. It crosses the floor of the rotator interval [6]. Along with the coracohumeral ligament, the superior glenohumeral ligament, it forms a reflection pulley for the biceps tendon. This pulley is in direct contact with the insertion of the subscapularis tendon. All these structures blend together to form a sleeve above the entrance to the bicipital groove that is analogous to the flexor tendon pulleys of the hand. This sleeve prevents the medial dislocation of the long biceps tendon. Though the superior glenohumeral ligament was previously considered

insignificant, it is now considered an important stabilizer for the biceps tendon.

There is a great interconnection between the supraspinatus and subscapularis tendons and the biceps; they fuse to form a sheath that surrounds the biceps tendon at the proximal end of the groove. Fibers from the subscapularis tendon pass below the biceps tendon and join with fibers from the supraspinatus to form the floor of the sheath.

The floor of the sheath is formed by the superior portion of the subscapularis and supraspinatus tendons. A slip from the supraspinatus forms the roof of the sheath along with the superior glenohumeral and coracohumeral ligaments. The deep portion of the sheath runs adjacent to the bone and forms a fibrocartilaginous lining in the groove that extends approximately 7 mm distal to the entrance of the groove [7].

Once the tendon has entered the groove, the principal structure maintaining the tendon within the groove is the falciform ligament, a tendinous expansion from the sternocostal portion of the pectoralis major. It forms a margin with the deep aspect of the main tendon that stabilizes the biceps. The falciform ligament is attached to both lips of the groove and blends with the capsule at the shoulder joint.

Moreover, the continuation of fibers from the supraspinatus and subscapularis tendons in the distal portion of the groove creates the transverse ligament that the role of stabilizing is still a debate.

25.3 The Biceps

The LHB originates from the supraglenoid tubercle of the scapula and the superior glenoid labrum, with a minimal intra-articular portion over the humeral head before it exists extraarticularly through the bicipital groove [8], an hourglass-shaped space between the greater tuberosity and the lesser tuberosity.

The LHB is roughly 8–9 cm long and 5–6 mm in diameter with an average thickness of 3.3–4.7 mm, depending on sex and activity of the patient [9] with a variable attachment at the superior glenoid pole.

The intra-articular portion is extrasynovial and is essentially static within the joint as the groove slides over the biceps during abduction and rotation; this part is flat and wide in shape with a length of 34.3 + −4.2 mm. The synovial sheath reflects on itself to form a visceral sheath that encases the biceps tendon (Fig. 25.3). The sheath is open, communicates directly with the glenohumeral joint, and ends in a blind pouch at the level of the bicipital groove.

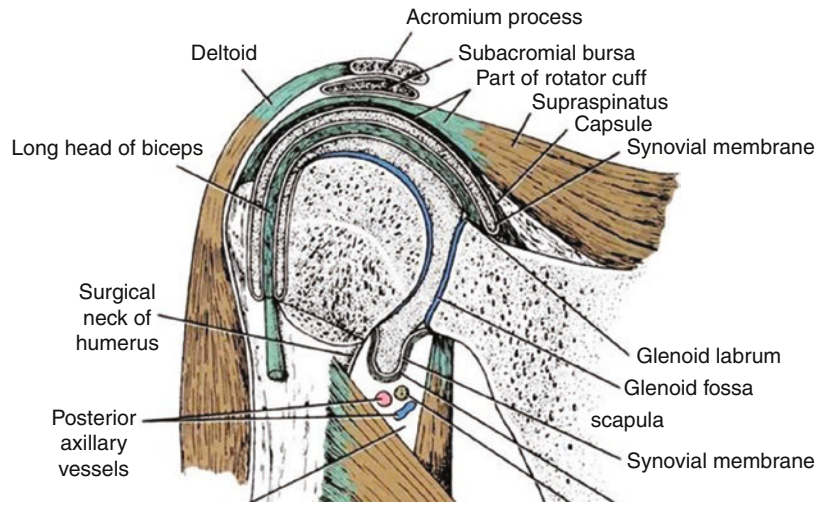

Fig. 25.3 The different extra- and intrasynovial part of the biceps (from shoulder.co.uk)

The extraarticular portion instead is round and narrower with a length of 30.6 + −5.7 mm [10].

The course of the LHBT is oblique over the top of the humeral head and runs distally into the bicipital (intertubercular) groove. The shape is changing during its way; it is oval near the glenoid with an area of 8.4 mm × 3.4 mm; when it enters the bicipital groove, its diameter reduces from 5.1 mm × 2.7 mm to 4.5 mm × 2.1 mm until the end of the groove [11]. Once out of the groove, the tendon continues down the ventral portion of the humerus and becomes musculotendinous near the insertion of the deltoid and the pectoralis major (Fig. 25.4).

From the attachment, the tendon then traverses the rotator cuff interval and runs through the bicipital groove. There it is secured by fibers of the subscapularis tendon, along with some fibers from the supraspinatus tendon and the coracohumeral ligament, forming a structure, which was formerly thought to be the so-called transverse humeral ligament [12].

The LHB receives blood supply from the brachial artery. The proximal part is perfused by the anterior circumflex artery, with branches running along the bicipital groove in both directions, proximally—distally; the labral attachment receives branches from the suprascapular artery. The innervation is extremely assorted and asymmetrical, more concentrated at the biceps origin and less at the musculotendinous junction. It is innervated by the musculocutaneous nerve arising from C5 to C7 [10].

Dierickx et al. [4], in a review of 3000 shoulder arthroscopies, found 57 (1.9%) variations, and they edit a classification of 12 variations of the intra-articular portion of the tendon. The four most important variations are synovial mesentery (pulley-like sling, vinculum), adherent to rotator cuff, split or bifid tendon, and the absence of LHB.

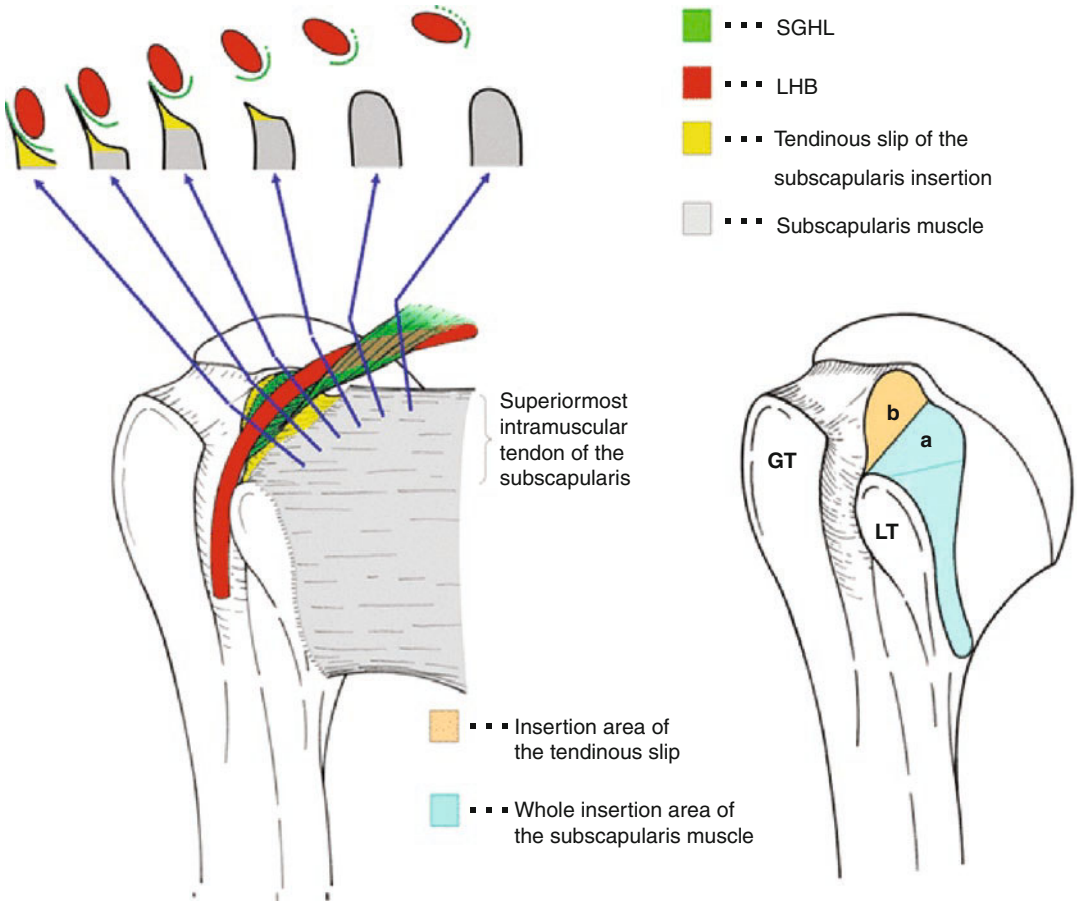

Fig. 25.4 The different shape of the bicep. From large and flat to thin and vertical from shoulder.co.uk

25.4 Function

The function of the pulley is to stabilize the biceps in the bicipital groove, reducing the risk of subluxation of the tendon.

Even if the superior insertion of the subscapularis is not a part of the pulley, it contributes significantly to the medial support of the biceps tendon and contributes to the medial sheath of the bicipital groove.

The associations of bicipital tenosynovitis, tendonitis, fraying, subluxation, and instability have been noted with lesions of the medial wall of the bicipital sheath; these lesions, if not repaired, may allow for the biceps tendon to continue to be irritated or frayed on the supratubercular ridge, allowing for continued symptoms.

Werner [13] showed that lesions of the pulley lead to anterior instability of the long head of the biceps in external rotation.

The tendon's importance seems to increase in pathologic states of the shoulder, such as rotator cuff tears and shoulder instability, as evidenced by increased EMG activity as well as observation of hypertrophy and resistance to translation. The observation of increased superior translation of the humeral head in patients with confirmed bicipital rupture reinforces these findings. The clinical relevance of this, however, is questionable given that measurable deterioration in shoulder function has not been demonstrated in patients who have undergone biceps tenotomy or tenodesis [7]. Therefore, if the LHBT is implicated as a possible source of the patient's symptoms (either through physical examination or at surgery), the risk of decreased shoulder function from tenotomy or tenodesis is negligible in comparison to the risk of continued pain from biceps pathology.

25.5 Diagnosis

Magnetic resonance imaging (MRI) is useful for proximal biceps pathology, both for articular and extraarticular portions. Increased fluid in the synovial sheath is suggestive of tenosynovitis. In sagittal and coronal views, a hyperintense signal under the superior labrum is suggestive of injury of the labrobicipital insertion. The normal and pathologic anatomy of the biceps reflection pulleys may also be studied by MR arthrography. Oblique sagittal images and axial images are valuable for identifying the individual components of the pulley system [14].

The pulley lesions have been diagnosticated and classified based on arthroscopic findings, and various mechanisms for injury to the medial sheath based on their respective findings have been proposed.

During the arthroscopy, the LHB tendon is one of the most important landmarks; for a better visualization of the intra-articular part, the arm needs to be in neutral rotation. To check the extraarticular portion or intertubercular portion, downward traction with a probe needs to be applied, for an additional 3–5 cm; this part of the biceps is a common location for "lipstick synovitis," delamination, and partial tears (Citation lipstick sign).

The medial and lateral pulleys complex can be seen with the scope from the posterior portal with the arm in 30° flexion and neutral rotation (Fig. 25.5). Medial displacement of the LHB with external rotation suggests an anteromedial pulley injury, whereas lateral displacement with internal

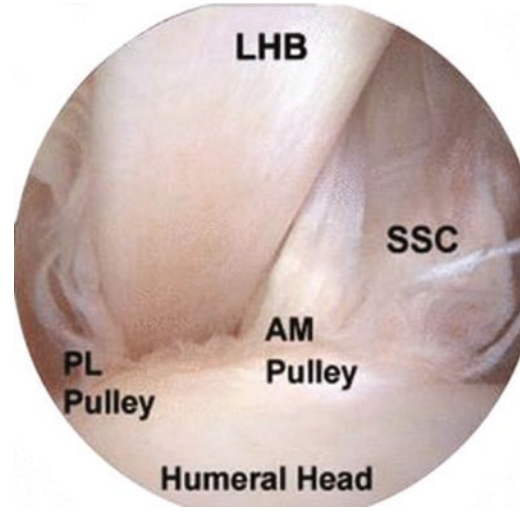

Fig. 25.5 Left shoulder. Arthroscopic view of anteromedial (*AM*) pulley and the posterolateral pulley from posterior viewing portal (from Bain, Itoi, Di Giacomo et al. Normal and pathological anatomy of the shoulder. Springer; 2015)

rotation of the arm suggests a posterolateral pulley injury. This is the so-called swinging test [6].

Generally, these lesions are associated with rotator cuff injuries or glenohumeral instability, rarely as isolated injury.

25.6 Instability

Although it was commonly believed that the dislocated tendon always displaces medially and rides over the subscapularis tendon, Petersson [15] found only one such case in his series. He found that in most cases, internal degeneration of the subscapularis in the region of the lesser tuberosity occurred, allowing the tendon to dislocate medially and under the subscapularis. Biceps lesions have historically been divided into biceps tendinitis and biceps instability. Biceps tendinitis has been subdivided into primary tendinitis (due to pathology of the biceps tendon sheath) and secondary biceps tendinitis (resulting from associated pathology such as rheumatoid or osteoarthritis.) Primary biceps tendinitis has been described for first by Lapidus and Guidotti [16], demonstrating the presence of thickening and stenosis of the transverse ligament and sheath and narrowing of the tendon underneath the sheath.

The LHB instability due to the pulley complex lesions can be classified in four groups, according to Habermeyer (Fig. 25.6) [17]:

Group 1—Isolated SGHL lesion.

Group 2—SGHL lesion and PASTA lesion, partial articular side supraspinatus tendon tear.

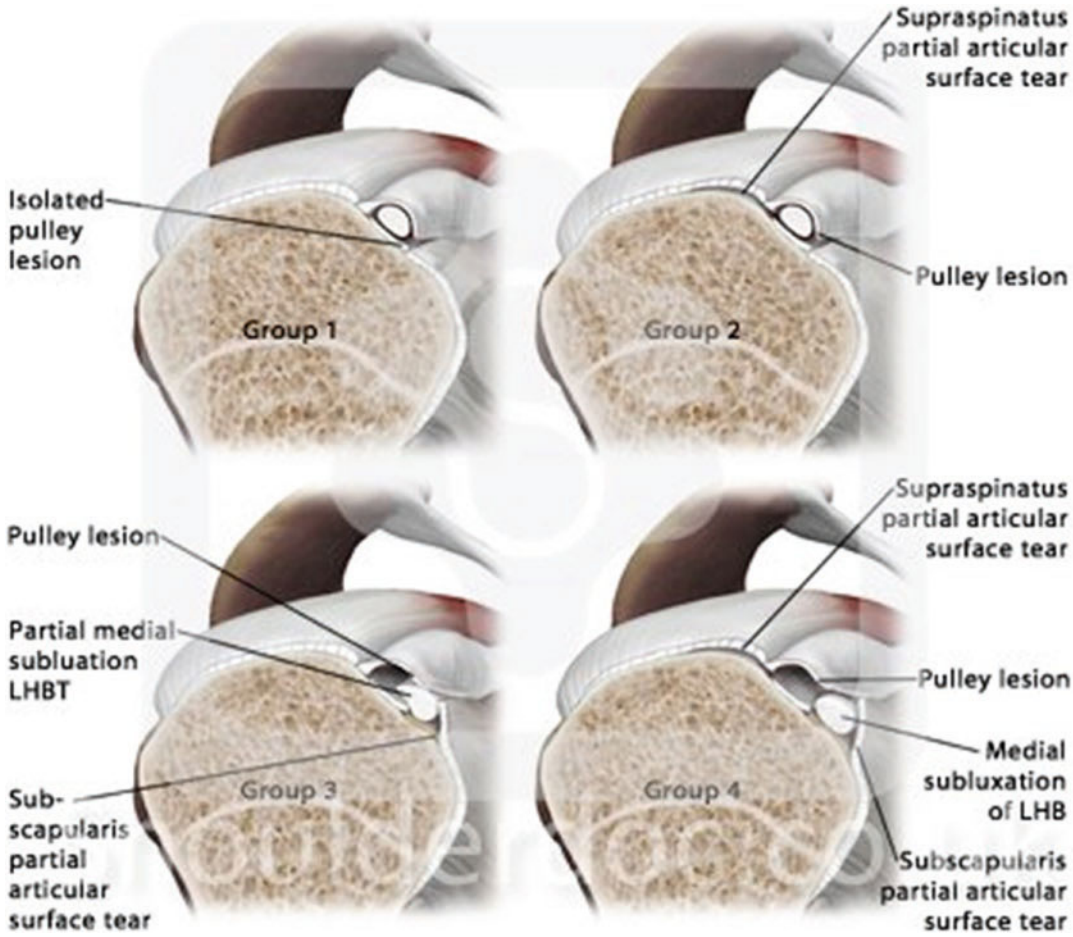

Fig. 25.6 The Habermeyer classification (from anterosuperior impingement of the shoulder as a result of pulley lesions: a prospective arthroscopic study. J Shoulder Elbow Surg. 2004)

Group 3—SGHL lesion and tear of the upper third of the subscapularis tendon.

Group 4—Combined lesion, SGHL, PASTA, and upper subscapularis.

LHB instability can be medial (more frequent) or lateral (less frequent); in medial instability, it can dislocate over the subscapularis when it is intact or under the subscapularis when it is disrupted.

Bennet edits another arthroscopic classification of biceps subluxation instability (Fig. 25.7) [18]:

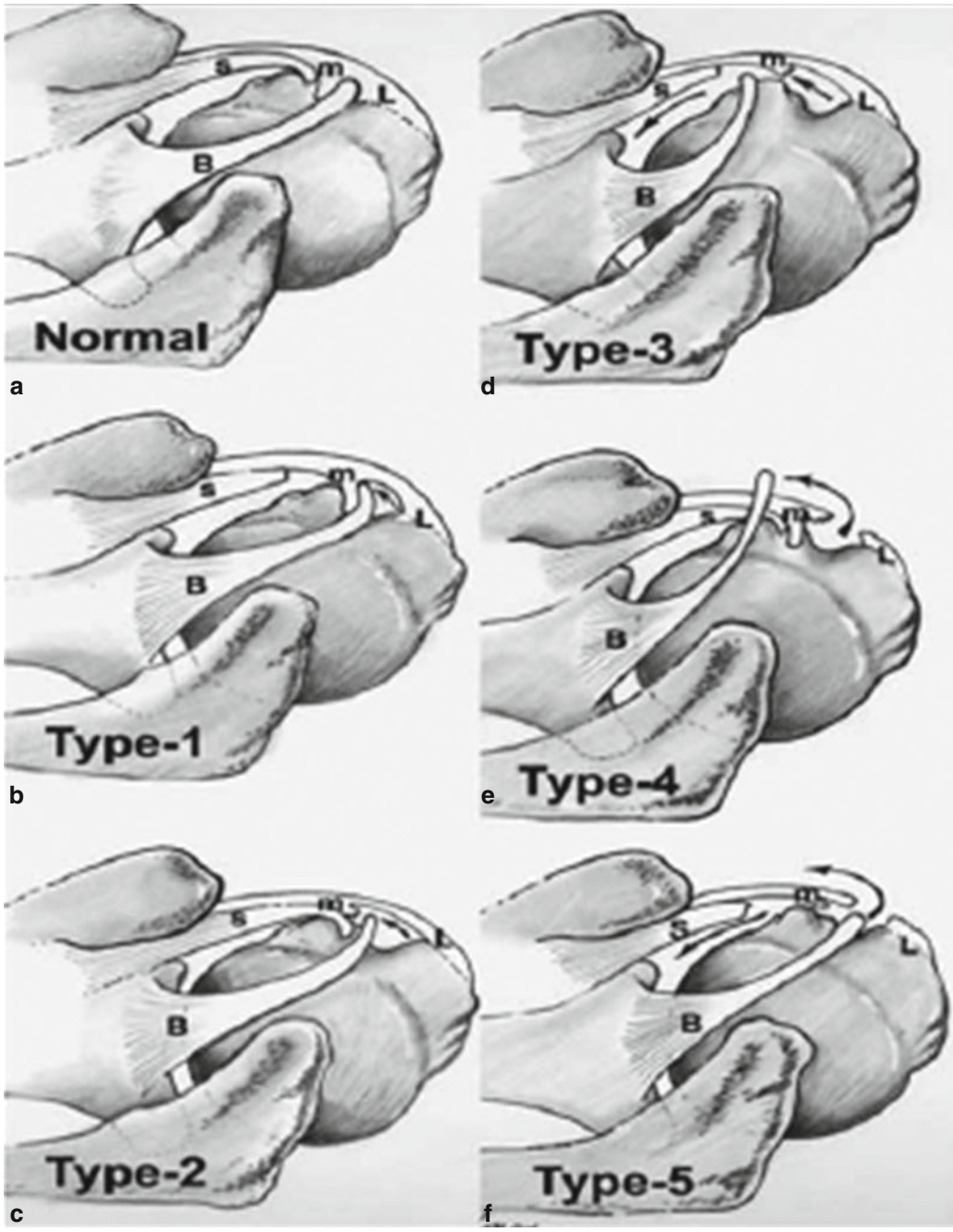

Fig. 25.7 The Bennet classification from correlation of the SlAP lesion with lesions of the medial sheath of the biceps tendon and intra-articular subscapularis tendon

- Type 1: Injury of the intra-articular subscapularis tendon without involvement of medial head of coracohumeral ligament (CHL).
- Type 2: Injury of the medial sheath (composed of SGHL-medial CHL ligament complex), without subscapularis involvement.
- Type 3: Injury involving both the medial sheath and subscapularis tendon.
- Type 4: Injury involving the supraspinatus and lateral head of CHL.
- Type 5: Injury involving all structures, intra-articular subscapularis tendon, medial sheath, supraspinatus tendon, and lateral CHL.

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26 Injuries of the Biceps Pulley System

Mike H. Baums

26.1 Introduction

The biceps pulley system (BPS) consists of capsulo-ligamentous threads that stabilize the long head of the biceps (LHB) before the tendon enters into the bony bicipital groove. The complex is shaped by conjoining parts of the superior glenohumeral ligament (SGHL), the coracohumeral ligament (CHL) consisting of a medial and lateral column and supporting fibres from the subscapularis (SSC) and supraspinatus (SSP) tendon (Figs. 26.1 and 26.2). Cadaveric studies have shown that the CHL is a key ligament for keeping the LHB aligned within the bicipital groove [1].

26.2 Pathomechanisms

The BPS stabilizes the LHB before it enters into the proximal portion of the bony bicipital groove in a 35° to 40° angle [2]. During rotation and forward flexion, the LHB is 'switched' to be able to slip into the bony channel. This system evolves the highest shear forces to the medial (SSC) and lateral (SSP) borders of the BPS [3]. Additionally, this mechanism produces friction as a consequence of the tendons excursion that is between 10 and 13 mm at the level of the BPS. Therefore, it becomes clear that an injury of the BPS results in destabilization of the LHB. In addition, the highest density of sensory and sympathetic neural elements is within the proximal segment of the tendon, which makes the LHB a significant pain generator to the anterior part of the shoulder [4], especially in cases with a BPS lesion.

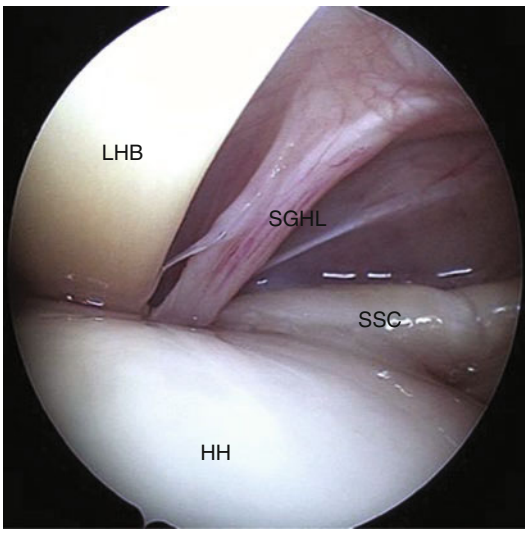

Fig. 26.1 'Dry' arthroscopy without irrigation fluid. View from a posterior portal: intact medial BPS showing the long head of the biceps tendon (LHB), the superior glenohumeral ligament (SGHL), the subscapularis tendon (SSC) and the humeral head (HH)

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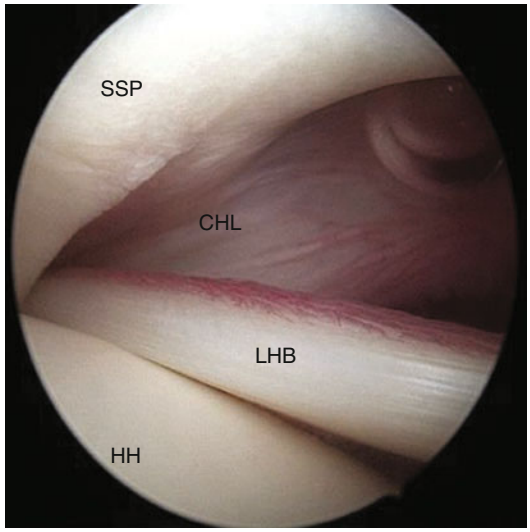

Fig. 26.2 Arthroscopic view from a posterior portal: intact lateral BPS showing an inflamed long head of the biceps tendon (LHB), the coraco-humeral ligament (CHL), the supraspinatus tendon (SSP) and the humeral head (HH)

Three different ways of damaging the BPS are known:

1. Degenerative or traumatic rupture of the SSP/SSC [3, 5].
2. Rupture of the BPS by immediate traction on the SGHL/CHL complex [6, 7].
3. Rupture of the BPS by straight shear forces of the LHB (like a 'saw mechanism') [8].

Several authors describe a dynamic course of the lesions development [2, 9]: it starts with a small laceration of the BPS, which causes a partial tear of the attendant rotator cuff (SSC/SSP). Afterwards, it results in a complete tear of the rotator cuff. This elucidates that approximately 90% of surgically treated rotator cuff tears are combined with BPS lesions, especially if the tear is articular sided in its appearance [10].

Partial or complete tears of the LHB are often found along the articular margin, a hypovascular area that is about 2.5 cm from the tendons origin [11]. Additionally, Boileau et al. [12] described a so-called 'hourglass' biceps lesion. In these cases, the tendon shows a hypertrophy proximal to the bicipital groove. This mostly results in symptoms related to incarceration of the tendon with the glenohumeral joint.

26.3 Classification Systems

Several classification systems (Tables 26.1 and 26.2) describe different groups and severities of BPS lesions depending on the anatomical structures that are involved (Figs. 26.3 and 26.4).

26.4 Clinical Examination

Clinical diagnosis and examination of BPS injuries often are difficult due to several reasons. Many of the lesions are associated with tears of the subscapularis and/or supraspinatus tendon. Therefore, different clinical tendon signs may be positive, but no proven test exists to evaluate specifically BPS lesions.

In several patients the avulsion of the BPS leads to biceps tendon instability causing an inflammation of the tendon itself. Therefore, all biceps tests can be positive. Subacromial impingement signs may be positive in every

Table 26.1 Classification system of Habermeyer et al. [2]

Type of lesion	Affected anatomical structure
Grade I	SGHL
Grade II	SGHL + SSP (articular sided)
Grade III	SGHL + SSC (articular sided)
Grade IV	SGHL + SSP + SSC (each articular sided)

Abbreviations: *SGHL* superior glenohumeral ligament, *SSC* subscapularis tendon, *SSP* supraspinatus tendon

Table 26.2 Classification system of Bennett et al. [18]

Type of lesion	Affected anatomical structure	Result
Type I	SSC (articular sided)	Increased motion of LHB in BPS
Type II	Medial head of CHL	Increased motion of LHB in BPS
Type III	SSC (articular sided) + medial column of CHL	Intra-articular dislocation of LHB
Type IV	Lateral column of CHL + SSC	Dislocation of LHB anterior to SSC
Type V	Medial and lateral column of CHL + SSC	Complete loss of BPS integrity

Abbreviations: *BPS* biceps pulley system, *CHL* coraco-humeral ligament, *LHB* long head of the biceps tendon, *SSC* subscapularis tendon

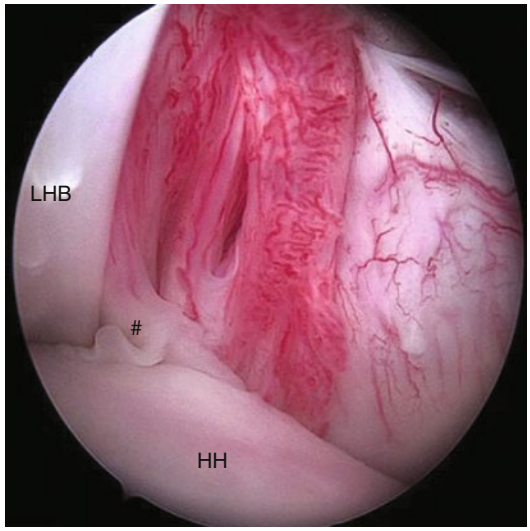

Fig. 26.3 Arthroscopic view from a posterior portal of a left shoulder in a 20-year-old overhead athlete: BPS lesion grade I according to Habermeyer [2]. Avulsion of the SGHL (#) resulting in instability of the LHB and consecutive antero-superior synovialitis. Humeral head (HH)

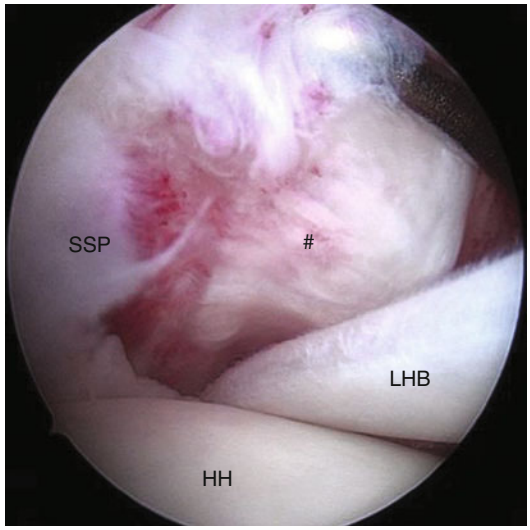

Fig. 26.4 Arthroscopic view from a posterior portal of a left shoulder of an 18-year-old soccer goalkeeper after fall on the arm: grade III avulsion of the supraspinatus tendon (SSP) with extent to the coraco-humeral ligament (#) resulting in instability of the long head of the biceps tendon (LHB) and accordingly a BPS lesion grade II according to Habermeyer [2]. Humeral head (HH)

second patient; positive palm-up and O'Brien sign may occur in 66% of the patients [2]. Other authors recommend a combination of Speed's test and uppercut test (Fig. 26.5) for detecting

Fig. 26.5 Uppercut test for detecting biceps tendon pathology

biceps tendon pathology but also do not describe specific BPS tests [13]. As a result, supplementary investigation regarding the best clinical examination of these lesions is necessary in the future.

26.5 Imaging Examination

Magnetic resonance arthrography (MRA) is proposed to be the best method to detect lesions of the BPS by a radiological imaging procedure. Critical hints are the displacement sign, an invisible or interrupted SGHL and a tendinopathy of the LHB on oblique sagittal planes [14]. Another sign may be the extension of contrast fluid to the cortex of the coracoid [15]. Walch et al. described the so-called pulley sign, which means increased contrast fluid anterior to the superior margin of the subscapularis tendon [6]. Overall, MRA demonstrated both high sensitivity (82–89%) and high specificity (87–98%) as confirmed by Schaeffeler et al. [14].

26.6 Arthroscopy and Its Diagnostic Limitations

During arthroscopy, lesions of the entrance to the BPS could be detected easily in most cases. The 'ramp test' could be used for confirming a normal superior glenohumeral ligament anatomy and function. Motley et al. defined a negative 'ramp test' with an intact SGHL and a freely moving biceps tendon in a V-type pattern [16]. They mentioned the test positive once the biceps tendon slips through a failed SGHL (Fig. 26.6) and appears with a U-shaped pattern [16].

The maximum visualization of the LHB could be reached in positioning the arm at 30° forward flexion, 40° abduction and 90° elbow flexion during standard arthroscopy [17]. In the authors' own experience, a dynamic check-up of the LHB tendons course within the BPS sheath is a mandatory part of diagnostic arthroscopy (Fig. 26.7).

A problem remains the bicipital tunnel itself that often conceals hidden lesions [18]. With use of the so-called pull test, the average excursion of the LHB could be enabled to 14 mm [19]. Nevertheless, the 'pull test' is only able to visualize 78% of the LHB relative to the inferior margin of the subscapularis tendon as approved in a cadaver model [20]. Gilmer et al. illustrated that shoulder arthroscopy only identified approximately 67% of pathologic transformations of the LHB and BPS [19]. Additionally, they found that the pathologies extent was underestimated in 56% of the considered cases. Moreover, these studies showed that almost half of the patients who had a lesion of the BPS and/or labral tears also had a hidden tunnel lesion that was concealed from standard shoulder arthroscopy [19, 20].

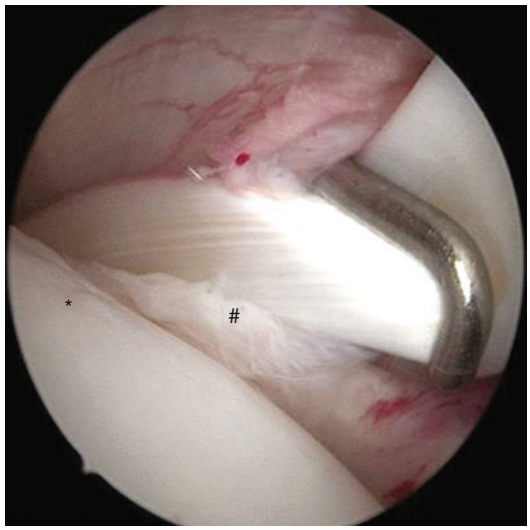

Fig. 26.6 Arthroscopic view from a posterior portal in a 38-year-old patient (left shoulder) during arthroscopic pull test showing an avulsion of the SGHL (#) and partial SSC tear (grade III BPS lesion according to Habermeyer [2]). In addition, a chondral humeral avulsion is detected (*) because of consecutive biceps instability

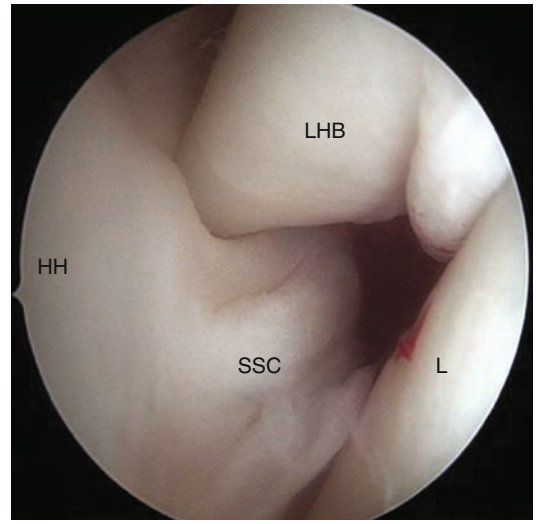

Fig. 26.7 Arthroscopic view from a posterior portal during dynamic check-up in forward flexion and internal rotation: the biceps tendon (LHB) slips into the intact BPS. Subscapularis tendon (SSC), humeral head (HH), anterior labrum (L)

In some cases a chondral avulsion or chondral bell mouth is apparent along the antero-medial aspect of the humeral head nearby the LHB's run to the BPS owing to its instability. In the author's own experience, a chondral bell mouth could be detected best using a 'dry' arthroscopy in the beginning of the arthroscopic procedure without irrigation fluid (Fig. 26.8).

26.7 Treatment Options

Conservative management using anti-inflammatory medication and/or physiotherapy may be a treatment option only in the elderly or

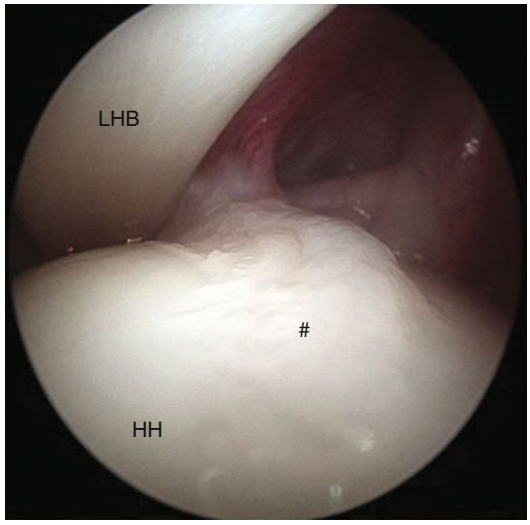

Fig. 26.8 Arthroscopic view from a posterior portal during 'dry' arthroscopy (without irrigation fluid) in a 32-year-old patient (left shoulder): chondral bell mouth (#) of the humeral head (HH) medially to the instable biceps tendon (LHB) due to BPS lesion grade II

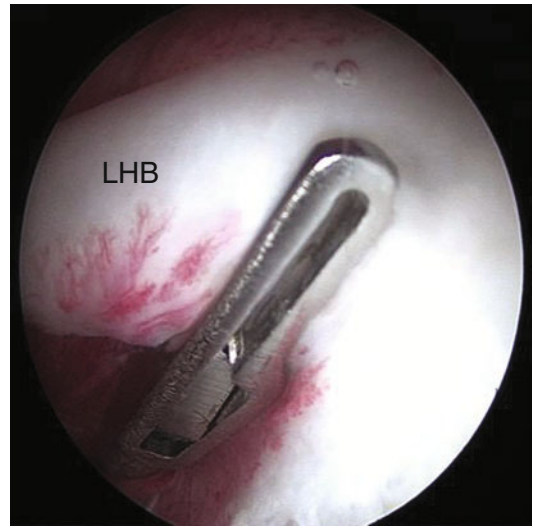

Fig. 26.9 Arthroscopic view from a posterior portal: tenotomy of the long head of the biceps (LHB) using an arthroscopic scissor

patients who do not want an operative intervention. But most of the lesions usually require accurate surgical treatment.

Bennett et al. introduced an arthroscopic repair technique for BPS lesions with considerable pain relief and increased shoulder function after 2-year follow-up evaluation [21]. But in summary, previous efforts to repair the BPS have been refused without success, because these methods have not been able to assert themselves as reproducible and safe alternatives [22, 23].

Walch et al. evaluated open SSC repair shared with restoration of the medial biceps sheath [6]. One third of their patients required scar tissue removal or bony groove deepening to stabilize the LHB; another three patients suffered from a tendon rupture. Improvement in discomfort was only low. Considering these outcomes the authors determined that tenodesis of the LHB is a more reliable treatment option in addition to SSC tendon repair.

The most simple and safe method for pain relief is the tenotomy of the LHB at its origin on the supraglenoidal tubercle (Fig. 26.9). This can easily be carried out arthroscopically using an arthroscopic scissor or biter as well as electrothermal devices. The disadvantage of a tenotomy is the risk of distalization of the biceps muscle belly resulting in a 'pop-eye' deformity or painful muscle cramping. This has been shown to occur in one fourth of the patients [24].

Tenodesis of the LHB can usually solve these two disadvantages of tenotomy. The tendon can be fixed to the humerus using different techniques (i.e. intra- vs. extraarticular tenodesis; soft tissue tenodesis including transfer to the conjoint tendon vs. bony tenodesis to the sub- or suprapectoral area with use of absorbable interference screws or suture anchor systems). Irrespective of the used technique for tenodesis, better tension can be applied to the muscle belly resulting in adequate muscle contraction. Additionally the risk for 'pop-eye' deformity can be minimized. Nevertheless, temporary muscle cramping can occur but usually disappears within a few weeks.

In the authors' clinic, the rehabilitation plan after tenotomy of the LHB is determined according to the concomitant procedure (i.e. tendon repair). In isolated biceps treatment, a sling is usually used no longer than a maximum of 2 weeks postoperatively. The patient is admitted to immediate passive motion followed by active motion to tolerance. Resisted elbow flexion and supination are not allowed within the first 6 weeks as well as strengthening or heavy weightlifting.

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Crossfire Tenotomy Versus Tenodesis: Pro-tenotomy

27

Stephen C. Weber

27.1 Introduction

The biceps tendon has now been recognized as an important pain generator in the shoulder [1], and biceps pathology occurs in up to 90% of patients presenting with rotator cuff pathology [2]. Failure to treat biceps pathology can result in significant postoperative pain and disability. Further complicating this issue is the fact that biceps pathology can be easily missed in the bicipital groove and often is a "hidden lesion." Proximal biceps tenodesis may not correct these problems. Tenotomy and tenodesis are the two mainstays of treatment for this pathology. Both techniques have proponents, but tenotomy has multiple advantages.

27.2 Literature Overview Summary

Tenotomy has undeniable advantages in the treatment of biceps and biceps-related pathology. Cost, ease of execution, and operating times are dramatically less. Associated complications should also be less, especially with the known risks of subpectoral tenodesis including hardware failure and neurovascular injury [1]. Operating time can become an important variable, as increasingly complex advances in shoulder arthroscopy often require multiple procedures to be performed at the same time, but with soft tissue swelling limiting overall operative time and so limiting the ability to execute these complex procedures. Postoperative activity restrictions are also substantially less with tenotomy, which was the deciding factor in the choice of several recent professional athletes who elected to treat their biceps pathology (successfully) with tenotomy. While postoperative cramping has been correlated with biceps deformity in the tenotomy group [3, 4], biceps pain has been reported both with tenotomy and otherwise successful tenodesis and tends to be equivalent in at least one report in both groups [5]. The only areas of controversy remain strength, pain, and cosmesis.

While historical articles have raised concerns regarding supination and elbow flexion strength post tenotomy [4, 6, 7], more recent articles, especially those comparing tenotomized versus tenodesed arms rather than normal controls, have shown little difference [4, 8]. Multiple comparative studies have now shown that patient-reported outcome scores comparing tenotomy to tenodesis in a wide range of clinical applications are virtually identical [3–6, 8–16]. Even in younger patients, little difference exists [10]. In a recent presentation [17], Gosselin et al. noted that the primary patient preference in the choice of biceps procedures was length of time needed to get back to unrestricted activities, clearly favoring

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tenotomy. Another recently presented review [18] again noted that the two procedures were equivalent in outcome based on a systematic review and meta-analysis.

Cosmetic issues can be an issue with tenotomy. Multiple studies have shown postoperative deformity in up to 70% of patients [7, 19]. It should be noted however that tenodesis does not eliminate the risk of biceps deformity, with up to 8% of patients showing residual deformity with tenodesis [1]. The modest deformity with tenotomy is often unrecognized by patients and is usually well tolerated. Duff et al. showed that only 3% of patients were concerned with the "popeye" deformity, and none requested surgical correction [3]. Appropriate preoperative informed consent is however critical, so that patients who may find postoperative deformity unacceptable can consider tenodesis.

27.3 Indications and Techniques

Biceps tenotomy is indicated for virtually any lesion of the bicipital labral complex [1]. A significant advantage of tenotomy over proximal tenodesis is that tenotomy addresses the pathology within the bicipital groove and intrasubstance lesions which may not be visible arthroscopically.

27.4 Specific Points in Rehabilitation

One of the major advantages of tenotomy is the absence of any need for postoperative restrictions. Wrapping the biceps muscle and modest restriction in resisted postoperative elbow flexion and supination may decrease the risk of biceps deformity.

27.5 Complications and How to Avoid Them

Complications, other than deformity with tenotomy, are negligible. While deformity issues are often not clinically significant, modifications of the tenotomy technique to include a portion of the labrum [20] or wrapping the biceps muscle postoperatively [1] can decrease the incidence and severity of deformity. Minimally invasive proximal tenodesis techniques such as the PITT technique [21] or the excellent long-term results of the Castagna technique [22] offer another option for the surgeon desiring a low cost, short operating time, and low-morbidity procedure while improving biceps cosmesis.

27.6 Conclusions

Biceps tenotomy offers numerous undeniable advantages in the treatment of biceps pathology. These include decreased operating time, complications, and cost, ease of execution, and decreased postoperative activity restrictions. Multiple reviews have shown that patient-reported outcome scores are virtually identical compared to tenodesis, and strength issues in recent publications have failed to show clinically significant differences in supination or elbow flexion strength. Cosmesis differences are often insignificant, but preoperative informed consent regarding possible deformity remains critical for successful biceps tenotomy.

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Crossfire: Tenotomy Versus Tenodesis # Pro Tenodesis

28

Mike H. Baums

28.1 Pro Tenodesis

While tenotomy and tenodesis both have been advocated to create good clinical outcome, an endless tight spot remained over the favored treatment approach in lesions of the biceps pulley system (BPS) and the long head of the biceps tendon (LHB). Despite the fact that tenotomy is the simplest and fastest way to solve pathologies of the LHB arthroscopically, there are some flaws in choosing this method.

In many cases a visible distalization of the LHB muscle belly develops which is cosmetically disturbing for many patients. This so-called "popeye" deformity may be also connected to a cramping or soreness discomfort of the LHB muscle belly. The incidence of a "popeye" deformity is reported to be 50% to 70% of the investigated shoulders [1, 2]. In addition, some studies confirmed both loss of elbow flexion and supination strength in young and active patients [3, 4]. Moreover, fatigue discomfort in the biceps muscle belly after resisted elbow flexion was present in approximately 40% of patients, interestingly merely in patients younger than 60 years of age.

In contrast, biceps tenodesis provides a new fixation point of the tenotomized tendon and consequently better maintains the relationship between its length and tension. Moreover, cramping muscle pain and soreness both can be avoided, and the risk of a cosmetic deformity is minimized. In everyday clinical life, tenodesis should be chosen especially in those patients that have a well-defined muscular structure of the arm and those that attach importance to a well-defined symmetry of both upper arms.

In the author's experience, especially thin, active, and well-trained patients will not be satisfied with the result of a distalized muscle belly as well as muscular cramping. This will be similar to the manual laborer. Therefore, especially those patients will benefit from a tenodesis procedure. However, tenodesis has to be protected by an initial period of immobilization in a sling, and both restricted elbow flexion and supination should not be allowed within the first 6 weeks.

Primarily, a well-defined cosmetic result can be reached by LHB tenodesis. Nevertheless, patients' request is an important issue that should be considered regarding the choice of treatment. Female gender, cosmetic outcome, and concerns about postoperative complaints like muscle cramping or soreness are reported to be positive predictors for choosing a tenodesis [5].

The technique for tenodesis is to the surgeons' preference (i.e., intra- versus extraarticular tenodesis; soft tissue tenodesis including transfer to the conjoint tendon versus bony tenodesis to the sub- or suprapectoral area with use of absorbable

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interference screws or suture anchor systems). If planning a bony tenodesis with use of a tenodesis screw, one has to be aware about the potential risk of creating a stress riser and therefore increasing the risk of a humeral fracture. Unicortical drilling at the surgical neck when doing a subpectoral tenodesis can theoretically reduce the torque to fracture significantly [6]. Nevertheless, complications like fractures, infections, or nerve irritations are very rare and mostly can be avoided doing the tenodesis with the right technique.

Tenodesis of the LHB is a safe treatment option in pathologies of the BPS [7] as well as LHB [8]. Cosmetic concerns and loss of muscle strength as well as muscle cramping especially are important for young and active patients. Therefore, tenodesis should be preferred in this active patient group to avoid this, especially when patients are younger than 60 years of age. Nevertheless, especially in high-performance or overhead sports activities, one has to anticipate a lower performance level after a tenodesis of the LHB was necessary [9].

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Intra-articular Biceps Tenodesis with an Interference Screw

29

F. Franceschi and A. Palumbo

The role of the long head of the biceps (LHB) tendon in producing anterior shoulder pain, first described by Hitchcock and Bechtol in 1948 [1], is now widely accepted. Pathology of the proximal portion of the biceps is commonly encountered by the physician treating shoulder diseases. Lesions of the long head of the biceps can vary in degree from tendinitis, delamination, and subluxation to frank dislocation and can be present in the tendon itself or in the pulley system of the tendon.

Treatment for pathology of the proximal portion of the biceps tendon generally consists of tenotomy versus tenodesis. Tenotomy is advantageous in that the procedure takes less time operatively than tenodesis and requires no particular postoperative protection.

Tenodesis was developed in response to the cosmetic deformity and biceps muscle belly weakness that came along with tenotomy, which has become generally recommended for younger patients and those with cosmetic concerns or those with the dominant arm involved.

The technique of tenodesis has undergone multiple iterations and, today, can be performed in either an open or arthroscopic fashion.

Since first being described by Gilcreest in 1926 [2], biceps tenodesis has been attempted using fixation sites both proximal and distal and using fixation methods which have included bone tunnels, interference screws, and suture anchors, bony keyholes, and suturing to adjacent structures such as the conjoint tendon or short head of the biceps or directly into bone within or adjacent to the bicipital groove [3–10].

29.1 Indications

The biceps tendon may be the primary source of a patient's shoulder pain when it is dislocated or becomes inflamed within the bicipital groove, or it may contribute to pain in conjunction with other pathologic entities, including rotator cuff tears, impingement, superior labral tears, and osteoarthritis, making tenodesis useful as an adjunct treatment when addressing pathology in these areas. By virtue of its position in the anterior shoulder, the biceps tendon is often injured when other structures become incompetent or by the same mechanism of injury affecting the other structures. Since the synovial lining of the glenohumeral joint is contiguous with the LHB tendon sheath, the conditions arising within the joint may also cause pain with the movement of the LHB tendon [9, 11–19].

Both tenodesis and tenotomy of the LHB tendon function to relieve anterior shoulder pain by unloading a damaged or inflamed tendon and tendon sheath. Biceps tenodesis is considered superior

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Indication	Contraindication
• SLAP lesions in elderly patients • Biceps instability • Symptomatic intra-articular partial tears of the LHBT • Chronic atrophic changes in the course of the LHBT • Painful and conservative therapy-resistant tenosynovitis • Additional treatment during rotator cuff repair, especially during repair of the subscapularis tendon • Painful and hyperthrophic LHBT with secondary impingement	• Severe osteoporotic bone • Tumors or cysts in the area of the tenodesis site • Implants in the area of the tenodesis

SLAP, superoanterior and posterior part of the labrum.

Fig. 29.1 Indication and contraindication for arthroscopic intra-articular tenodesis of LHBT [10]

to tenotomy for three primary reasons: (1) reattachment of the proximal biceps tendon maintains a normal length-tension relationship and prevents muscle atrophy, (2) elbow flexion and supination strength are maintained at near-normal levels, and (3) reattachment of the proximal biceps tendon affords a better cosmetic result by avoiding the "Popeye" deformity often seen following biceps tenotomy or rupture. The incidence of pain attributable to unchecked biceps contraction following tenotomy has been considered nonsignificant in comparison to that following tenodesis, but this consideration in combination with loss of strength and cosmetic deformity has made tenodesis the more desirable procedure in most cases. The loss of the proximal attachment of the LHB has been shown to lead to a 20% loss of forearm supination strength and an 8% to 20% loss in elbow flexion strength. Currently, biceps tenodesis is preferred over tenotomy in all patients except for older patients in whom cosmetic concerns and diminished strength are less important than are early pain relief and minimal healing time [9, 14–16, 19–23].

Figure 29.1 illustrates the table of indications and contraindications for a tenodesis of the LHBT according to Voss et al. [10].

29.2 Interference Screw Tenodesis: Surgical Technique

The principle of this arthroscopic biceps tenodesis is simple: the biceps tendon is fixed using a bioabsorbable interference screw into a humeral socket realized intra-articular, approximately 10 mm below the top of the groove entrance to prevent any anterosuperior impingement with the acromial arch.

Although the lateral decubitus position can be used, we prefer to perform this technique with the patient in the beach-chair position under general anesthesia or interscalene block. The shoulder should be placed in approximately 30° of flexion, 30° of internal rotation, and 30° of abduction (arthrodesis position), allowing the anterior part of the subacromial bursa to be adequately filled with water in order to have a clear view of the superior part of the bicipital groove. When using the beach-chair position, a classical knee U-shaped support is used with a Mayo stand to place the shoulder in the desired position. The elbow can be extended and flexed to 90°. Bony landmarks are drawn on the shoulder to identify the spine of the scapula, the acromion, the coracoid process, and the coracoacromial ligament. This procedure requires three arthroscopic portals: the classical posterior portal is created 2 cm inferior and 2 cm medial to the posterolateral corner of the acromion, and two anterior portals (anteromedial and anterolateral) are created 1.5 cm on each side of the bicipital groove (Fig. 29.2). The posterior and anterolateral portals are used for the arthroscope (viewing portals), and the anteromedial portal is used for the instruments (working portal). A pump is helpful to obtain distension of the joint and the bursa, but it is important to maintain low pump pressure (30 mm Hg or less) during the procedure, to prevent excessive soft tissue distension.

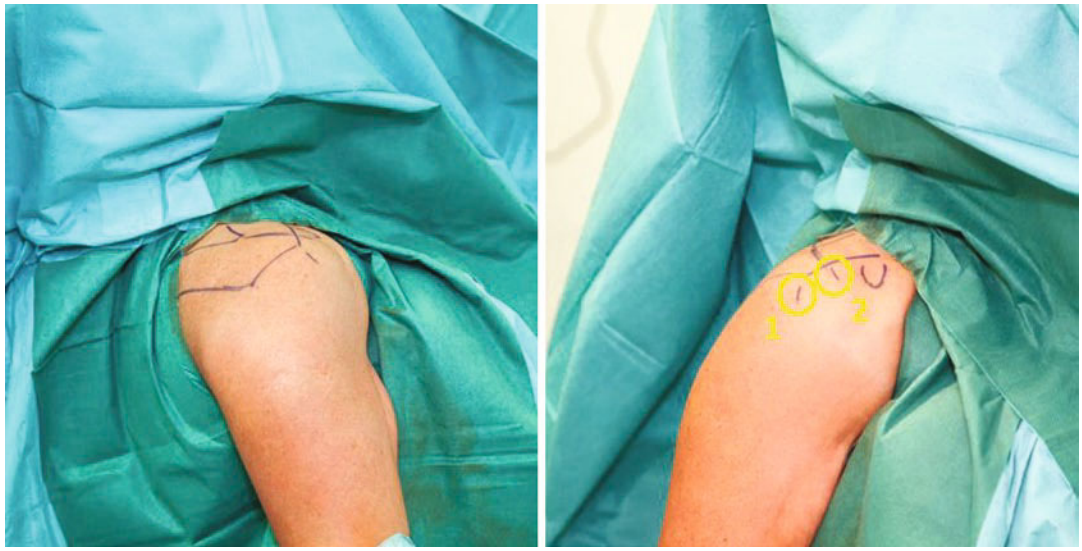

Fig. 29.2 Arthroscopic portals for surgery's procedure [23]

29.2.1 Step 1: Glenohumeral Exploration and Tenotomy of the Long Head of the Biceps

The glenohumeral joint is first explored with the 30° arthroscope through the posterior portal. An anteromedial portal is established from inside to outside passing the trocar of the arthroscope through the rotator interval, lateral to the coracoid process, 1 cm distal to it, and just above the subscapularis tendon. After insertion of a cannula, the deep surface of the rotator cuff is assessed, and pathology of the biceps tendon is confirmed: tenosynovitis, subluxation, dislocation, or prerupture. Biceps tendon pathology is very often in the intertubercular groove portion, and it is important to draw this part of the biceps tendon into the joint with a probe introduced through the anteromedial portal. The long head of the biceps is intra-articularly transfixed with a spinal needle at its entrance into the groove: this will avoid its retraction into the groove and help identify its location during subacromial bursoscopy. The tendon is then detached from its glenoid insertion using either a knife, a punch, or electrocautery.

29.2.2 Step 2: Biceps Exteriorization and Preparation

The long head of the biceps is grasped in its groove with a forceps while the spinal needle is removed. The biceps should then be grasped by its most proximal end to facilitate exteriorization. The tendon is now exteriorized through the anteromedial portal while the cannula is temporarily removed. A vascular clamp is used to grasp the tendon more distally and to keep it outside the wound; this will help to avoid tendon damage and to allow tendon preparation. Exteriorization of the tendon is facilitated by flexion of the elbow. About 4 to 5 cm of tendon should be exteriorized and the tendon is prepared.

After tenosynovectomy 2 cm of tendon with absorbable suture is prepared. The size of tendon for drilling the socket is measured.

29.2.3 Step 3: Drilling the Humeral Socket

The bicipital groove is cleaned of all fibrous tissue with the shaver or the VAPR. Care must be taken

not to shave on the most lateral or medial parts of the groove, because the leash of several small vessels there will bleed. The socket placement is assessed with probe measurement; this is optimally placed approximately 10 mm below the top of the groove entrance to prevent any anterosuperior impingement with the acromial arch. The location of the humeral socket is identified and penetrated with a sharp-tipped pick or awl, because the bone within the groove is quite hard; this prevents skiving or sliding of the guide pin along the cortical bone of the groove when drilling. A guidewire is then placed in the pilot hole and is oriented strictly perpendicular to the humerus and parallel to the lateral border of the acromion.

A guide (Shoulder-Guide, Future Medical System, Glen Burnie, MD) can be used to perform this procedure safely, without any risk to the axillary nerve; this makes the procedure reproducible for any surgeon. The guidewire is drilled until it just penetrates the posterior cortex of the humerus. The humeral guide pin is over-drilled with a 7- or 8-mm cannulated reamer, depending on the size of the double tendon, to a depth of 25 mm. The reamer and guide pin are then removed. The motorized shaver and an arthroscopic burr are placed through the same portal and into the humeral socket, to chamfer smooth its entrance by removing bone debris and tissues that may contribute to tendon blocking and abrasion (Fig. 29.3). Most attention should be paid to the inferior part of the humeral socket, where the tendon will enter. The synovial tissue around the biceps tendon is also removed.

29.2.4 Step 4: Interference Screw Fixation

The suture ends are then brought on a bioabsorbable tenodesis screw (e.g., BioComposite SwiveLock, Arthrex GmbH, Germany), and the final construct is brought back into the joint. As a general rule, a 9 × 25-mm interference screw for a 7- or 8-mm socket diameter is used.

Using a few slight hammer blows, the tendon and the screw are brought into position turned in manually. At this point it is important to check the depth of screw, as an overlap can cause irritation with less stability (Fig. 29.4).

29.3 Complications

The most common reported complications include loss of fixation resulting in Popeye deformity with and without cramping and pain. The failure of fixation can occur at the implant-bone interface as well as at the implant-tendon interface. It has been suggested that the occurrence of a Popeye deformity occurs more commonly than thought, never the less not all patients are afflicted by the deformity.

Biceps cramping and pain at the tenodesis site can appear, but the incidence is low compared with the tenotomy. According to Slenker et al. [24], a major difference between tenotomy and tenodesis was the cosmetic deformity, or the Popeye sign, with tenotomy (42%) compared with tenodesis (8%). Regarding the recent literature, the risk of Popeye sign is between 17% and 70% and cramping pain between 9% and 24% in the patients treated with tenotomy.

A technical error is the use of a too small diameter screw. It should be 1 or 2 mm larger than the socket diameter, as a rule. Due to habitual size of the biceps tendon, a 7- or 8-mm humeral socket is usually drilled and systematically paired with an 8- or 9-mm interference screw.

Infection and neurovascular complications are expected to occur with this technique (few incidence). In particular the axillary nerve is not at risk, if the humeral socket is drilled strictly perpendicular to the lateral border of the acromion with the arm at side.

Sometimes the humeral fractures are possible in position where humeral socket is drilled.

In summary, it is important to follow up patients on a regular base with complications after LHBT tenodesis [23–29].

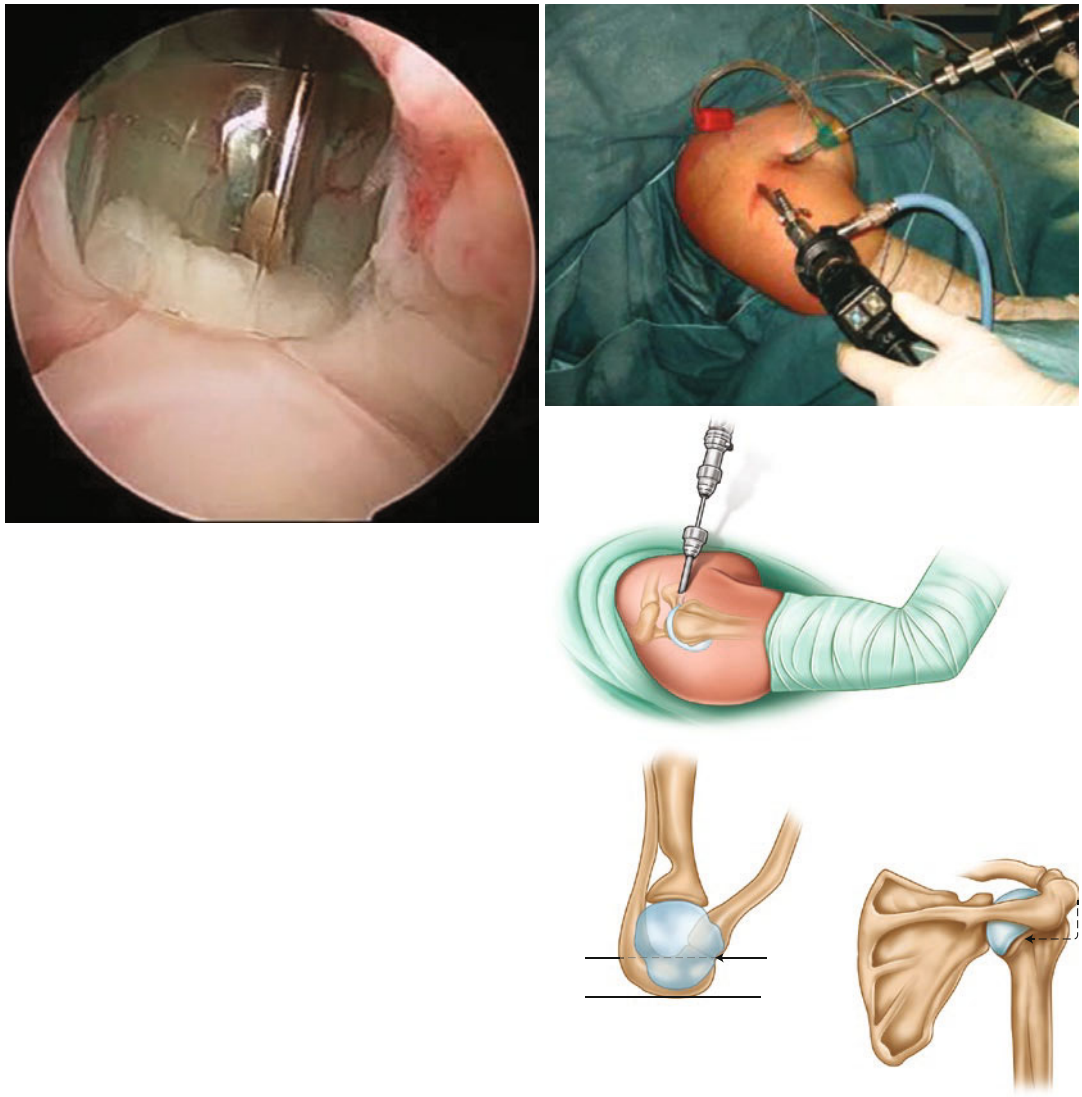

Fig. 29.3 Position for drilling the humeral socket [27]

29.4 Postoperative Management

Postoperative management is often limited due to an additional surgery (e.g., rotator cuff repair). If an intra-articular biceps tenodesis is the only treatment, it is recommended sling for 4 weeks and no active flexion exercise to the biceps muscle for 6 weeks. Patients can start with passive range-of-motion exercises, and full elbow range of motion is allowed immediately. He can start with full passive flexion and extension of the elbow, and full supination and full pronation of the forearm are allowed from the day after surgery with no restriction. Further limitations are dictated by concomitant procedures.

After 6 weeks, a stepwise weight-bearing treatment with active motion is recommended [9, 10, 23].

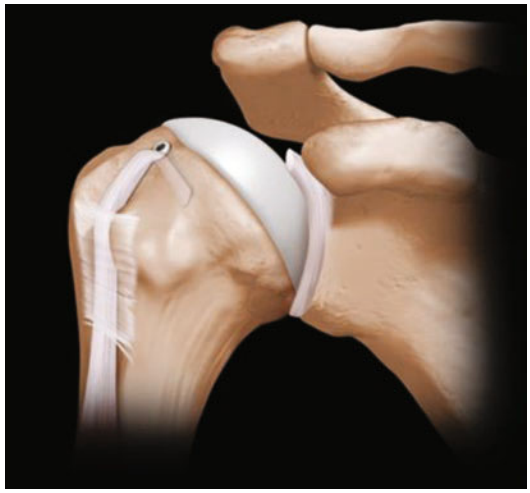

Fig. 29.4 Imaging of final intra-articular LHBT tenodesis

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Arthroscopic Supra-pectoral Biceps Tenodesis

30

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30.1 Introduction

The long head of the biceps tendon's (LHBT) role can range from being a vital component of shoulder biomechanics to solely a vestigial structure. Despite this controversy, the LHBT represents a frequent source of shoulder pain due to tendon degenerative changes or instability as well as residual pain after shoulder surgery [1–4].

A few ligaments and tendons are involved in LHBT stability conforming the bicipital groove. The coracohumeral ligament (CHL), the superior glenohumeral ligament (SGHL), the subscapularis (Subs), the supraspinatus (SSP), and the bone trough along with the transverse ligament (TL) are the main components of the biceps sliding pulley [5–9].

Orthopedic surgeons often face a dilemma during the treatment of LHBT injuries. This chapter describes in detail the arthroscopic supra-pectoral biceps tenodesis (ASBT) procedure and recommends it as the treatment of choice in patients with symptomatic biceps pathology.

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30.2 Operative Principles

Patients with LHBT degenerative tendinopathy are best served by biceps tenotomy or tenodesis. Tenotomy is a straightforward technique with high degree of pain relief, particularly in patients with low-demand activities. On the other hand, young individuals with high-demand activities present residual weakness, postoperative cramps, and cosmetic deformity (Popeye sign) after this procedure, and thus, biceps tenodesis seems better suited for this age subset [10–16].

Awkwardly, the most appropriate location to fix the tendon at the humerus remains unclear [17–21]. Although there are several tenodesis techniques, arthroscopic supra-pectoral biceps tenodesis (ASBT) emerges as the best option to ensure good results [3, 22–24].

30.3 Preoperative Assessment: Symptoms, Physical Exam, and Imaging Studies

The patient usually reports strong labor activity and rotations over the shoulder level or history of trauma. Sports with overhead or throwing swings (tennis, baseball, volleyball, or basketball) frequently lead to LHBT tendinopathy.

Patients with biceps tendinitis or tendinosis usually describe pain at the bicipital groove. They often refer "one finger pain" at the bicipital

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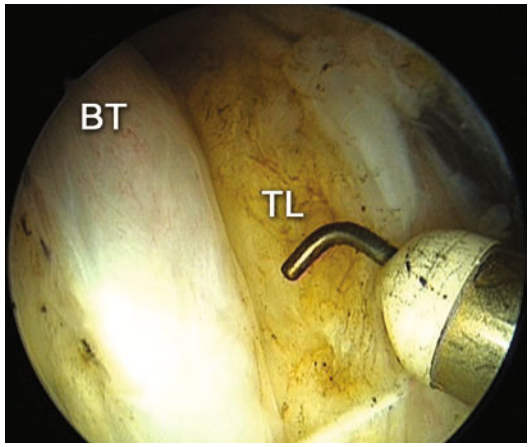

Photo 30.1 Right shoulder. Arthroscopic view from the lateral portal. *BT* biceps tendon, *TL* resected and retracted transverse ligament

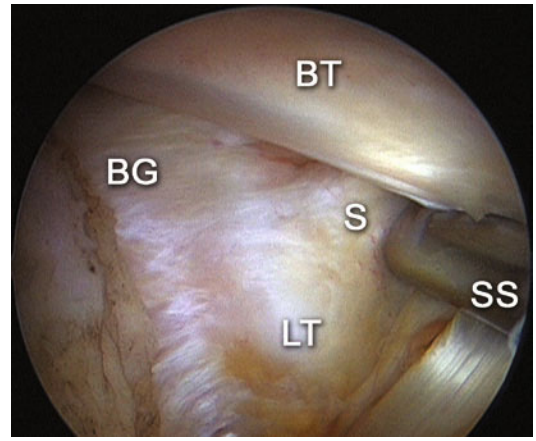

Photo 30.2 Right shoulder. Arthroscopic view from the lateral portal. *BG* biceps groove, *BT* biceps tendon, *LT* lesser tuberosity, *S* subscapularis, *SS* switching stick working as a static retractor during the reaming of the bone socket at the biceps trough

trough, right at the front of the shoulder and about 7 cm distal to the acromion edge (arm in 10° internal rotation). Occasionally, it is hard to distinguish this pain from diffuse tenderness related to other shoulder conditions.

The impingement tests such as Neer's or Hawkins' are unreliable for this pathology.

Biceps tendon instability is frequently associated with injury of the subscapularis tendon. Therefore, whenever we observe a positive belly press or a lift-off test demonstrating subscapularis tendon tear, the LHBT is frequently involved. The Speed's Test (resistance with the arm in 90° of forward flexion with forearm supinated) and O'Brien's Test (similar but with arm adducted 10° and a pronated forearm) may help to define pain originated by the LHBT (Photos 30.1, 30.2 and 30.3).

In high-demand athletes, reproducing the discomfort during sport swing before and after local anesthetic infiltration at the bicipital groove can help identify the pain source.

Shoulder X-rays anterior-posterior in slight external rotation, axillary and tangential bicipital groove projections (Fisk view), along with computed tomography (CT) identify degenerative changes at the bony bicipital trough. Dynamic ultrasonography allows an assessment of tendon tissue quality and instability, while non-contrast or the gadolinium-enhanced magnetic resonance imaging (MRI) provides information about LHBT structural distortions. Identification of biceps insertion site at the superior labrum and the superior labrum anterior and posterior (SLAP) lesions is best evaluated by contrasted MRI, while non-contrasted MRI provides sufficient information for the assessment of increased fluid at the biceps pulley and the bicipital sheath.

30.4 Indications

The fraying and degenerative changes among tendon instability at the groove are the main surgical indications for biceps tenodesis. Superior labrum anterior and posterior avulsions (SLAP lesions) in patients over the age of 40 years are also common indications for these procedures.

LHBT tenotomy is a successful procedure for elderly patients [10–14, 16]. Conversely, biceps tenodesis remains the treatment of choice for athletes and relatively young patients who suffered LHBT instability or tendinosis and required a better functional and cosmetic performance. During arthroscopic proximal tenodesis, fixation takes place close to the articular cartilage and frequently results in postoperative tenderness [14, 17, 18, 21, 25–27]. In an attempt to avoid this complication, surgeons have tried open

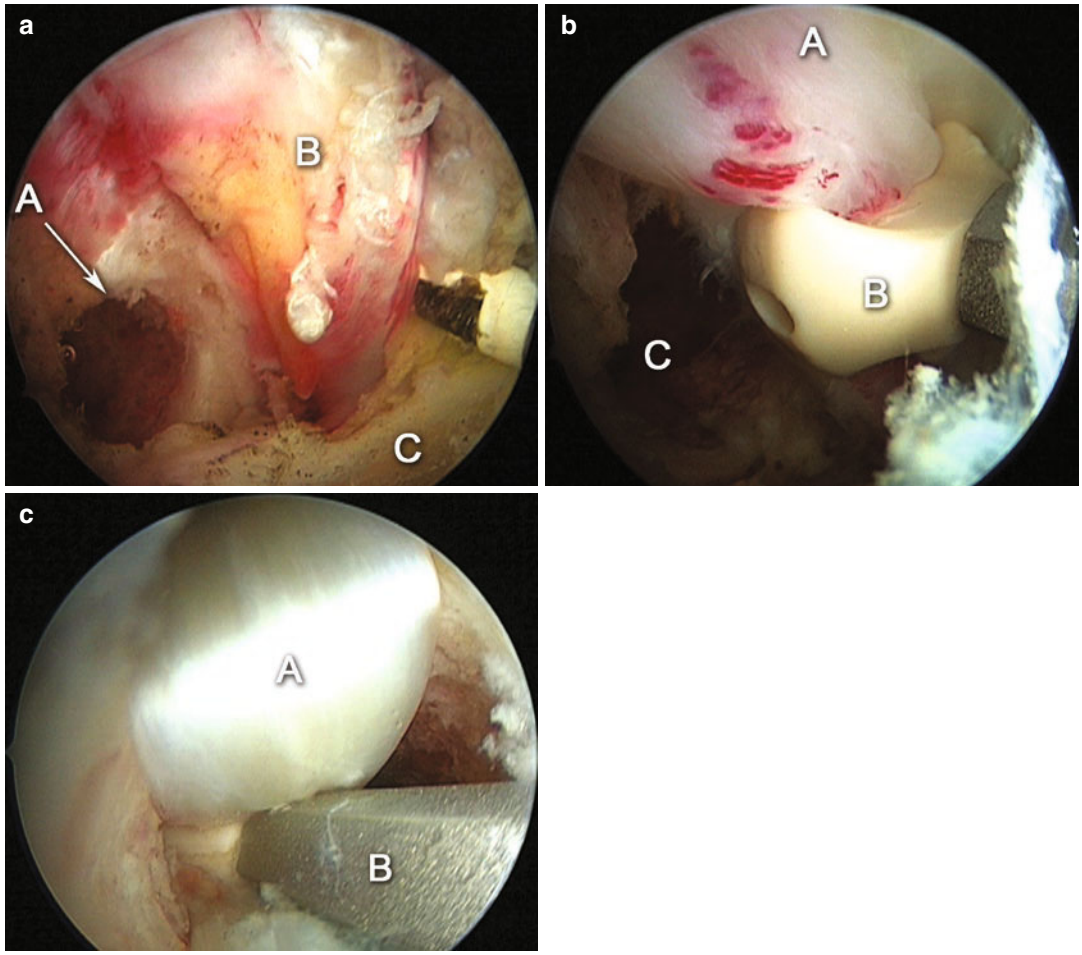

Photo 30.3 (**a**) Right shoulder. Arthroscopic view from the lateral portal. *A*: bone socket after reaming. *B*: biceps tendon. *C*: pectoralis major tendon. (**b**) Right shoulder. Arthroscopic view from the lateral portal. *A*: Biceps tendon. *B*: Forked tip of the implant. *C*: bone socket. (**c**) Right shoulder. Arthroscopic view from the lateral portal. *A*: biceps tendon steered into the socket. *B*: implant shaft before delivering the cannulated screw in

subpectoral tenodesis [3, 11, 24, 28–33]. Despite reducing postoperative pain, neurological complications and humeral fractures have occurred following this open procedure [34, 35]. Moreover, this procedure is technically challenging in patients with a strong, athletic shoulder [29, 36].

Recent data suggest that residual free nerve endings at the transverse ligament, tendon sheath, and bicipital groove can cause postoperative pain, especially in the setting of chronic inflammation [19, 20, 24, 27, 35, 37–39]. Surgical debridement and excision of those structures (transverse ligament, tendon sheath, and bicipital groove) [40, 41] may reduce the amount of residual free nerve ending tissue, improving long-term surgical results [27, 39].

30.5 Surgical Technique

With the patient positioned in beach chair position, the entire scapula and arm are prepared and draped to allow full access to the anterior and posterior shoulder structures. After drawing the bony landmarks (lateral and anterior edge of the acromion, acromion spine, and coracoid tip) on the skin, four arthroscopic portals are performed as follows. The posterior portal enables evaluation

of the glenohumeral joint and LHBT. This portal is placed 2 cm distal and 2 cm medial to the posterolateral corner of the acromion. The lateral portal is located with outside in technique between the middle and anterior third of the humeral head, 3 cm lateral from the acromion lateral edge. In addition, two anterior portals are established at the proximal and distal portions of the bicipital groove.

With the scope at the posterior portal and a probe through the anterior-superior portal, we perform a thorough inspection of the glenohumeral joint [42]. The use of the Ramp Test enables assessment of the stability and integrity of the extra-articular portion of the biceps tendon [30, 34, 43, 44]. We assess tendon quality and stability by pulling from the tendon in a downward fashion using a nerve hook.

When the rotator cuff is torn, the LHBT is readily recognized from the subacromial space. In the setting of an intact cuff, we scope from the glenohumeral joint and locate a spinal needle just anterior to the LHBT. We then introduce the scope into the lateral portal and enter the subacromial space; this needle helps us to identify the biceps tendon from above.

A radiofrequency device is used to dissect the tendon laterally. With the scope at the lateral portal and using the anterior-superior portal for instrumentation, we excise the roof of the bicipital groove, the TL along with the tendon sheath. Typically, dissection goes from proximal to distal, reaching the level of the falciform ligament, which is located at the upper portion of the pectoralis major tendon.

Interference screw fixation, rather than suture anchors, constitutes the best method to achieve strong fixation with rapid tendon healing inside a bony socket [4, 11, 13, 18, 19, 25, 26, 28, 32, 36, 45–47]. After optimal LHBT dissection, we should be able to move the tendon freely. A switching stick is used to retract the tendon medially (out of the groove), during the drilling process. The stick is delivered through the Subs and used as a static retractor of the LHBT during this step of the procedure. With a bullet tip reamer, we drill a 20 mm deep bone socket approximately 10 mm above the pectoralis major tendon. A caliper determines tendon width. Drill bit diameter is oversized 1 mm. Typically, we drill a 9-mm diameter tunnel for female patients and a 10-mm diameter tunnel for male patients. Usually, screw diameters are 8 and 9 mm, respectively, for females and males. For both genders, screw length is approximately 20 mm (range 19.5–23 mm). Drilling at the bicipital groove should be precisely perpendicular to the bony surface because any angulation of the reamer may enlarge the tunnel outlet and jeopardize final fixation.

A critical objective of the procedure is to restore the normal length-tension relationship of the tendon [22, 23]. As the tunnel is 20 mm long and the tendon will run down and then up the socket, a 40–45 mm long LHBT segment should be steered into the tunnel.

To obtain a normal length-tension relationship, we bury the LHBT proximal segment into the bone socket. Therefore, it is best to use a spinal needle to fix the biceps tendon to the pectoralis major immediately distal to the bone tunnel. By doing so, we prevent steering of the distal tendon segment into the socket. The latter frequently leads to over-tensioning and, hence, technical failure.

Despite reported patients' variation in shoulder anatomy and size, David and Denard have described several intraoperative anatomic measurements that have proven to be very useful for planning the appropriate tension of the tendon [22, 23].

If the chosen interference screw is 20 mm long, then the forked tip of the implant should grab the tendon 20–25 mm above the socket level or approximately halfway between the superior edge of the pectoralis major tendon and the articular cartilage rim. The tenotomy is performed with radiofrequency prior to interference screw fixation. The proximal limb of the tendon must be held by a tag stitch or a clamp.

Many systems for biceps tenodesis exist in the market, all of them sharing the same principles. Some implants have a polyether ether ketone forked tip as part of the insert to push the tendon inside the socket. This tip stays inside the bone with the screw. With other systems, the fork constitutes part of the instruments and comes out

before fixation leaving a pin for a cannulated screw.

In systems where the forked tip becomes part of the implant, additional tendon control can be obtained by delivering another tag suture through the tendon at the target level. By loading the suture tails through the eyelets at the implant tip, we can easily steer the tendon inside the socket, obtaining an optimal length-tension relationship.

An 8.25-mm wide cannula is used to press the tendon against the bone and prevent tendon spinning. The screw is left flush. Further depression of the screw into the socket can jeopardize fixation strength [4, 13].

Fixation is then probed with a hook during elbow motion. The remaining tendon is trimmed and the arthroscopic portals are closed with figure eight skin stitches.

30.6 Postoperative Care

The use of a shoulder sling is recommended for 4 weeks. Progressive range of motion exercises are allowed 3 weeks after surgery. Resisted elbow flexion and forearm supination are contraindicated for 2 months. Strengthening and gradual return to sports is expected between 3 and 5 months after surgery.

30.7 Potential Complications and Failures

Due to intraoperative bleeding and visualization problems, the procedure may require conversion to an open subpectoral tenodesis. Lack of tendon integrity seems to be the Achilles heel of any fixation method, including ASBT. In our experience, the presence of tenodesis fixation failure or postoperative cosmetic deformity was always associated with poor tendon tissue quality. Any system (interference screws or suture anchors) could eventually fail in the presence of severely degenerated tendon with tendinosis. Therefore, such condition should contraindicate tenodesis and dictate a tenotomy procedure. Although rare with the above-described distal groove supra-pectoral technique, the presence of postoperative tenderness at the groove may occur during the first postoperative year.

The ASBT technique is frequently performed in association with other arthroscopic repairs, and thus, it can be difficult to pinpoint the actual culprit of the pain. Unfortunately, there is no specific tool that can assess clinical results after biceps tenodesis. Recently, Scheibel et al. described the LHB score, which takes into account pain, cosmetics, and elbow flexion strength. Possibly, the use of this test will enable monitoring more precisely the long-term outcome following ASBT [32, 33].

30.8 Conclusions

The precise role of the biceps tendon for shoulder biomechanics is a matter of considerable controversy. Obtaining an accurate diagnosis of biceps tendon instability remains a challenge; nonetheless, its detection becomes less confusing when the tendon suffers degenerative tendinosis. The biceps tendon problems are better treated by tenotomy or tenodesis, depending on patient's demands.

Even though the best place to fix the LHBT at the proximal humerus has not been well defined, the arthroscopic supra-pectoral biceps tenodesis constitutes a valuable surgical option for young patients or athletes who suffer biceps tendinopathy.

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Biceps Transfer to the Conjoint Tendon

31

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31.1 Introduction

Tendinopathies and lesions of the tendon of long head of biceps (LHBT) are common causes of anterior shoulder pain and in combination with functional limitation. They are usually associated with rotator cuff tears, frequently located at the posterosuperior part, but in several cases, they have been described as isolated pathology [1]. LHBT can be schematically divided in two parts, intra-articular (from the insertion to glenoid labrum to the upper part of humeral groove) and extra-articular (from the top to the bicipital groove to the musculotendinous junction). The proximal part of the LHBT is relatively anchored at its origin on the supraglenoid tubercle and the superior labrum. After a brief intra-articular course where it is mobile, the tendon turns into the bicipital groove. Within the bicipital groove, the tendon is again relatively fixed. This relative fixation of the proximal part of the LHBT at two sites in the setting of extensive mobility of the glenohumeral joint predisposes the LHBT to high stresses [2]. The intra-articular part LHBT can be affected by inflammation, trauma, impingement, instability (typically associated with subscapularis tears), intrinsic degeneration, and fibrosis in the rotator interval. SLAP (superior labral tear, anterior to posterior) lesions represent also a specific group of lesions found at the superior labrum-biceps tendon complex, classified into four types in 1990 by Snyder [3]. The extra-articular segment of the LHBT is a common site of pathologic processes in particular within the bicipital tunnel. Lesions can include LHBT partial tears; fraying, shredding, and fasciculations of the tendon; scar/adhesion development; loose body collection; and osteophyte formation along the floor of the bicipital tunnel. Despite many symptomatic lesions may occur in the extra-articular part of the LHBT, unfortunately bicipital groove is difficult to assess with a standard 30° arthroscope [4]. Positioning the arm in the "best viewing" position with 30° forward flexion, 40° abduction, and 90° elbow flexion was shown to improve proximal excursion of the LHBT during simulated pull of an arthroscopic probe. Even under ideal circumstances, a substantial portion of the LHBT remains hidden from arthroscopic view [5].

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31.2 LHBT Pathology Management

Conservative management for LHBT pathology includes activity modification, physical therapy, local steroid injections, and oral anti-inflammatory medications. Physical therapy consists of rest, ice, heat, ultrasound, gentle massage, and periscapular muscle strengthening. Although the majority of symptomatic LHBT lesions can effectively be managed with conservative measures, surgery may be indicated in a subset of patients with recalcitrant symptoms. Surgery should be advocate in patients with failed conservative management lasting more than 6 months, presenting symptoms defined as the "3-pack" at physical examination (tenderness with palpation of the bicipital groove, positive throwing test result, and positive active compression test result) [6] or positive to other traditional tests. The best surgical management of LHBT has not been identified, and tenotomy and tenodesis are commonly undertaken [7]. Tenodesis has emerged as a more popular technique in the recent past and, despite the different techniques, its use increased significantly in the last few years [8]. Biceps tenodesis is generally performed in younger people, active patients (athletes and laborers), and people who want to avoid cosmetic deformity [9]. Tenodesis preserves the length-tension relationship of the biceps muscle, which may prevent muscle atrophy and Popeye deformity [7]. LHBT tenodesis can be performed as an arthroscopic, open or mini-open procedure [10, 11]. A tenodesis can be performed in the upper portion of the bicipital groove, in the proximal portion of the bicipital groove, in the distal portion of the bicipital groove and also to the conjoint tendon, or in a subpectoral position, 1 cm proximal to the inferior border of the pectoralis major tendon [12–15]. Tenodesis in the upper portion of the groove may allow this inflammation to persist, causing residual pain after tenodesis [16]. Surgeons who propose distal, subpectoral fixation believe that removal of the LHBT and tenosynovium from the bicipital groove allows the orthopedic to avoid residual "groove pain," which is believed to originate from the inflamed intertubercular part of the LHBT. Mazzocca et al. [17] suggested that a more distal tenodesis could remove pain generators located within the groove. Sanders et al. [18] conducted a retrospective study on 127 biceps surgeries with a mean follow-up of 22 months. The authors recorded the rate of ongoing pain localized in the biceps groove, severe enough to warrant revision surgery. They observed a statistically significant difference in revision rate between the techniques that released the biceps sheath (6.8%, 4/59) when compared to those that did not (20.6%, 14/68). The different incidence in postoperative pain could be explained according to the anatomical observations. Depalma et al. [19] suggested that the intra-articular tenosynovitis of the LHBT could extend distally into the bicipital groove. Other anatomical studies revealed also to the LHBT tendon itself could be addressed as the source of referred symptoms and not only the bicipital groove sheets. The observation of a dense neuronal network in pathologic human LHBT tendon consisting of sympathetic and sensory elements has been correlated with neural development and nociceptive pathways [20]. The ideal LHBT reinsertion location is thus still controversial, and a great debate is growing up on this topic. Recently a new technique has been described, proposing the LHBT management with tenodesis to the conjoint tendon. In this chapter we will describe briefly surgical features and available outcomes of this technique.

31.3 Open\Mini-Open LHB Tenodesis to the Conjoint Tendon

First experiences with LHBT tenodesis for chronic symptomatic tendinopathy with open transposition of the tendon to the coracoid process were described by Dines et al. [21] in 1982. Preoperative diagnosis was biceps tendinitis in 13 shoulders and biceps instability in 7. At last follow-up, there was a 30% failure rate; failures were related to misdiagnosing biceps instability, not identifying an impingement syndrome, or glenohumeral instability. Those patients who

were relieved of symptoms had in addition to biceps tenodesis, an excision of a portion of the coracoacromial ligament. In four of the six failures, the coracoacromial ligament was not released. Post et al. [22] in 1989 published data about patients with chronic painful shoulders affected by isolated bicipital tendinitis involving only the extracapsular, intertubercular portion of the long head of the biceps. All these patients were chosen for surgical treatment after conservative treatment failure. Open transfers of the LHBT were performed in four patients, reporting two excellent and two good results at an average follow-up of 42.5 months (range 28–81 months). One patient developed adhesive capsulitis at 7 months postoperatively requiring a manipulation of the shoulder under general anesthesia. It's important to highlight that both aforementioned papers presented techniques of LHBT transposition with direct tenodesis to the coracoid process. A recent paper by Pastor et al. [23] compared 2 different techniques for open/mini-open biceps tenodesis to test their biomechanical properties in 12 cadaveric specimens, divided into 2 groups of 6. In the first group, the biceps was transferred to the conjoint tendon. The LHB was attached to the conjoint tendon with a continuous suture (Fiberwire No. 2, Arthrex Inc., Naples, FL, USA), beginning directly below the coracoid process running 4 cm distally with a surgeon's knot at the end. In the second group, an intraosseous suprapectoral tenodesis was performed. The proximal part of the LHBT was shortened by 2 cm and reinforced with 2 cm no. 2 Fiberwire (Arthrex Inc., Naples, FL, USA) in a running whipstitch technique. A 20 mm bone socket was drilled over the Kwire with a 7 mm drill. The whipstitched sutures were fed through the closed eyelet of the 8 mm PEEK SwiveLock tenodesis screw (Arthrex Inc., Naples, FL, USA). The maximum strength of both groups and failure mode were analyzed. After a preload of 10 N, cyclical loading with a maximum of 60 N and 100 N with 100 cycles and 0.5 Hz was applied to the tendons for both groups. An axial ultimate loading to failure was conducted subsequently. No significant differences were found in age, bone mineral density, or weight between the two groups. The mean ultimate load to failure was 294.15 N in the transposition group and 186.76 N in the suprapectoral group, but this difference was not significant ($P = 0.18$). The biomechanical results demonstrated equal biomechanical properties for both techniques.

31.4 Arthroscopic LHB Tenodesis to the Conjoint Tendon: Surgical Technique

In the first years of the new millennium arthroscopy registered great advancements, allowing surgeons to develop new mini-invasive techniques to address in a novel manner disease affecting the shoulder. Verna et al. [24] published in 2005 a technical note describing an arthroscopic tenodesis technique for LHBT transfer to the conjoint tendon.

31.4.1 Diagnostic Arthroscopy, LHBT Preparation, and Subacromial Decompression

The patient is placed in the beach chair position under general anesthesia. Lateral decubitus position must be avoided for two reasons: inability to achieve necessary exposure of subdeltoid space and risk of medial fluid extravasation due to gravity. A good visual field is crucial for the procedure success, so the arterial blood pressure should be kept at 90~95 mmHg to reduce intraoperative bleeding. The involved upper extremity is keep free to make sure that the shoulder joint has complete passive range of motion. Bony landmarks, acromion, coracoid, and acromioclavicular joint should be accurately outlined preoperatively. A standard posterior portal is established, and the diagnostic arthroscopy is performed (Fig. 31.1b). The LHBT, especially the entry to the bicipital groove and its anchor to the superior labrum must be inspected to detect fraying of the base of the tendon and partial tears [4]. A probe is used to displace the tendon inferiorly to allow visualization of the entire intra-articular portion [5]. Using this information

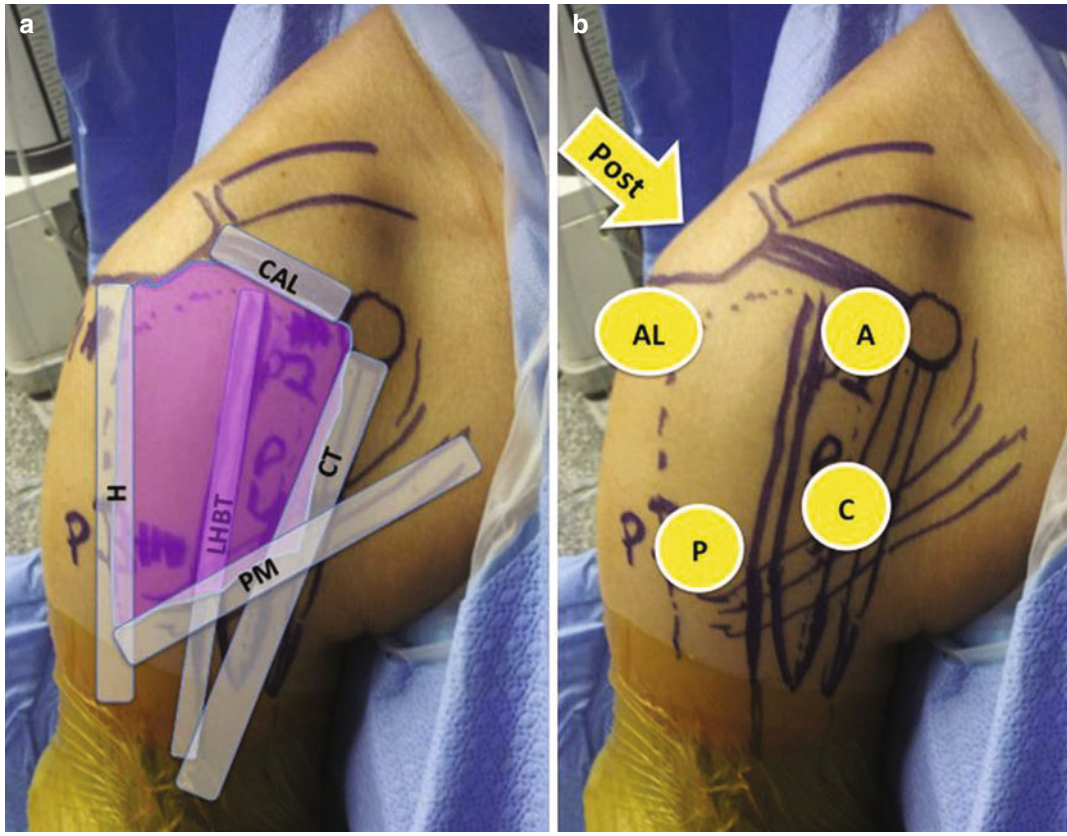

Fig. 31.1 (**a**) The subdeltoid space (purple) is defined superiorly by the coracoacromial ligament (CAL), medially by the coracoid and conjoint tendon (CT), inferiorly by the pectoralis major (PM), and laterally by the lateral border of the humerus (H). The long head of the biceps tendon (LHBT) exists in the floor of the subdeltoid space. (**b**) Five portals are used during subdeltoid arthroscopy: the standard posterior (post) portal, anterolateral portal (AL), an anterior portal (A), a conjoint portal (C), and the pectoralis (P) major portal (Reprinted from: "The arthroscopic "subdeltoid approach" to the anterior Shoulder" O'Brien S, Taylor S, DiPietro J, Newman A, Drakos M, Voos J; JSES 2013) [26]

combined with the preoperative physical examination findings, a decision to proceed with the transfer can be made. In this phase intra-articular procedures, such as removal of loose bodies or limited labral debridement should be performed primarily. If the surgeon decides to proceed with the transfer, the biceps tendon is tagged with No. 0 PDS sutures. This is accomplished by placing a spinal needle percutaneously through the rotator interval using a starting point just off the anterolateral corner of the acromion. The needle is then passed through the LHBT, and the suture is passed through the needle and brought out through an accessory posterior portal. This keeps the sutures in the joint for the time being and allows for simple suture management after release. In this manner, 2 or 3 No. 0 polydioxanone (PDS) sutures can be placed through the tendon for later use as a tagging stitch. Once the long head biceps tendon has been tagged, it is released by a simple resection as close as possible to the biceps origin on the superior labrum. Tenotomy can be performed using an arthroscopic basket or scissors or using a radiofrequency device; the remaining stump is also debrided using a mechanical shaver. The arthroscope is subsequently redirected into the subacromial space from the posterior portal.

31.4.2 Subacromial Space Decompression and Associated Lesion Treatment

A subacromial decompression is performed using a radiofrequency device and a burr when clinically indicated by impingement signs and symptoms. An accurate bursectomy and, if indicated acromioplasty, extending from the anterolateral border of the acromion to the acromioclavicular joint is performed to allow exposure of the conjoint tendon medially. In presence of a rotator cuff tear, the involved rotator cuff is treated at this time with debridement or suture.

31.4.3 Subdeltoid Space Exposure

The subdeltoid space is extra-articular and defined superiorly by the acromion and coracoacromial ligament, medially by the coracoid and the conjoint tendon, inferiorly by the musculotendinous insertion of the pectoralis major to the humerus, and laterally by the lateral border of the humerus (Fig. 31.1a). When insufflated with saline, it provides reliable, versatile, reproducible, and unprecedented arthroscopic access to the anterior shoulder. In the original technique described by Verna et al. [24], the first step is to reposition the ipsilateral arm into the *90-90-15 position*. Shoulder is positioned in forward flexion of 70° to 90°, elbow flexion to 90°, and arm abduction to 15° to 30° allows the humeral head to fall posteriorly, which facilitates exposure of the subdeltoid space anteriorly. Fluid inflow and outflow during this phase is crucial to avoid excessive swelling. Very low pressures, compared to those used in the subacromial space, should be maintained during subdeltoid space exposure. Some authors [25–27] suggest adoption of gravity inflow and outflow to prevent excessive pressure that can led to fluid extravasation, particularly between soft tissues located medially to the conjoint tendon. With the arthroscope in the posterior portal (Fig. 31.1b), an anterolateral working portal is established under spinal needle localization at the anterior third of the acromion such that the bony edge of the acromion does not impede the working vector (Fig. 31.2b). For most patients, this is approximately 1 to 2 cm distal to and 1 to 2 cm posterior to the anterolateral edge of the acromion. This working portal is later converted into a viewing portal (Fig. 31.1b). Most authors suggest radiofrequency ablation of the subdeltoid bursa: this minimizes bleeding and heeds warning (stimulates contraction) if a nervous structure is approached inadvertently [26, 28]. To safely expose the subdeltoid space, the surgeon meticulously performs a clockwise debridement, sequentially identifying a "safe" structure and then following it to the next "safe" structure (Fig. 31.2a). Subdeltoid space exposure can schematically be divided in four steps as described by O'Brien et al. [26] with sequential identification of the aforementioned landmarks.

31.4.3.1 Step1: From the Upper Part of the Coracoacromial Ligament to the Coracoid Process

The subdeltoid approach starts adopting the posterior portal as viewing portal and the anterolateral portal as operative portal. The coracoacromial ligament is exposed at its acromial attachment and followed medially to the coracoid. The coracoid marks the medial boundary of dissection (Fig. 31.2c).

31.4.3.2 Step 2: From the Coracoid Insertion of the Conjoint Tendon to the Musculotendinous Junction

Successive exposure of subdeltoid space requires creation of two additional portals, according to the technique described by Verna et al. [24]. Using the anterolateral portal for visualization, the "pectoralis portal" and "coracoid portal" are created at this time (Fig. 31.1b). All portals are made via spinal needle localization. It's important to remember that incisions at this point should be limited only at the skin. Subsequent passages must be performed with a blunt cannula placed over a guide wire to avoid neurovascular injury.

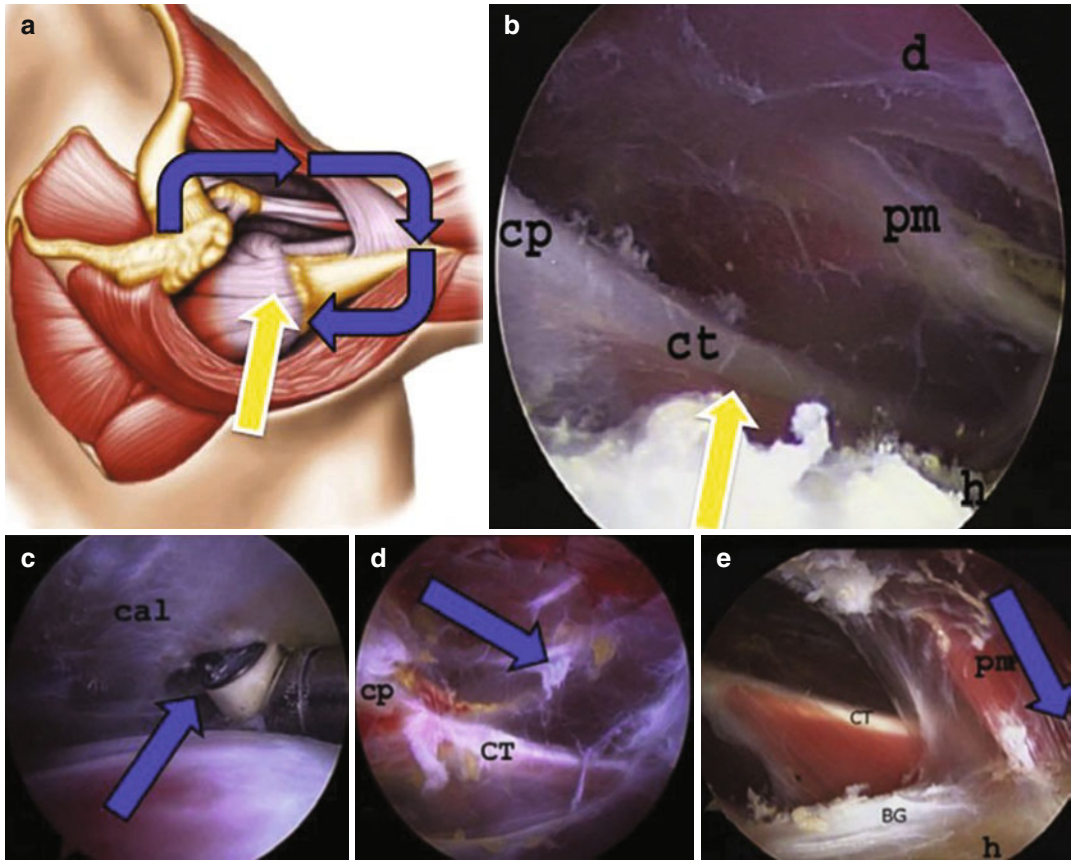

Fig. 31.2 (**a**) The subdeltoid space is exposed by using the posterior portal for viewing and an anterolateral portal (yellow arrow) for working and instrumentation. Exposure is accomplished in a sequential clockwise manner (blue arrows) in which a safe structure is identified and followed to the next safe structure. (**c**) First, the coracoacromial (cal) ligament is identified and traced medially (blue arrow). (**d**) Next, the coracoid process (cp) is identified, and the conjoint tendon (ct) is traced distally (blue arrow) to its intersection with (**e**) the pectoralis major tendon (pm). (**b**) A panoramic view of the subdeltoid space is seen from the anterolateral portal (yellow arrow). *BG* bicipital groove, *d* deltoid, *h* humerus (Reprinted from: "The arthroscopic "subdeltoid approach" to the anterior Shoulder" O'Brien S, Taylor S, DiPietro J, Newman A, Drakos M, Voos J; JSES 2013) [26]

- "Coracoid portal" (also referred as "conjoint portal"): the tip of the coracoid is the anatomic landmark for needle localization through the anterior deltoid. This portal is approximately 2 cm distal to the tip of the coracoid process and in line with the conjoint tendon (Fig. 31.1b).
- "Pectoralis portal": the superolateral margin of the pectoralis major tendon is the anatomic landmark for spinal needle localization through the deltoid. This portal is optimally positioned at the inferolateral corner of the subdeltoid space, the junction of the superior margin of the pectoralis major tendon, and the long head of the biceps tendon (Fig. 31.1b).

The camera is then placed in the anterolateral portal, and the pectoralis portal is used for working.

One or two inflow cannulas, according to surgeon's preference, are placed in the coracoid and anterior portals, respectively. The conjoint tendon is exposed at its attachment to the coracoid process. Dissection proceeds inferiorly to its musculotendinous junction (Fig. 31.2d).

31.4.3.3 Step 3: From the Pectoralis Major Intersection to the Humeral Insertion

The pectoralis major tendon is identified at the intersection with the musculotendinous junction of conjoint tendon. It is traced as it runs inferiorly and laterally toward the humeral insertion, lateral to the tendon of the long head of the biceps (Fig. 31.2e).

31.4.3.4 Step 4: From the Humeral Shaft to the Acromion

The humeral shaft is then tracked proximally to the anterolateral border of the acromion.

Radiofrequency ablation of the subdeltoid bursa within the exposed boundaries can then be completed safely. After the subdeltoid space is fully exposed and insufflated with saline, additional portals may be placed to improve functional access as needed. Spinal needle localization guarantees functional angles. Incision is "skin-deep only," followed by blunt transdeltoid passage of a switching stick and subsequently of a cannulated trocar [26].

31.4.4 LHBT Tenodesis

While viewing from the anterolateral portal, the overlying pectoralis major tendon is visualized, and the biceps should be released to this level. An aperture is made in the bicipital hood at the junction of the pectoralis major tendon, and the LHBT is then delivered into the subdeltoid space. At this point, the biceps tendon is removed extracorporally through the pectoralis portal and tagged with two Ethibond Thompson traction stitches. A small skin incision is placed directly anterior to the superior aspect of the coracoid. The tendon is then placed back into the subdeltoid space, and the traction sutures are brought through this superior aperture and held for transfer. LHBT is then tensioned in line with the conjoint tendon. The elbow is flexed to 90°, and the transfer is tensioned by pulling on the tagging sutures until the biceps is slightly bowstrung. A critical technical point is to suture the LHBT to the lateral aspect of the anterior surface of the conjoint tendon [26]. This will avoid coracoid impingement as well as protect from injury to the musculocutaneous nerve. A looped suture retriever is then passed from one of the lateral portals reducing the long head of the biceps to the conjoint, while the superior tensioning is held, and the reduction is held in place by an assistant. A spectrum or other suture-passing device is then used to pass a loop-ended No. 0 PDS suture through the biceps and the conjoint tendon. The loop is passed through one of the lateral portals, and No. 2 nylon suture is shuttled back through the anterior coracoid cannula. The other end of the No.2 nylon, suture is then retrieved out through the coracoid cannula, and the long head of the biceps is then sutured in place using arthroscopic knot-tying techniques. In this manner, three or four sutures can be placed to secure the transferred long head biceps tendon. Although the common observation of bad LHB tendon quality at this level, fixation is achieved over approximately 3 cm of tendon length with four separate sutures, enabling easy bypass of the potentially diseased tendon segment. Finally, the excess portion of tendon is cut and removed along with the tagging sutures, thus completing the transfer [24].

31.5 Surgical Risks and Complications

Risk to neurovascular structures during LHBT tenodesis to the conjoint tendon can occur at two levels: portal placement and manipulation of structures within the subdeltoid space itself [26]. Two neurovascular structures are potentially at risk during portal placement, the cephalic vein and the axillary neurovascular bundle [29–31]. Iatrogenic cephalic vein laceration can be avoided by staying lateral to the deltopectoral interval and using the blunt portal placement. The axillary neurovascular bundle can be found within the roof of the subdeltoid space, along the undersurface of the deltoid, 3.5 cm distal to the greater tuberosity and 6 cm distal to the anterolateral edge of the acromion. It is generally not encountered [32].

More frequently encountered, however, are the anterior humeral circumflex artery and its two vena communicantes, also known as the "three sisters" [26]. Along the floor of the subdeltoid space, they transverse deep to the musculotendinous junction of the coracobrachialis and short head of the biceps, typically just medial to the bicipital groove. The ascending branch of the anterior humeral circumflex artery may be encountered along the lateral border of the bicipital groove and can be coagulated safely if bleeding is encountered. The percentage of the contribution of the anterior humeral circumflex artery to humeral head perfusion remains a controversial topic. If possible, ligation of the anterior humeral circumflex artery should be avoided to prevent postoperative avascular necrosis of the humeral head. The brachial plexus runs in concert with the subclavian/axillary artery medial to the conjoint tendon. These structures remain protected as long as the dissection remains lateral to the conjoint tendon [28]. The musculocutaneous nerve, however, pierces the coracobrachialis muscle and then runs distally within its belly. It enters the conjoint tendon from the medial side at an average of 49 mm from the tip of the coracoid, but this can be less than 25 mm in 5% of patients. The relationship of the musculocutaneous nerve to the coracoid is dynamic [33]. With the shoulder in 90° abduction and internal rotation, it moves to within 20 mm of the coracoid process. During subdeltoid arthroscopy, the upper extremity is maintained in the 90-90-15 position, and thus, the musculocutaneous nerve remains medial and well protected [26]. When releasing the LHBT from the bicipital groove, it is necessary to create an aperture over the tendon sheath. The hood extends distally to the superior aspect of the pectoralis major tendon. During the delivery of the LHBT into the subdeltoid space, care should be taken to avoid injury to the overlying pectoralis major tendon. If visualization of the tendon is difficult, a retractor can be placed across the overlying deltoid using a small stab incision to retract it anteriorly and increase the working area of the space. Failure to release the hood will result in an acute angle as the tendon is transferred to the conjoint tendon.

Drakos et al. [25] reported an overall failure rate of the transfer is 7.5%, while 95% of patients referred a relief of their site-specific biceps symptoms. Nonadherence with postoperative protocols in the first six postoperative weeks resulted in LHBT tenodesis rupture with consequent failure and Popeye sign development, as reported by Tailor et al. [27] Postoperative breast asymmetry, which resolved spontaneously at 3 months, has also been reported [26].

31.6 Postoperative Management

Postoperatively patients are placed in a sling full time for the first 3 days, and then only at night and in crowds for the remainder of the first 2 weeks. Patients are allowed and encouraged to come out of the sling for active and active-assisted shoulder and elbow range of motion immediately postoperatively. They are not allowed to lift anything heavier than a pen, knife, fork, or spoon. Formal physical therapy is started 2 weeks after surgery. They are allowed complete activities of daily living at 4 weeks, full throwing and swimming as tolerated at 3 months, and unrestricted activity including lifting at 4 to 5 months.

31.7 Outcomes

Soft tissue transfer of the LHBT to the conjoint tendon was originally described in 1989 by Post and Benca [22] in four cases. In these patients, an open procedure was used to weave the LHBT through the origin of the conjoint tendon and then onto itself. The concept of transferring the biceps tendon to the conjoined tendon had not resurfaced in the literature until recently in 2005 when Verma et al. [24] presented an arthroscopic technique for the transfer LHB to the conjoint tendon as a method of tenodesis. Drakos et al. [25] reported good short-term outcomes after subdeltoid LHB transfer to the conjoint tendon at an average of 28 months postoperatively. They found ASES, L'Insalata, and UCLA scores to be 79.6, 78.9, and 27.8, respectively. Five percent of patients had a

Popeye sign postoperatively. Ma et al. [34] reported short-term outcomes of 6 patients with a mean follow-up was 8.4 months (range, from 3 to 15 months). Three months after surgery, the shoulder pain disappeared, the Speed and Yergason tests were negative, and we found no Popeye sign or side-by-side difference in elbow-flexed strength. No complications of blood vessel, nerve, tendon injury, or restricted ROM of shoulder and elbow occurred. The satisfaction rate ranged from 80% to 95%. In the series presented by Ma et al. [34], all patients received a LHB tenodesis to the conjoint tendon with a technique modified by the author. This technique avoids the creation of "subpectoral portal," adopting the "Neviaser portal" as operative one. Taylor et al. [27] reported the midterm functional outcomes for arthroscopic subdeltoid transfer of the LHB to the conjoint tendon. At an average of 6.4 years postoperatively, ASES and L'Insalata scores were 86 and 85, respectively, corresponding to 88% of patients rated good to excellent. Twelve shoulders (10 from men patients, 2 from women patients; mean age, 41 years; average follow-up, 6.3 years) underwent physical examination. Mean UCLA score was 31, and there were no significant differences in side-to-side elbow flexion strength or endurance using a 10-pound weight.

31.8 Conclusions

Biceps tendon tenodesis is a reliable treatment for pathological abnormalities of the LHBT, providing a new, distal level of fixation for the tendon. The right choice between different tenodesis techniques for the long head of the biceps tendon can significantly influence the overall results of surgery. Currently there is no high-quality evidence to recommend one surgical technique over the other. Sustainers of LHBT arthroscopic tenodesis to the conjoint tendon affirm that transfer may provide improved results over traditional bony tenodesis for multiple reasons. First, transfer more closely reproduces the native axis of pull of the biceps muscle and allows the long head and short head to share load. Second, the transfer allows for soft tissue healing, which may be more favorable than soft tissue to bone as it recreates the normal "bungee-effect" of the superior labrum/biceps anchor complex. Finally, this technique provides the surgeon with direct visualization during tensioning and suturing to help prevent overtensioning of the tendon. Another advantage of this technique is its simplicity. The technique is performed in an avascular plane without the use of implants and adds only 10 to 15 min to the operative time once the subacromial decompression is completed. In addition, the technique will help avoid the cosmetic deformity and muscle cramping that may occur with isolated tenotomy. Arthroscopic tenodesis to the conjoint tendon produced good functional result associated with a low incidence of postoperative pain. This finding supports the hypothesis that residual synovial and neural elements in the biceps groove and can cause postoperative pain. Techniques that remove the tendon from the intertubercular groove, including the tenodesis to the conjoint tendon seems to achieve better outcomes than proximal tenodesis ones. However a limitate amount of paper enrolling a reduced number of patients and related data on this topic have been published to date. Further studies are needed to confirm the promising results of LHBT arthroscopic tenodesis to the conjoint tendon.

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Subpectoral Biceps Tenodesis with an All-Suture Anchor

32

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32.1 Introduction

The long head of the biceps tendon (LHBT) is a common source of anterior shoulder pain and frequently occurs with concomitant shoulder pathology [1–4]. Numerous factors have been associated with proximal biceps tendon injury; however, the intimate anatomic relationship of the LHBT with the rotator cuff and superior glenoid labrum underlies most of the associated pathology [5–7]. Additionally, a hypovascular watershed region within the intra-articular segment of the tendon may lead to degenerative changes [8]. Pathology involving the LHBT is frequently symptomatic due to the extensive sympathetic and nociceptive innervation, which is more concentrated proximally [9, 10].

32.2 Diagnostic Evaluation

Evaluation of the patient with shoulder pain should always include a thorough assessment of the LHBT. Patients with shoulder pain secondary to LHBT pathology frequently complain of anterior shoulder pain, which may be exacerbated by overhead activities. Additionally, biceps pathology is rarely isolated and often occurs with concomitant shoulder conditions [11]. Various physical examination maneuvers exist for the detection of LHBT pathology; however, most are sensitive, but not specific [11–13]. Magnetic resonance imaging (MRI) is often helpful for detecting degenerative changes within the tendon, for fluid surrounding the tendon, and for instability or subluxation of the tendon often into the subscapularis.

Arthroscopic evaluation of the LHBT remains the gold standard for diagnosis; however, it is not without limitations. Intraoperatively, the LHBT can be further retracted into the glenohumeral joint to visualize some of the extra-articular segment of the tendon. Limited excursion of the proximal tendon and the propensity for more distal tear propagation make it challenging to reliably diagnose and recognize the full extent of biceps pathology [14–17]. Taylor et al. [14] reported that 47% of patients with chronic LHBT symptomatology had extra-articular pathology that was not evident from arthroscopic evaluation. Similarly, Gilmer et al. [16] reported that 33% of extra-articular biceps lesions were not evident during arthroscopic evaluation.

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32.3 Treatment Strategies for Biceps Pathology

Operative treatment of LHBT pathology usually consists of either tenotomy or tenodesis. This decision is usually influenced by the patient's body habitus, functional demands, age, desire for cosmesis, and surgeon preference. Biceps tenotomy is a fast and straightforward procedure, which has demonstrated predictable pain relief without necessitating prolonged rehabilitation [11, 18–25]. High rates of patient satisfaction have been reported following tenotomy, particularly in an older, low-demand population [22, 25–28]. Following tenotomy, the tension from the biceps at the biceps-labral complex no longer exists, which significantly decreases pain. In up to 80% of patients, the proximal tendon stump can remain in the bicipital groove [29]; however, it is unclear whether this remains a persistent pain generator [21, 30]. Concerns over cosmetic deformity [18, 20, 21, 25, 29, 31, 32] and muscle fatigue/cramping [18, 21, 27, 33] following tenotomy may cause some surgeons to favor biceps tenodesis. Biceps tenodesis may better restore the normal length-tension relationship of the LHBT, which may decrease both cosmetic concerns and muscle cramping symptoms following the procedure. Biceps tenodesis has also proven to be a very reliable procedure with excellent outcomes regarding function, pain relief, and cosmesis [22, 29, 30, 34–36].

32.4 Types of Biceps Tenodesis

Various techniques exist for tenodesis of the LHBT. Some of the more notable differences include open versus arthroscopic techniques, location of the tenodesis site, and fixation method. The rate at which tenodesis procedures are being performed appears to be increasing, with arthroscopic tenodesis procedures outnumbering open procedures [37]. Overall, biceps tenodesis is associated with a low complication rate [38]. The vast majority of studies which have compared arthroscopic suprapectoral tenodesis to open subpectoral tenodesis have demonstrated no significant differences regarding functional outcome scores, pain, or satisfaction [35, 36, 39]. Some authors have recently reported possible over tensioning and increased postoperative stiffness with arthroscopic suprapectoral tenodesis [36, 40]. However, a recent randomized prospective study comparing arthroscopic suprapectoral tenodesis with open subpectoral tenodesis demonstrated no significant differences regarding anterior shoulder pain, side-to-side biceps length, elbow strength, or biceps fatigue at various time points up to 1 year [41].

32.5 Surgical Technique for Open Subpectoral Biceps Tenodesis with All-Suture Anchor

Following the induction of general anesthesia, the patient is placed into the beach chair position (the technique can be performed in the lateral decubitus position as well). Preoperative intravenous antibiotics are administered, followed by sterile preparation of the extremity with placement into a pneumatic arm holder (Spider 2, Smith & Nephew). The arm is abducted and externally rotated to identify the inferior border of the pectoralis major tendon. A 3 cm longitudinal skin incision is marked in an axillary skin crease over the inferior border of the pectoralis major tendon.

The senior author prefers to perform the first half of an in situ LHBT tenodesis prior to initiating shoulder arthroscopy. The advantage with this technique is that it may better restore the anatomic resting length and tension of the LHBT, since the tendon is not initially released from the superior labrum. In our experience, this results in a more cosmetic result with a lower likelihood of biceps cramping or fatigue. Additionally, the pilot hole can be made in an independent location not dependent on the position of the whipstitch, ultimately determining the position of the anchor placement. Finally, performing the initial in situ tenodesis offers a surgical approach with less soft tissue edema resulting from fluid extravasation and thus cleaner, more readily identifiable soft tissue planes.

With the arm abducted and externally rotated to expose the axillary crease, the positioning not only allows for adequate exposure, but it also helps decrease the distance from the eventual tenodesis site to the musculocutaneous nerve [42]. A No. 15 blade is used to incise the skin; care is taken not to penetrate deeper than the dermal layer. Curved Metzenbaum scissors are used to bluntly dissect the subcutaneous tissue, eventually exposing the interval between the inferior border of the pectoralis major tendon and the conjoined tendon. It is critical to identify this muscular interval to avoid iatrogenic neurovascular injury. A sharp Hohmann retractor is placed deep to the pectoralis major tendon and over the lateral humeral cortex exposing the LHBT (Fig. 32.1). A blunt Hohmann retractor can be placed anterior and lateral to the conjoined tendon to help isolate the LHBT; however, no retractive force is utilized due to the proximity of the musculocutaneous nerve. Once the LHBT is confirmed, the blunt Hohmann is repositioned to reflect the LHBT medially and expose the bicipital groove. A small Cobb elevator is used to roughen the periosteum of the bicipital groove at the planned tenodesis site.

After bony preparation, the drill guide is placed at the planned tenodesis site, and a unicortical pilot hole is made using a 2.8 mm drill (Fig. 32.2). It is critical to drill perpendicular to the bicipital groove to avoid eccentric hole placement, which has been demonstrated to reduce the torsional load to fracture the humerus by creating a stress riser [43]. We prefer to drill a small unicortical pilot hole, since larger 8 mm unicortical holes have been shown to reduce the torsional load to humeral fracture by 28% (Fig. 32.3) [44]. The 2.8 mm double-loaded all-suture anchor is then placed into the pilot hole and deployed. The blunt Hohmann retractor is used to assist with visualization of the LHBT. A right-angle clamp is used to secure the LHBT proximal to the

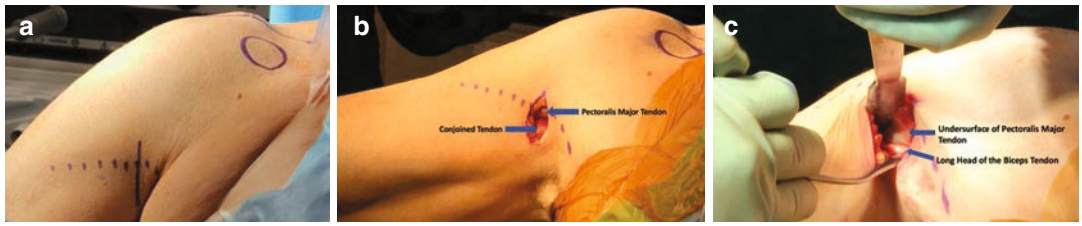

Fig. 32.1 3 cm incision in an axillary crease (**a**). Identification of the interval between the inferior border of the pectoralis major tendon and the conjoined tendon is critical (**b**). A retractor placed deep to the pectoralis major tendon and over the lateral humeral cortex exposes the LHBT (**c**)

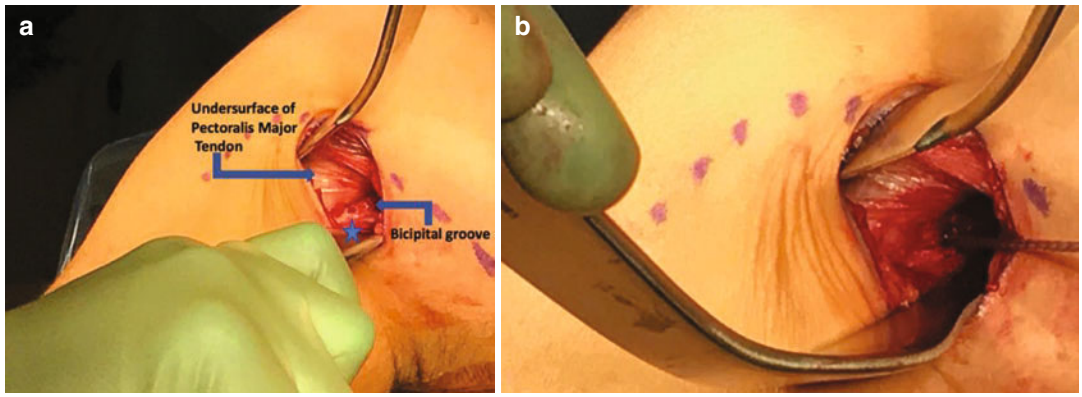

Fig. 32.2 After bony preparation a unicortical pilot hole (blue star) is made using a 2.8 mm drill (**a**). The double-loaded suture anchor can then be deployed through the pilot hole (**b**)

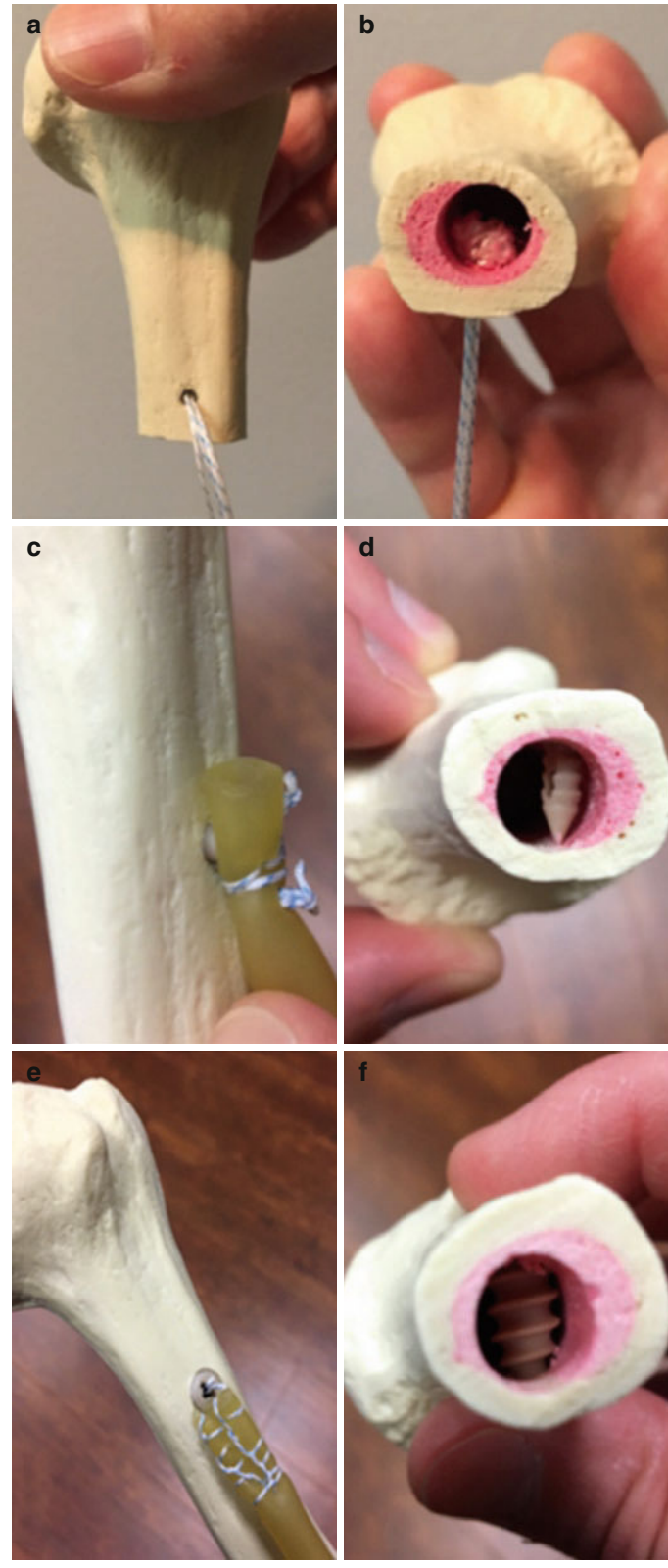

Fig. 32.3 Relative cortical and intramedullary appearance of various fixation devices for biceps tenodesis. 2.8 mm double-loaded all-suture anchor (**a** and **b**), compared to 2.9 mm double-loaded PEEK suture anchor (**c** and **d**) and 8 mm PEEK interference screw (**e** and **f**)

planned tenodesis site. Using a small-diameter suture shuttle device, one of the suture limbs (initial post suture) is passed in situ through the LHBT at the same level as the anchor. Care must be taken during this step due to the proximity of the musculocutaneous nerve [45]. This suture will function as a post and has provided an anatomic in situ position for the tenodesis for theoretical appropriate tensioning and symmetry.

Following surgical exposure, suture anchor placement, and in situ passage of a post through the LHBT, shoulder arthroscopy is initiated. Standard diagnostic arthroscopy is used to identify any additional intra-articular pathology. Tenotomy of the LHBT near its insertion to the superior glenoid labrum is then performed using either an arthroscopic cutter or radiofrequency device. A stump of tissue on the superior labrum is left to ensure that the labrum is not violated during the tenotomy. This tissue is later debrided and the superior labrum recontoured with a motorized shaver.

After tenotomy of the LHBT is performed, attention is returned to the axilla to complete the tenodesis. The LHBT is pulled from the shoulder into the incision with a right-angle clamp. Using the opposite limb of the suture that was initially passed through the LHBT as the post, a circumferential double lasso-loop technique [46] is used to capture and secure the tendon allowing a complete 360° circumferential tenodesis. The step is then repeated (post and double lasso-loop) with the second suture set of the anchor (Fig. 32.4). Once both sutures have been passed, the two suture limbs which are posts are pulled tensioning and delivering the tendon into the incision and down to the suture anchor against the periosteum. Each suture set is then tied and cut. The biceps tendon is then cut a minimum of 1 cm above the tenodesis site to avoid loss of suture fixation.

The axillary wound is then copiously irrigated and a layered closure is performed. After the wound has been closed, we return to the shoulder to perform any additional procedures indicated. Once all arthroscopic shoulder procedures have concluded, skin glue followed by a sterile nonadherent dressing strip is placed over the axillary incision and then covered with a sterile dressing.

32.6 Rationale for Subpectoral Tenodesis

Open subpectoral biceps tenodesis is a safe, reliable, and efficient procedure for managing various pathologies of the LHBT. Subpectoral tenodesis offers a unique advantage by removing all potentially diseased tissue from the bicipital groove. This may reduce the incidence of persistent pain, which otherwise may be left unaddressed with more proximally based techniques [17, 36, 47]. Moon et al. [17] reported that 78% of proximal LHBT tears propagate distally, with 80% of patients having degenerative histological changes over 5.6 cm from the proximal origin, suggesting that subpectoral tenodesis may

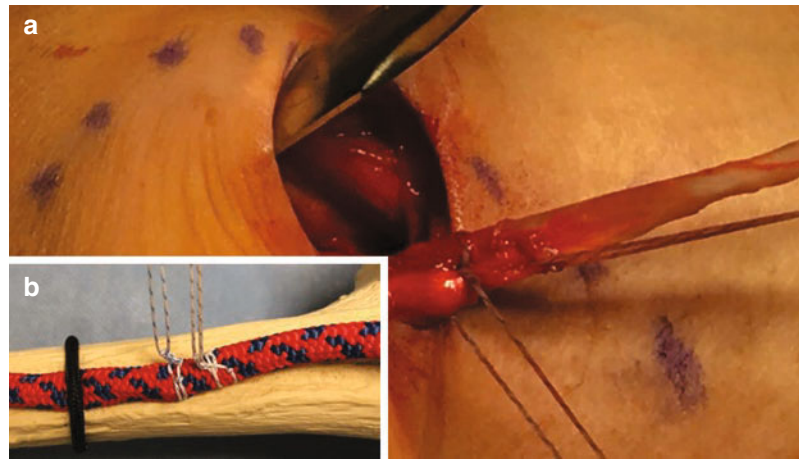

Fig. 32.4 Clinical image (**a**) and anatomic model (**b**) demonstrating a complete 360° double lasso-loupe circumferential biceps tenodesis

eliminate any potential for persistent degenerative tendon. Extra-articular LHBT pathology is exceedingly common and is often concealed from standard arthroscopy, leading to high rates of underestimating the extent of biceps pathology [14, 16]. Additionally, subpectoral biceps tenodesis may better restore the anatomic resting length and tension of the LHBT, thereby providing a more cosmetic result with a decreased likelihood of biceps cramping [40].

32.7 Rationale for All-Suture Anchor

Various fixation techniques and implants are available when performing a subpectoral biceps tenodesis [48–53]. Interference screw fixation has traditionally served as the baseline comparator in biomechanical studies for tenodesis methods given the superior ultimate loads to failure [54–58]. However, given the concern for a humeral stress riser with larger holes to accommodate the tenodesis screw [43, 44], other techniques have evolved to mitigate this risk while taking advantage of the benefits imparted by the subpectoral approach [17, 36, 47].

Recent basic science research suggests that tendon-to-bone healing in an animal tenodesis model by fixation within a bone tunnel or to the cortical surface results in similar biomechanical and histological outcomes. Tan et al. [59] compared these two methods of tenodesis fixation in a rabbit model. Biomechanical testing of the two constructs demonstrated similar load to failure and stiffness. Additionally, micro-CT was used to quantify new bone formation on the humeral surface, which demonstrated no difference between the groups. The authors reported minimal new bone formation within the bone tunnel, questioning the purported benefit of intratunnel healing. Lastly, histological analysis evaluating tendon-to-bone healing on the humeral surface of both groups was similar; however, minimal intra-tunnel healing was observed in the bone tunnel group. The results of this study suggest that while similar biomechanical and histological properties may be obtained with either technique, the risk profile of humeral bone tunnel fixation may outweigh previously perceived benefits [59].

The recent development of all-suture anchors has yielded promising biomechanical results for biceps tenodesis. In a recent cadaveric biomechanical study for suprapectoral tenodesis, Hong et al. [60] compared the properties of transtendinous all-suture anchor tenodesis to interference screw tenodesis. During cyclic loading and maximum load to failure testing, the authors noted similar ultimate load to failure with the all-suture anchor group and interference screw group. However, cyclic and failure displacement were greater with the all-suture anchor group. In a similar biomechanical study for subpectoral tenodesis, Chiang et al. [61] compared all-suture anchor tenodesis to interference screw tenodesis. The authors evaluated ultimate load to failure, displacement with cyclic and failure loads, and mode of failure. Similar to Hong et al. [60], the authors note similar ultimate load to failure between the two techniques, however higher displacement with cyclic and failure loading with the all-suture anchors [61].

A recent study by Bernardoni and colleagues [62] provides the most comprehensive comparative biomechanical evaluation of the all-suture anchor to date. The authors performed a cadaveric study to evaluate the biomechanical properties of all-suture anchors in comparison to both interference screws and conventional suture anchors during subpectoral biceps tenodesis. Each treatment group had seven fresh frozen cadavers (mean age of 55 ± 6.1 years), which were randomly allocated. The authors then evaluated the three subpectoral biceps tenodesis constructs in cyclic displacement, maximum load to failure, and failure mode. Moreover, the authors also evaluated the unique properties of each specific suture anchor construct when the humerus was subjected to torsional forces. During cyclic loading evaluation, there were no failures with either the all-suture anchor or the conventional suture anchors; however, the interference screw group had tendon tear failures in 42% of specimens. The authors also reported no significant differences in peak load to failure among the treatment groups.

Unique to this study was the evaluation of torsional forces on the humerus with each specific tenodesis construct. Spiral fractures through the anchor or screw hole occurred in two of seven specimens with all-suture anchors compared to four of seven specimens with conventional suture anchors and in all seven specimens with interference screws. There were no significant differences in maximum torsional load between the groups. Therefore, while the all-suture anchor demonstrated similar biomechanical properties regarding fixation strength, it may have the added benefit of lowering the risk of humeral fracture secondary to a smaller pilot hole.

32.8 Conclusion

Subpectoral biceps tenodesis offers reliable pain relief, high patient satisfaction rates, and low rates of complications. An all-suture anchor utilizes a smaller osseous pilot hole and has the benefit of unicortical intramedullary fixation. Performing an in situ tenodesis may better restore the anatomic resting length and tension of the LHBT resulting in a more predictable symmetric contour of the biceps and lower incidence of biceps cramping and fatigue. Biomechanical studies of the all-suture anchor are promising and demonstrate similar biomechanical properties compared to other techniques with a potentially lower risk of humeral fracture. Clinical outcome data is necessary to more fully ascertain the potential benefits and complication profile of this technique.

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33 Arthroscopic Proximal Biceps Versus Subpectoral Tenodesis: Short-Term Differences and Long-Term Follow-Up

Stephen C. Weber

33.1 Introduction

Recent publications have suggested that proximal biceps tenodesis creates higher reoperation rates and complications related to retention of the biceps in the bicipital groove. Few studies have presented comparative data between the two techniques. Presented here is the first study contrasting the long-term outcome of arthroscopic proximal biceps tenodesis versus mini-open subpectoral repair. Ninety-two patients were followed for a mean 10.4 years in the proximal group. Fifty-three were soft tissue tenodesis, the remainder proximal suture anchor repairs. This was in contrast to 44 patients treated with mini-open subpectoral repair with mean follow-up of 6.71 years. The biceps was tenotomized arthroscopically. It was then sutured to the rotator cuff tendon using permanent sutures in the soft tissue group, and in the remainder, the suture used was from an arthroscopically placed suture anchor incorporated in the repair. In open, distal group, the bicipital groove was exposed through a subpectoral approach, and the tendon is then fixed in place using a screw and spiked washer. UCLA scores improved in the proximal group from a mean of 18.93 to a mean of 30.12 and in the distal group from 17.61 to 32.37. Following proximal tenodesis, two patients had mild deformity, but all patients rated their arms as cosmetically normal, and no patient complained of upper arm cramping. There were no complications related to the procedure in either group. Operative times were significantly shorter for proximal tenodesis ($p < 0.0001$), but perioperative narcotics and recovery room stays were not significantly different between the two procedures. The shorter operating times and absence of cost of an interference screw resulted in a cost savings of $1647.37 with proximal tenodesis. All patients who obtained a good result at short-term follow-up continued to maintain a good result at final follow-up. Reoperation involving conversion to distal tenodesis was not required in any proximal tenodesis patient. Arthroscopic proximal biceps tenodesis appears to be a reliable technique to manage the pathologic biceps tendon. The operative time and cost were significantly less than with a subpectoral approach, especially if interference screws were used. The subpectoral approach however did not appear to have significant increase in morbidity in short or long term. Concerns about pain related to the retention of the biceps within the bicipital groove appear unfounded even at long-term follow-up.

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33.2 Literature Overview

The biceps has been recognized as a pain generator for some time [1–3]. This diagnosis came into disfavor in the 1980s with the work of Becker and Cofield [4] who showed generally poor results with isolated biceps tenodesis in an era without MRI or arthroscopy. Subsequent reports have generally been more favorable. Arthroscopic subpectoral biceps tenodesis was first developed by Dr. Richard Caspari as a unique surgical exposure for his arthroscopic Gallie procedure and first published in 1993 [5]. Numerous other centers have adopted this technique as their own since [6–13]. While generally successful, this represented an open technique, and other authors represented arthroscopic techniques that could be performed without a short incision. This included tenotomy [14–18], proximal soft tissue tenodesis [19–22], proximal fixation to the bone [7, 23–25], and arthroscopic distal bicep fixation to the bone [26] or soft tissue [27]. Post [28] first raised the concern that leaving a diseased biceps tendon in the bicipital groove would lead to persistent pain. This concept was resurrected by Sanders et al. [12]. They represented that proximal tenodesis that did not release the sheath carried a 20.6% revision rate, as opposed to a 6.8% revision rate with release. This was at odds with all the reported results with proximal tenodesis. Both Brady et al. [23] and our data [21] showed excellent long-term results with proximal tenodesis. Comparative studies remain few. Werner et al. performed a level four retrospective review [29] showing more stiffness in the proximally tenodesed group but similar outcomes. Gombera et al. [26] compared an arthroscopic distal tenodesis technique to open subpectoral tenodesis. ASES, patient satisfaction scores, and outcomes were the same in both groups. No increase in stiffness was noted. One serious neurovascular injury was noted in the open group.

While outcomes have generally been good with open subpectoral tenodesis, serious complications such as fracture [30], neurologic injury [31], and failure of fixation [32] can occur. Given the paucity of data directly comparing the two techniques, it seemed to evaluate this more thoroughly. Presented here is the first study comparing long-term outcomes of arthroscopic proximal versus distal open subpectoral biceps tenodesis.

33.3 Indications and Techniques

Two series previously reported were retrospectively compared in regard to outcome of proximal [21] and distal biceps tenodesis [5]. This data was further studied to establish operative times for the biceps tenodesis, total operative times, parenteral narcotics in the postanesthesia recovery (PAR), oral narcotics in PAR, and total PAR time. A narcotics calculator was used to convert differing parenteral and oral narcotics to morphine and hydrocodone equivalents. The proximal tenodesis data was further subdivided into those with concomitant rotator cuff repairs and those with simple arthroscopic procedures such as debridement and acromioplasty.

Those patients with proximal tenodesis and no rotator cuff repair were tenodesed as described by Castagna [19] with modifications previously presented [21]. A spinal needle was used to pass sutures through the biceps of #2 Ticron and then tied in the subacromial space. With a rotator cuff tear, the biceps was tenodesed to the anterior suture anchor as originally described by Gartsman [24]. Other pathology was corrected as indicated.

Open subpectoral tenodesis was performed as described previously [5, 13] (Figs. 33.1 and 33.2). A unicortical screw and spiked washer was used to fix the biceps at the distal bicipital groove.

Postoperatively, all patients were maintained in a sling and started on early passive motion. Suture tenodeses were maintained in the sling for 3 weeks. Rotator cuff repairs and distal tenodesis were maintained in a sling for 6 weeks. Active-assisted motion was started following discontinuation of the sling. Full activities were resumed by no sooner than 3 months in both groups.

Data was collected and maintained on an Excel spreadsheet, with statistical significance determined to be $p < 0.05$ using a double-tailed T test.

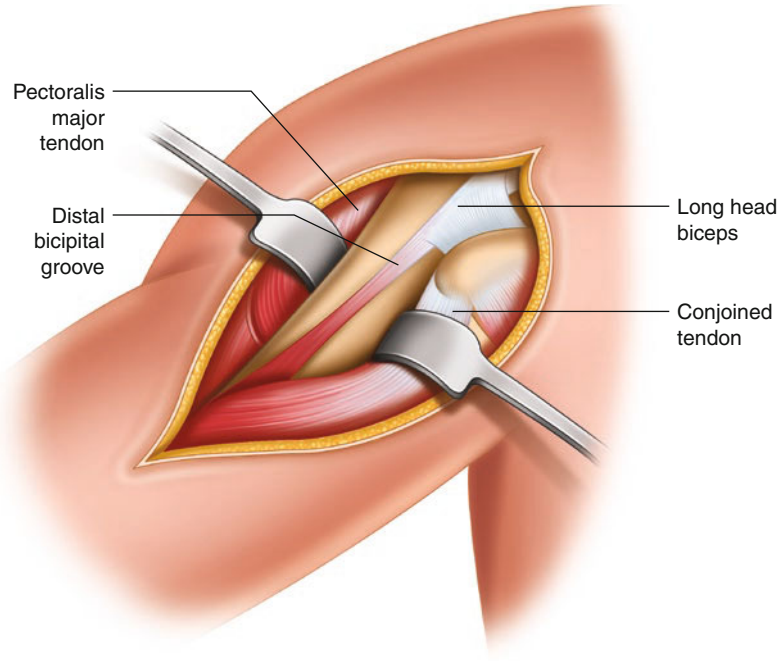

Fig. 33.1 Anatomy of subpectoral biceps tenodesis technique

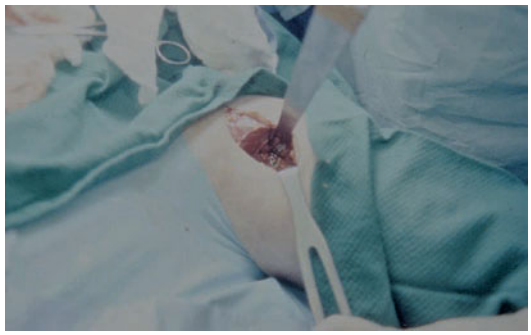

Fig. 33.2 Screw and washer in place after subpectoral biceps tenodesis

33.4 Results

Demographic data is shown in Table 33.1. No significant differences were noted retrospectively comparing the two groups. Demographics were generally consistent with other studies on this subject in regard to age and male preponderance.

Operative times and perioperative morbidity data are shown in Table 33.2. It can be seen that proximal tenodesis involved significantly less operative time, both for the tenodesis procedure alone and also for the entire operative procedure.

Table 33.1 Preoperative demographics, proximal versus distal tenodesis

	Distal tenodesis	Proximal tenodesis
Age	49.37	63.0
R/L	30/14	58/34
Male/female	39/5	
Preop UCLA	18.93	17.61
Preop SST	3.21	5.82

Table 33.2 Operative times and perioperative morbidity in proximal and distal biceps tenodesis

	Distal w/o RCR	Proximal + RCR	Proximal w/o RCR
Total operative time	85.0 (17.79)	55.88 (16.51)*	50.0 (15.49)**
Biceps operative time	35.0 (7.07)	11.23 (3.84)#	10.63 (4.18)##
Parental PAR ms equivalents	12.50 (9.57)	17.55 (15.64)***	12.15 (14.14)***
Oral PAR narco equivalents	4.58 (3.16))	5.23 (2.58)***	4.44 (2.32)***
PAR times	73.75 (16.53)	70.58 (18.19)***	65.90 (17.43)***

*$p < 0.03$, **$p < 0.017$, ***p = N.S, #$p < 0.017$, ##$p < 0.0001$

Table 33.3 Outcome measures, proximal versus distal tenodesis

	Distal tenodesis	Proximal tenodesis
UCLA	32.37 (3.25)	30.12 (4.31)
SSt	10.25 (1.29)	10.17 (1.89)
Forward flexion	164.02 (10.32)	165.90 (9.45)
External rotation	72.74 (7.42)	68.32 (8.14)

Perioperative morbidity was not statistically different despite the additional surgical approach and violating the proximal humeral bone with distal tenodesis in regard to PAR narcotic consumption and total PAR times. This was true for both the combined proximal tenodesis and when comparing the isolated tenodesis to the isolated distal tenodesis.

Final outcomes are shown in Table 33.3. There were no complications in the arthroscopic group. Only two patients complained of minimal deformity. In the subpectoral group, there were no failures of fixation with screw and washer technique. No neurologic injuries occurred. There was one superficial infection, which was successfully managed with oral antibiotics. Operative times both for the actual tenodesis and the overall procedure were significantly less for arthroscopic tenodesis. Perioperative morbidity was the same for both procedures at all times evaluated. No increase in stiffness was noted at any time with proximal tenodesis.

Cost was significantly different between the two treatments. Assuming a facility charge of $650/15 min, this would be a mean cost increase of over $600 per case. Proximal tenodesis implant costs are negligible, as it would be either a suture and spinal needle or a suture off an anchor already used for the rotator cuff repair. While the subpectoral technique described here is the original technique described using a screw and ligament washer [33] with minimal implant charges, the more widely used interference screw technique would result in significant additional charges. Cost of a bio-composite (30% biphasic calcium phosphate and 70% PLDLA) screw was 299.25 marked up to 1147.37 and a biotenodesis screw (PLLA) 271.75 marked up to 947.62. While cost is always difficult to assess, this calculation would mean an increased cost of $1647.37, billed to the patient in a hospital setting and absorbed by the surgery center in an outpatient setting.

33.5 Discussion

The controversy of proximal versus distal biceps tenodesis has been an issue since originally reviewed by Sanders et al. [12]. These authors first raised concerns about reoperation rates for proximal biceps tenodesis. Careful review of this paper however showed that revision surgery rarely resulted in a satisfactory outcome. Gregory et al. [34] represents the only publication on revision biceps tenodesis. While improvement was noted, 5/21 had unsatisfactory results, and lack of data prevented the analysis of the technique of the proximal tenodesis failures. Werner et al. [29] represent the only other level four study comparing proximal and distal tenodesis, which also showed increased stiffness between the two techniques using an arthroscopic interference screw. Follow-up was as little as 4.5 months. While stiffness was increased short term, there was no long-term difference in outcomes. While their and this paper represent level three data only, the combination of a relative absence of any comparative data suggesting superior outcomes with distal biceps tenodesis and the numerous level four case series with excellent results [19, 21, 23, 24] with proximal tenodesis suggest that the cost of distal tenodesis, especially with interference screw fixation, may be unnecessary. Gombera et al. [26] recently presented their results with arthroscopic versus open tenodesis. Both techniques were distal however, and one serious neurologic injury occurred in the open subpectoral group. They concluded that open tenodesis might have an increased risk of complications. Although numerous concerns have been raised about "hidden lesions" of the biceps [26, 29, 35–37] creating symptoms post proximal tenodesis, their clinical relevance remains unclear absent studies that show increased complications with proximal tenodesis that are corrected with subsequent distal tenodesis.

Complications with open subpectoral tenodesis were rare in this series, consistent with other

series of experienced surgeons performing this technique [7–11, 13, 38]. Problems do occur with open subpectoral tenodesis, however. Neurologic injury is not unheard of, as occurred in the series of Gombera [26] and reported in four cases by Rhee [31]. Dickens [39] showed that numerous structures were "at risk" with this approach. Iatrogenic fractures continue to be reported. While not reported in our series [13] or Ngo's [10], they continue to occur [30], and the Rush team reports a biomechanical study showing a 30% decrease in strength with placement of an 8 mm drill hole [40]. This would be further compounded by the expected bone resorption that would occur around a PLLA implant with time. Koch et al. [32] reported a disturbing rate of failure of interference screw fixation, the reason of which was unclear. They did point out that in vitro mechanical strength superiority could be offset by biologic factors that cause the tenodesis to fail. None of these complications are reported with arthroscopic tenodesis.

It is important to understand that failed shoulder surgery exists with and without proximal tenodesis. The patient with a poor result can be a frustration to the surgeon looking for a solution. The data suggesting that these patients will benefit from revision to distal tenodesis is minimal despite the attractive basic science and clinical speculation about retention of the biceps within the groove [12, 28, 35–37, 41], and revision surgery to subpectoral tenodesis on this basis should be offered with caution at this time. While widely quoted, Sanders et al.'s study showed that few of the patients revised from proximal to distal tenodesis were actually improved [12].

There are numerous problems with this study. It has all the problems of selection bias and data collection associated with a retrospective study. There certainly was a selection bias in regard to recommending what was perceived as a larger procedure involving mini-open tenodesis. Follow-up and data collection however was surprisingly good, and this series represents the largest and the only long-term study comparing these two techniques. Soft tissue tenodesis was felt to be inferior by Scheibel et al. [25], but the clinical outcomes were actually the same and differences limited to minor cosmetic changes that were not perceived to be important by the patients. This was similar to data presented here. As the costs and operating times are significantly increased with subpectoral tenodesis, the burden of proof would seem to be in justifying subpectoral tenodesis, especially given the list of rare but potentially devastating complications.

33.6 Summary

Both proximal and distal tenodesis show good result at long-term follow-up. Morbidity between the two procedures is not significantly different. The time of surgery and potential implant costs clearly favor proximal tenodesis and may be a deciding factor in the choice of procedures. Rare serious complications such as fracture and neurologic injury with subpectoral tenodesis continue to be reported; while not represented in this study, these issues may also favor arthroscopic proximal tenodesis.

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Glenohumeral Osteoarthritis: Biological Interposition

34

Robert U. Hartzler and Stephen S. Burkhart

34.1 Introduction

> In our work we have been able, by the interposition of fascia and muscle, covered with a layer of adipose tissue, to produce normal movable joints…
>
> John B. Murphy, 1905 [1]

> The future, like everything else, is no longer quite what it used to be.
>
> Paul Valéry, 1937 [2]

In this chapter, we consider a highly interesting and unusual operation: arthroscopic, biologic, interposition arthroplasty of the shoulder—"interesting" as to the historical nature of the operation, recast in an era in which the tools of arthroscopic surgery are nearing maturity but the science of regenerative medicine remains in its infancy, and "unusual" as to the rarity of the coincidence of the properly indicated patient and surgeon.

For hip, knee, and shoulder surgeons, interposition arthroplasty seems a relic of the past, particularly given the success of the modern endoprosthesis (total joint arthroplasty) for treating osteoarthritis (OA) in large joints. However, interposition arthroplasty has never really gone away. For smaller, non-weight-bearing joints (e.g., temporomandibular, trapeziometacarpal), interposition arthroplasty remains an effective treatment for joint arthrosis and ankylosis [3].

We consider biologic interposition arthroplasty of the shoulder as a "joint preservation" operation, especially when considered next to the alternative of prosthetic arthroplasty. In joint preservation, the surgeon aims to improve pain and function of the joint with reconstruction of diseased anatomical structures, if possible, instead of sacrificing the native tissues. Other joint preservation options exist for shoulder OA, such as extensive arthroscopic debridement procedures without an interposition graft [4]. One feature of joint preservation surgery is that morbidity to the surrounding tissues is minimized, as in the ability of the arthroscopic surgeon to access the joint without detaching the subscapularis.

Shoulder surgeons should not be too quick to cast aspersions on alternative operations to prosthetic total shoulder arthroplasty (TSA), which continues to demonstrate an alarmingly high radiographic failure rate of the glenoid at mid- to long-term follow-up [5, 6]. Even more concerning are the high rates of clinical and radiographic failure of hemiarthroplasties and total shoulder arthroplasties in young patients [7–9]. Clearly, there is a need for alternative treatments to the endoprosthesis for young and active patients.

Electronic Supplementary Material The online version of this chapter (https://doi.org/10.1007/978-3-662-58729-4_34) contains supplementary material, which is available to authorized users.

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In fact, the problems of the painful hemiarthroplasty and the wear and loosening of the glenoid (for TSA) in young patients became the driving force for the development of modern interposition arthroplasty of the shoulder by Burkhead [10]. Although Burkhead's biologic glenoid resurfacing in conjunction with prosthetic hemiarthroplasty is neither joint preserving nor reliable [11], it did lead to the initial development [12, 13] of the all-arthroscopic glenoid resurfacing techniques (AGR) that we discuss in this chapter.

34.2 Pathoanatomy

Candidates for shoulder preservation surgery usually have primary or secondary OA of the shoulder. Pathoanatomic changes in the arthritic shoulder include erosion of the cartilage surfaces of the glenoid and humeral head, subchondral sclerosis, marginal osteophytes, loose bodies, subchondral cysts, and capsular thickening and contracture. The glenoid in primary, concentric shoulder osteoarthritis becomes enlarged and flattened over time. Subluxation of the humeral head and bone erosion are significant problems in primary OA [14]. Eccentric (particularly posterior) wear patterns require careful assessment, as these tend to progress over time and can result in substantial bone loss and glenoid deformity [15].

34.3 History and Physical Examination

In older patients with primary osteoarthritis, the history may not often be critically important for medical and surgical decision-making. In patients who are candidates for joint preservation by age or desired activity level, a careful history should be taken since this often has treatment implications. For example, these patients usually have some identifiable cause for their degenerative joint disease such as history of prior surgery (resulting in chondrolysis or capsulorrhaphy arthropathy), trauma (such as dislocation), or overuse (heavy labor, martial arts, or weight lifting).

The patient's symptoms need to be carefully elucidated, as these are quite variable in terms of pain, stiffness, and overall disability for specific activities. Often, either pain or stiffness predominates, and this can greatly impact preoperative decision-making, as detailed below.

On physical examination, the surgeon should take careful note of the degree of stiffness in all planes. A careful examination of strength should be performed with provocative testing of the rotator cuff and long head of biceps. The acromioclavicular joint should be assessed for symptomatic arthritis.

34.4 Imaging

A standard series of shoulder radiographs should include axillary, scapular Y, and internal and external rotation Grashey (true AP of the glenohumeral joint) views. X-rays should be assessed for the degree of osteoarthritis noting the amount of residual joint space, the size of marginal osteophytes, and the presence of loose bodies. Posterior subluxation should be noted, as well as the pattern and amount of any glenoid bone loss.

If a biconcave glenoid is present or if significant bone loss is suspected on x-rays, a CT with coronal and sagittal plane 2D reconstructions should be obtained. The amount of posterior subluxation and the degree of retroversion of the intermediate and neoglenoids should be determined according to Walch [14]. An MRI is usually obtained for surgical candidates to determine the status of the rotator cuff and the long head of biceps tendon, particularly in the setting of prior surgery or traumatic injury.

34.5 Preoperative Decision-Making

Many patients who develop severe arthrosis of the glenohumeral joint are unfavorable candidates for prosthetic arthroplasties because of age, desired activity level, or simply the desire to avoid a joint replacement. The decision-making process in these patients is complex and

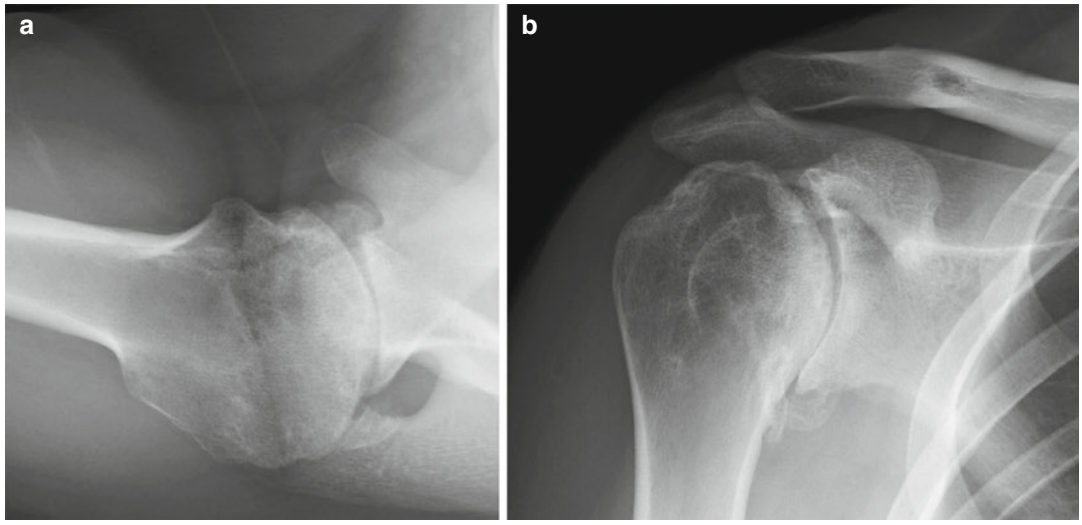

Fig. 34.1 Right shoulder preoperative (**a**) axillary and (**b**) Grashey radiographs of a 32-year-old man with severe osteoarthritis after developing chondrolysis from an arthroscopic surgery performed at age 16

involves numerous factors: the nature and severity of the patient symptoms, the severity of arthritis, the age and activity level of the patient, and the patient's goals and expectations.

Some patients with shoulder OA should be considered for joint preservation surgery by arthroscopic extensive debridement (without interpositional graft) to include treatment of the biceps and capsular releases. Our experience has been that patients with the primary complaint of stiffness and with some preserved joint space are the best candidates for this type of operation. Patients with severe pain and with severe radiographic arthrosis (Fig. 34.1) have a much higher rate of revision surgery [4], and these patients should be considered for AGR with dermal interposition allograft.

Surgeon factors are equally important. Does the surgeon have the skills, patience, and tenacity to perform a long and technically demanding arthroscopy? Does the surgeon routinely perform complex arthroscopic procedures such as massive or revision rotator cuff repair, superior capsular reconstruction, arthroscopic-assisted fracture surgery, and extensive labral repairs? How comfortable is the surgeon learning and practicing new techniques in the cadaver laboratory?

Before attempting to perform AGR, it is useful to consider what are the necessary arthroscopic skills for this operation. First, the surgeon should be comfortable performing arthroscopic capsular releases (particularly of the inferior joint capsule) for stiffness in adhesive capsulitis or mild OA. Next, the surgeon should be comfortable placing suture anchors on all parts of the glenoid, particularly inferior and posteroinferior. The surgeon should be prepared to make percutaneous, trans-rotator cuff and accessory portals (e.g., 5 o'clock and the Port of Wilmington portals) for placement of "difficult anchors." Last, the surgeon should have some experience and comfort in working arthroscopically with dermal allograft, specifically performing shuttling and fixation of a graft.

Relative contraindications also exist for AGR. Older patients are at higher risk for revision surgery [3], probably because of a combination of lower healing capacity and lower threshold for the patient and surgeon to proceed to revision with an endoprosthesis. Severe humeral and glenoid deformities may preclude a successful outcome with AGR. We have performed AGR successfully in patients with B2 glenoid deformities. Although we don't have strict exclusion criteria for B2 humeral subluxation or glenoid bone loss, it is reasonable to adopt the guidelines for TSA proposed by Walch [14] in the setting of AGR (<80% subluxation, <27° of neoglenoid retroversion by CT). Lastly, rotator cuff deficiency is a relative contraindication to AGR, particularly a full-thick-

ness retracted tear greater than 1–2 cm in width. Fortunately, these contraindications are rare.

In summary, young (<50 years of age) and high-demand patients with shoulder osteoarthritis should be offered joint preservation surgery. Those with severe disease should be educated about AGR so that they can seek a subspecialty consultation if they desire to pursue this operation. In selected older patients—usually physiologically younger than chronologic age—who desire to avoid a prosthetic arthroplasty, AGR is reasonable to offer judiciously (Figs. 34.2 and 34.3).

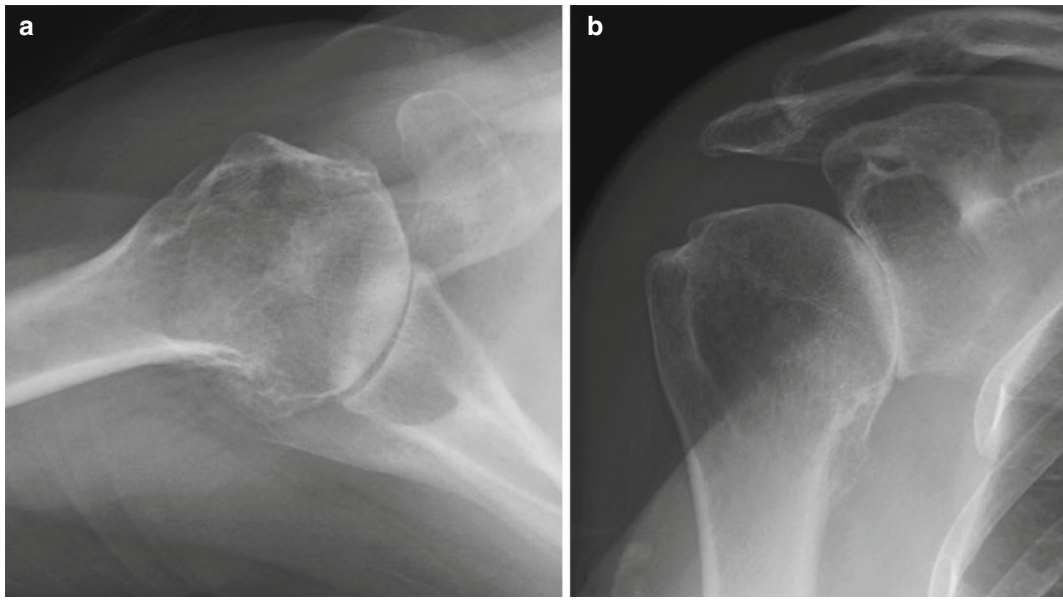

Fig. 34.2 Right shoulder preoperative (**a**) axillary and (**b**) Grashey radiographs of a 60-year-old woman with primary osteoarthritis who wished to avoid the activity restrictions associated with a total shoulder replacement

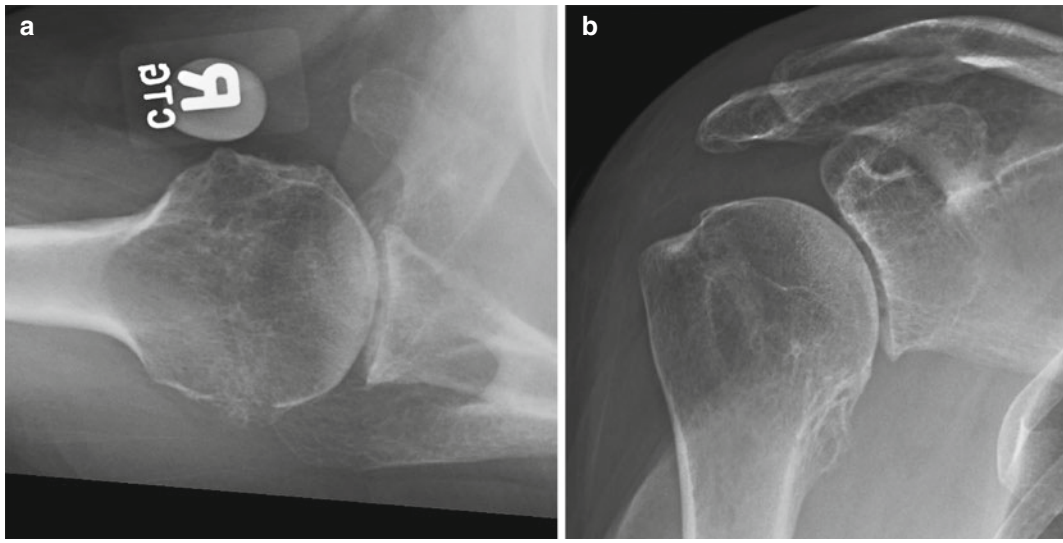

Fig. 34.3 Right shoulder postoperative (**a**) axillary and (**b**) Grashey radiographs of a 60-year-old woman with primary osteoarthritis who underwent AGR and was able to successfully return to horseback riding and ranching activities

34.6 Results

Unlike biologic glenoid resurfacing with prosthetic hemiarthroplasty [11], AGR has demonstrated very consistent short- to midterm results at multiple centers [3, 16, 17]. The revision rate from AGR to prosthetic arthroplasty averages about 25% when patients are followed for 3–5 years postoperatively. The rate of major complications has been very low. Importantly, pain relief (approximately 70% decrease in VAS pain) seems to be as good or better than what is reported for total shoulder arthroplasty in young patients [3]. Range of motion and functional outcomes are also reliably improved. Furthermore, these results have been reported in young patients with severe arthritis that have traditionally had high rates of complications, reoperation, and failure to improve with prosthetic arthroplasties [8, 9].

Thus, in the young patient with severe glenohumeral arthritis (Figs. 34.1 and 34.4), AGR represents the opportunity to achieve dramatic improvement with minimal risk. At a minimum, AGR represents a viable interim operation for patients who are not ideal candidates for prosthetic arthroplasty. When graft healing occurs (Figs. 34.5 and 34.6), patients report dramatic pain relief and the ability to return to recreational or occupational strenuous use of the shoulder without surgeon restrictions. Our limited experience in revising the failed AGR to TSA has been that there is minimally increased difficulty compared with a primary TSA.

34.7 Surgical Technique of Arthroscopic Glenoid Resurfacing

34.7.1 Setup and Equipment

An experienced team is necessary for advanced shoulder arthroscopy and consists of the surgeon, anesthesiologist, circulating nurse, primary surgical technician, and two assistants. The team should be prepared for a procedure up to 2–3 h in duration, with the possibility of significant swelling around the shoulder and neck. Necessary equipment includes the following: traction boom, 30 and 70° arthroscopes, 4–5 mm arthroscopic shaver and burr, a shoulder arthroscopy instrument set, microfracture or subchondral drill instruments, anchors and instrumentation for biceps tenodesis, a 2–3 mm thickness acellular human dermal allograft (e.g., ArthroFLEX 3.0 mm, Arthrex, Inc., Naples, FL), and a variety of suture anchors for graft fixation.

Lateral decubitus position (Fig. 34.7) offers several advantages over beach chair for com-

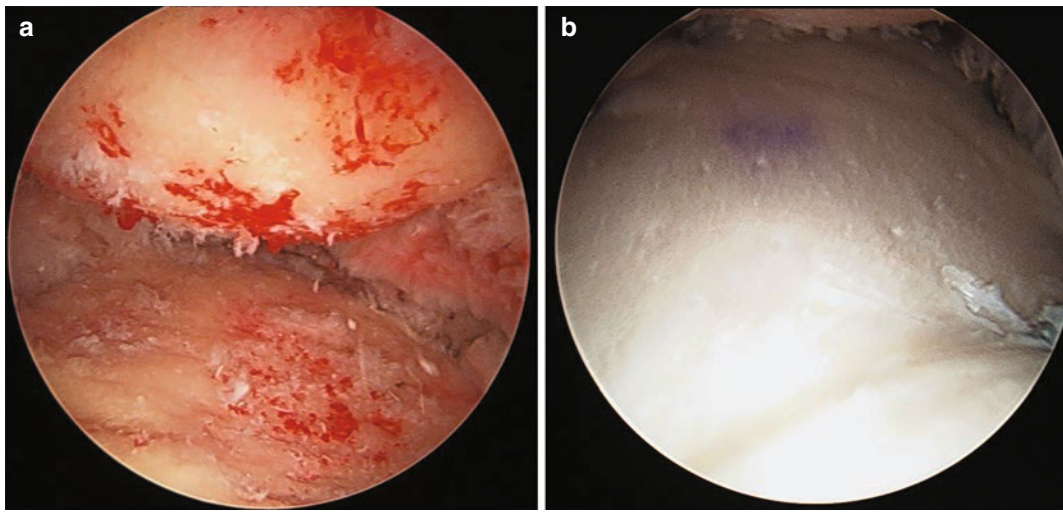

Fig. 34.4 Right shoulder anterosuperolateral arthroscopic views (**a**) before and (**b**) after AGR. This 32-year-old chondrolysis patient had complete graft healing and symptom relief

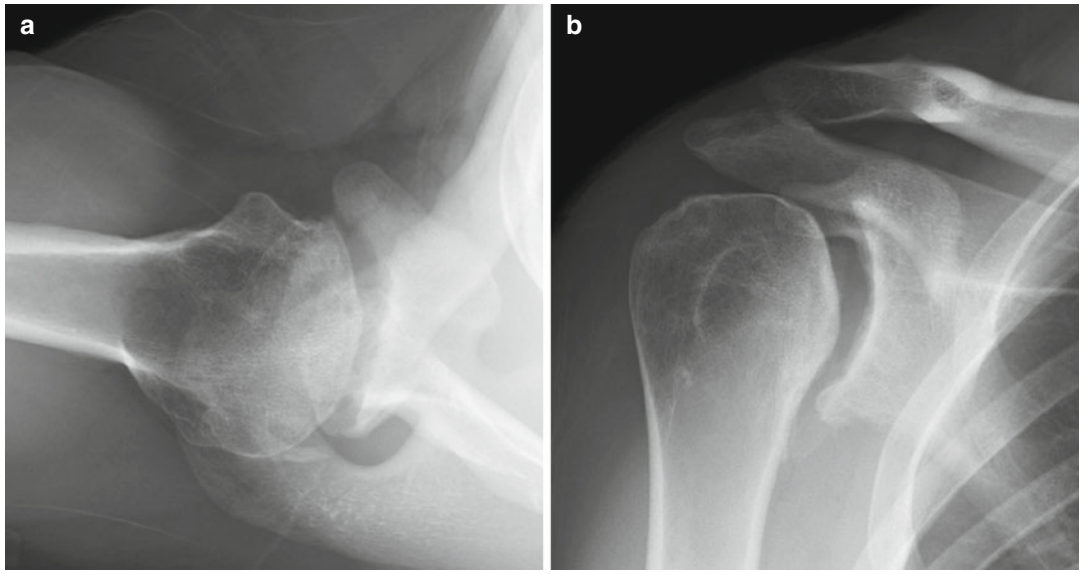

Fig. 34.5 Right shoulder postoperative (**a**) axillary and (**b**) Grashey radiographs 2 years after AGR in a 32-year-old man with chondrolysis

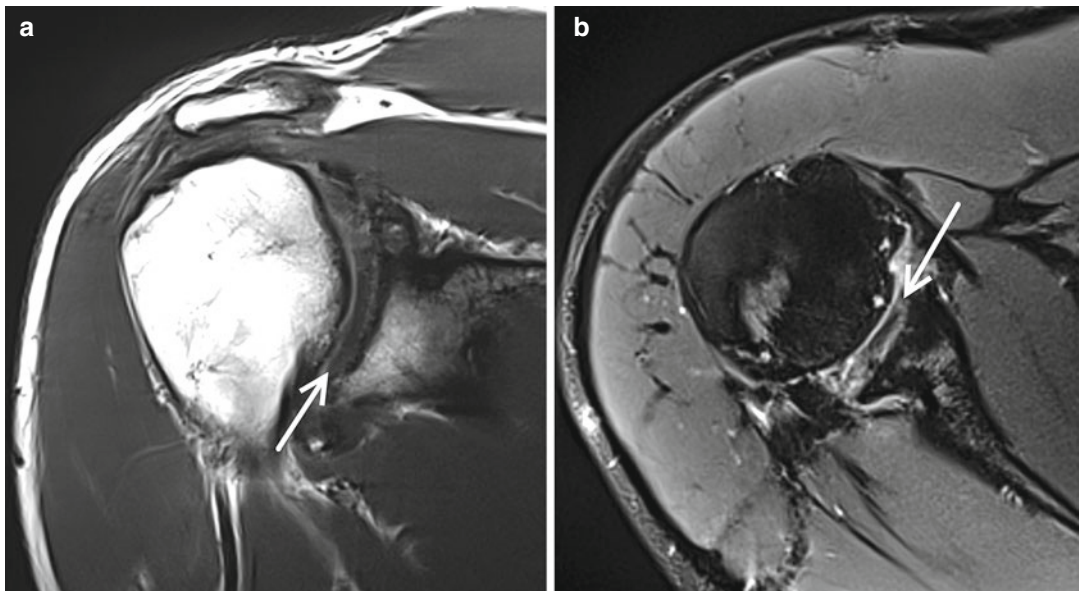

Fig. 34.6 Right shoulder postoperative MRI 2 years after AGR in a 32-year-old chondrolysis patient shows the healed graft (white arrows) on (**a**) T1 coronal and (**b**) T2 axial images

plex shoulder arthroscopic procedures such as AGR. First, an additional assistant who can manipulate the arm to improve exposure is more easily positioned on the opposite side of the table from the surgeon and first assistant. Second, the arm can be more easily adducted over a large bump to provide joint distraction. Third, holding the scope for viewing through an anterosuperolateral (ASL) portal is more ergonomic for the surgeon in lateral decubitus. An

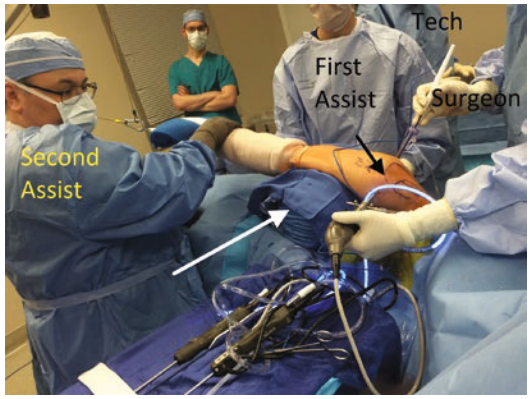

Fig. 34.7 Intraoperative setup with lateral decubitus positioning for a right shoulder arthroscopy. A second assistant can manipulate the arm to improve exposure. Adduction of the arm over a large bump (white arrow) can facilitate joint distraction. The ergonomics of an anterosuperolateral viewing portal (black arrow) are improved in this position

ASL viewing portal allows the surgeon access across the joint using anterior and posterior working portals. Last, cerebral perfusion in lateral position is improved over beach chair, and so the anesthesiologist typically feels safer in maintaining hypotensive anesthesia, a critical factor for improving visualization.

34.7.2 Associated Procedures

The long head of biceps tendon can be a pain generator in the arthritic shoulder. A low treatment threshold should exist for treating associated biceps-labral pathology, such as a SLAP tear, biceps tendinosis or partial tearing, or instability. In most joint preservation patients, an arthroscopic tenodesis with interference screw fixation at the top of the groove is performed [18]. A key technical point in this scenario is to capture the biceps, tenotomize it, and whipstitch the tendon as early as possible in the case prior to the onset of significant shoulder swelling. The tenodesis can then be performed later, typically after capsular release and manipulation, so as to protect the tenodesis from iatrogenic disruption.

Any loose bodies identified on preoperative images should be identified and removed. Significant rotator cuff tears are unusual for the typical shoulder preservation patient. High-grade partial-thickness or small full-thickness tears can be repaired with the AGR. The subacromial space should be inspected at the conclusion of the resurfacing in order to assess for evidence of arch impingement and bursal rotator cuff tears. When indicated, arthroscopic subacromial decompression and/or distal clavicle excision (arthroscopic Mumford) are performed toward the conclusion of the operation.

34.7.3 Capsular Release

An arthroscopic capsular release must be performed as a part of AGR, as this increases the joint space for graft shuttling and fixation. Additionally, capsulotomy improves range of motion in the arthritic shoulder and provides some pain relief through denervation. A 270° release, sparing the superior capsule from about 10–1 o'clock in the right shoulder, is sufficient to achieve these aims.

Begin by incising the rotator interval capsule from an anterior working portal while viewing from posterior (Fig. 34.8a). The release should extend from the upper border of the subscapularis to the anterior edge of the supraspinatus with care taken to protect these tendons. Next, incise the posterior capsule up to approximately 10 o'clock with a pencil tip cautery probe while viewing from anterior or ASL (Fig. 34.8b). The inferior capsule can be released safely about 1 cm off the inferior labrum (Fig. 34.8c). Last, extend the release through the anterior capsule taking care to incise the middle glenohumeral ligament while sparing the subscapularis tendon (Fig. 34.8d).

The arm is then gently manipulated by axial rotation, elevation, and cross-body adduction and abduction to break up any residual capsular attachments and stretch the periscapular muscles that may have become contracted secondary to stiffness and disuse. A repeat diagnostic arthroscopy should be done after manipulation to make sure no iatrogenic injury has occurred to the rotator cuff.

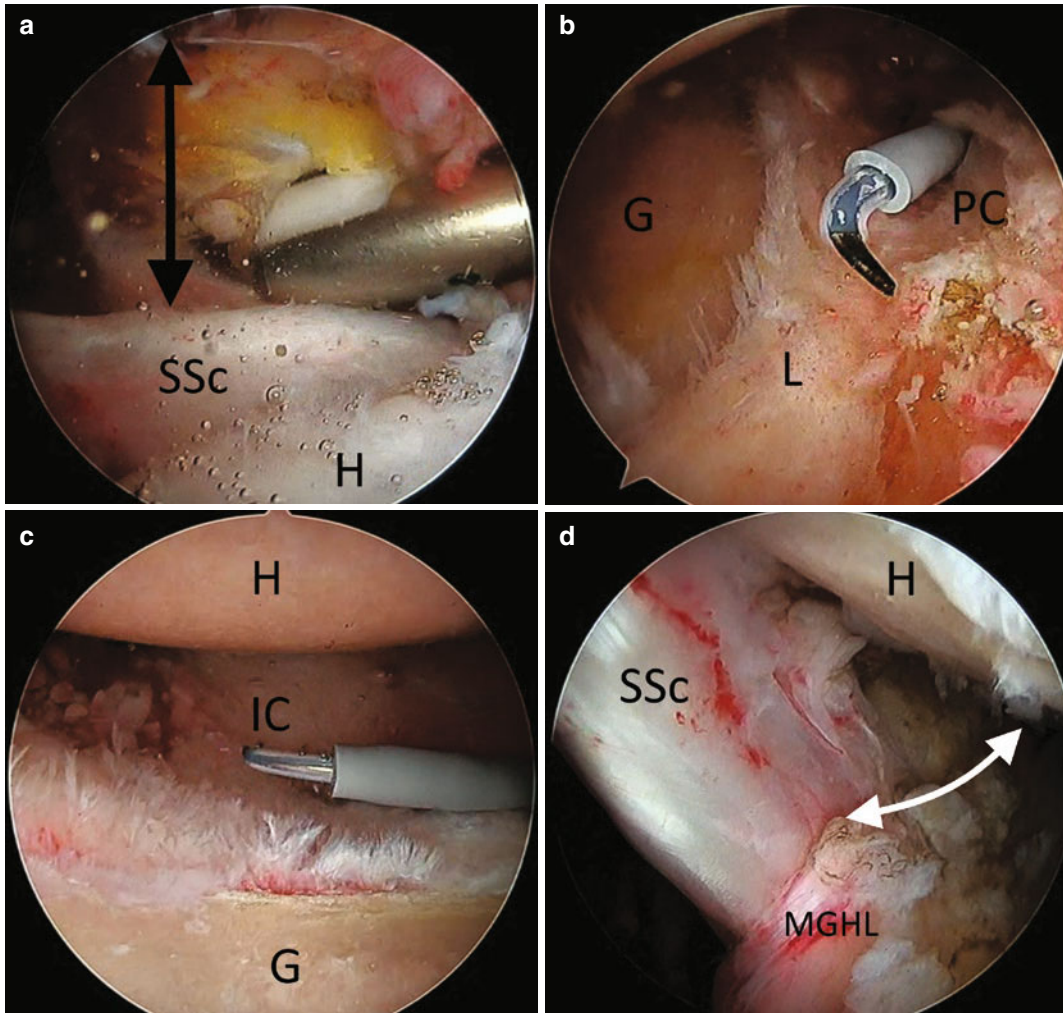

Fig. 34.8 (**a**) Right shoulder posterior view of arthroscopic rotator interval capsular release working through an anterosuperolateral portal. The release should extend from the upper border of subscapularis tendon (SSc) to the anterior border of supraspinatus tendon. (**b**) ASL view of the posterior capsule (PC) release using a hook cautery probe extending to about 10 o'clock. (**c**) The inferior capsule (IC) should be cut approximately 1 cm from the outer margin of the inferior labrum. (**d**) The anterior release should be extended through the middle glenohumeral ligament (MGHL). *G* glenoid, *L* labrum, *H* humeral head

34.7.4 Osteophyte Debridement

The extent of marginal osteophyte debridement in arthroscopy for shoulder arthritis remains controversial. Some authors believe that osteophyte removal (particularly inferiorly) improves pain and motion and should be an independent goal of the operation [4]. Our experience has been that the inferior osteophytes are very difficult to access without first performing a capsular release, which then places the axillary nerve at risk with the use of a burr. Alternatively, the use of a narrow osteotome (Fig. 34.9) through a large cannula can increase the margin of safety for inferior osteophyte removal. Our experience has been that inferior osteophyte removal doesn't seem to be particularly important for achieving good outcomes with AGR and that for most patients the risk-benefit calculation is not favorable for this step. Marginal osteophytes at the anterior and posterior joint lines are more amenable to safe resection with a burr. Since these likely also rep-

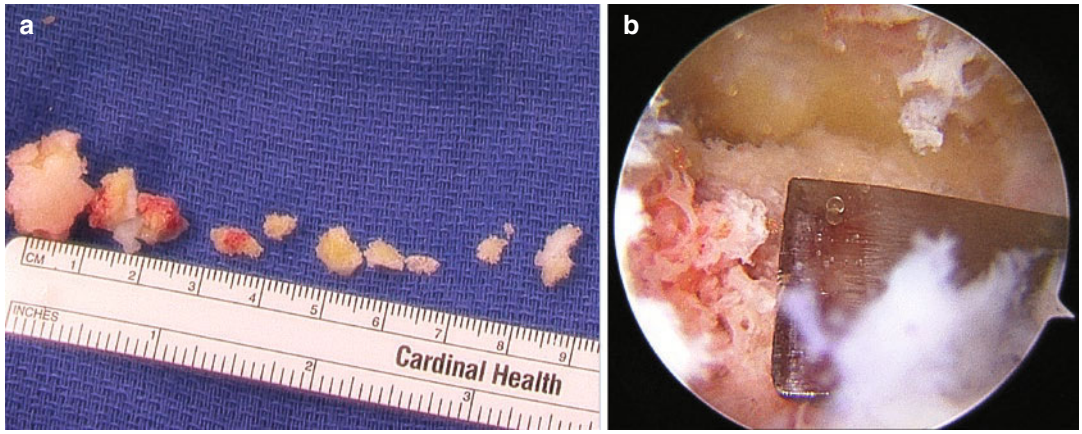

Fig. 34.9 (**a**) Large marginal osteophytes have been removed from an arthritic shoulder arthroscopically. (**b**) A narrow osteotome can be placed through a large 8–10 mm cannula and can facilitate safe osteophyte resection

resent a block to rotation of the glenohumeral joint, they should be resected to the extent that it is safely possible.

34.7.5 Glenoid Preparation

The glenoid should be prepared such that the potential for graft healing is maximized. First, any remaining cartilage should be removed using a ring curette. Next, a light burring should be done to freshen the glenoid surface, usually with the burr on reverse. If a B2 glenoid is present, the ridge between the neo- and paleoglenoids should be removed in order to restore a single flat surface. The arthritic glenoid can be significantly larger than the normal glenoid because of osteophytes, and the preoperative imaging should be scrutinized for the presence of thin, fragile spurs. If present, these should be removed so that the graft can be fixed to structurally supportive bone. We prefer subchondral drilling (PowerPick, Arthrex, Inc., Naples, FL) (Fig. 34.10) over microfracture to access the marrow elements for promoting graft healing.

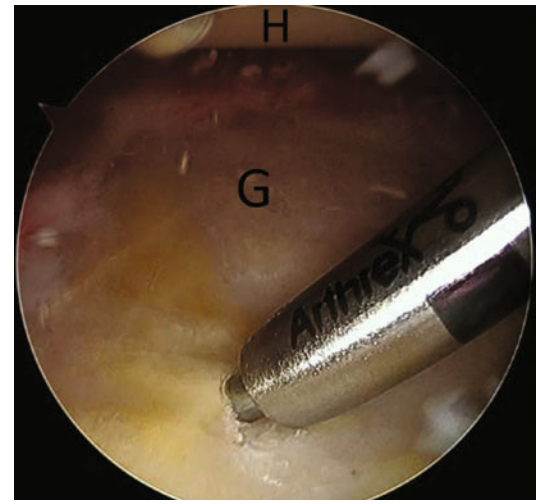

Fig. 34.10 Subchondral drilling of the glenoid surface (PowerPick, Arthrex, Inc., Naples, FL) should be performed to access the marrow elements for graft healing. *G* glenoid, *H* humeral head

34.7.6 Graft Preparation

Graft preparation begins with measuring the dimensions of the glenoid using rigid (Fig. 34.11a) or flexible (Fig. 34.11b) calibrated probes. Since the typical dermal graft has some elasticity and will stretch slightly during fixation, oversizing the graft should be avoided. Next, establish a percutaneous posterolateral portal using a spinal needle, which will be used to place the posteroinferior and/or inferior (6 o'clock) anchors (Fig. 34.12a). Two or three inferior glenoid anchors (Fig. 34.12b) will be placed during the graft preparation phase of the case since the distance between these

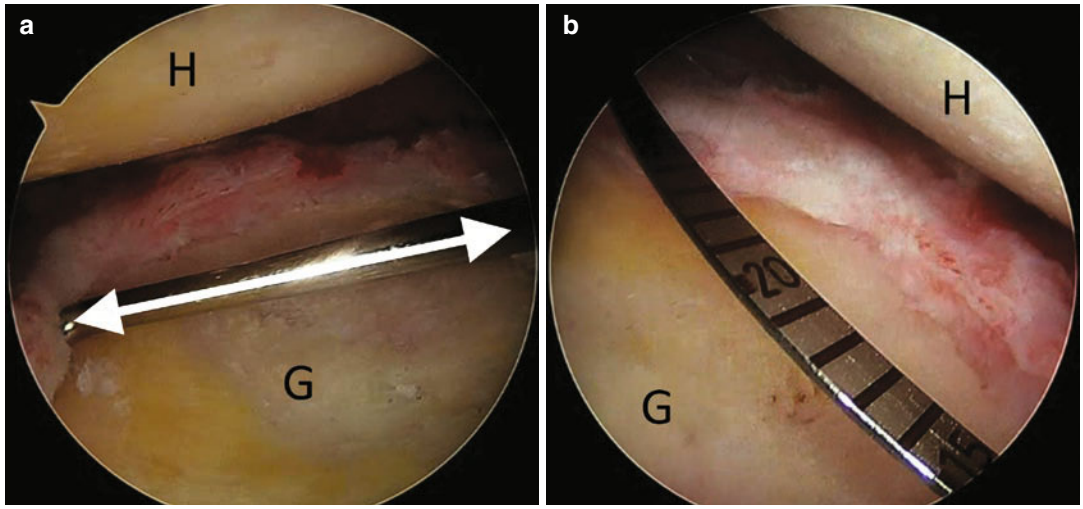

Fig. 34.11 (**a**) Right shoulder anterosuperolateral view: a rigid, calibrated probe from a posterior portal is used to measure the anterior-posterior dimension of the inferior glenoid. (**b**) Right shoulder posterior view: a flexible, calibrated probe (Arthrex, Inc., Naples, FL) from the ASL portal is used to measure the superior-inferior dimension of the glenoid. *G* glenoid, *H* humeral head

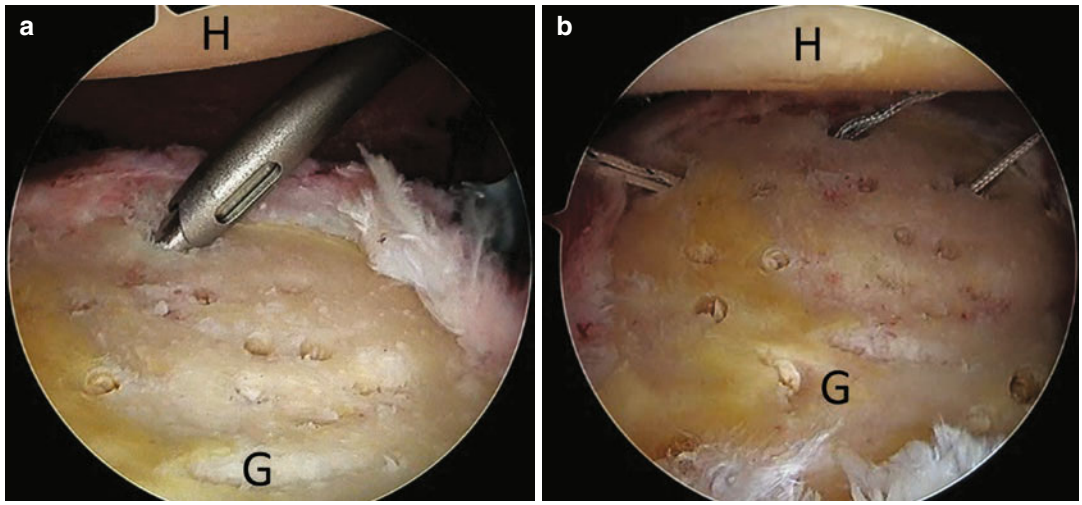

Fig. 34.12 (**a**) Anterosuperolateral view showing drilling for the inferior (6 o'clock) anchor through a percutaneous posterolateral portal. The ability to establish this portal is a necessary skill for performing AGR, since the inferior and posterior anchors will usually be placed through this portal. (**b**) Three inferior anchors have been placed, and these will be used for graft shuttling. *G* glenoid, *H* humeral head

anchors must be measured and recorded. Place an anteroinferior anchor at 4:30–5 o'clock through an anterior portal.

Next, the dermal graft is sized and cut on the back table. Three millimeter human dermis can be difficult to cut, and a scalpel or heavy curved Mayo scissors are usually necessary for this purpose. One limb from each of the inferior anchors is then retrieved out of the ASL portal *taking care to maintain the correct orientation of the sutures* to prevent tangling. At this point, the surgeon must anticipate how the graft will pass through the ASL portal. Smaller grafts may pass through a rigid 8 mm cannula with the dam removed. Larger

grafts may need to be brought through a flexible cannula (8 or 10 mm PassPort, Arthrex, Inc., Naples, FL) or percutaneously (cannula removed).

With the ASL portal properly configured for graft passage, as above, measure the distances between the inferior anchors. Then, pass the sutures accordingly through the graft, and tie large mulberry knots tied on the "smooth" dermal surface of the graft (Fig. 34.13). Additional sutures are preplaced around the periphery of the graft (Fig. 34.13), and these can be used directly for fixation or as suture shuttles. The surgeon should plan for 6–8 points of fixation in this fashion.

34.7.7 Graft Shuttling

Graft shuttling via the inferior anchor sutures accomplishes the tasks of bringing the graft into the shoulder and providing initial temporary fixation in the correct orientation. Recall that one suture limb from each anchor has been retrieved, passed through the graft, and tied on the surface of the graft. The other suture limb (the "pulling limb") from each anchor remains out of its originally placed portal (typically two from a posterolateral portal and one from an anterior portal). The surgeon can now bring the graft into the joint using the "pulling limbs" (Fig. 34.14a), often with the aid of a pushing instrument (Fig. 34.14b).

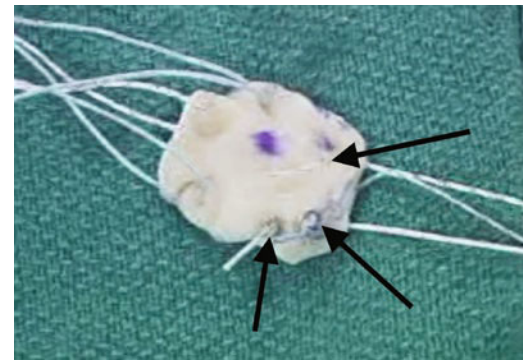

Fig. 34.13 Fully prepared dermal allograft. One suture limb from each inferior anchor has been passed from the basement membrane side to the dermal ("shiny") side of the graft and then a mulberry knot (black arrows) tied for each. Additional sutures have been preplaced through the graft for convenience

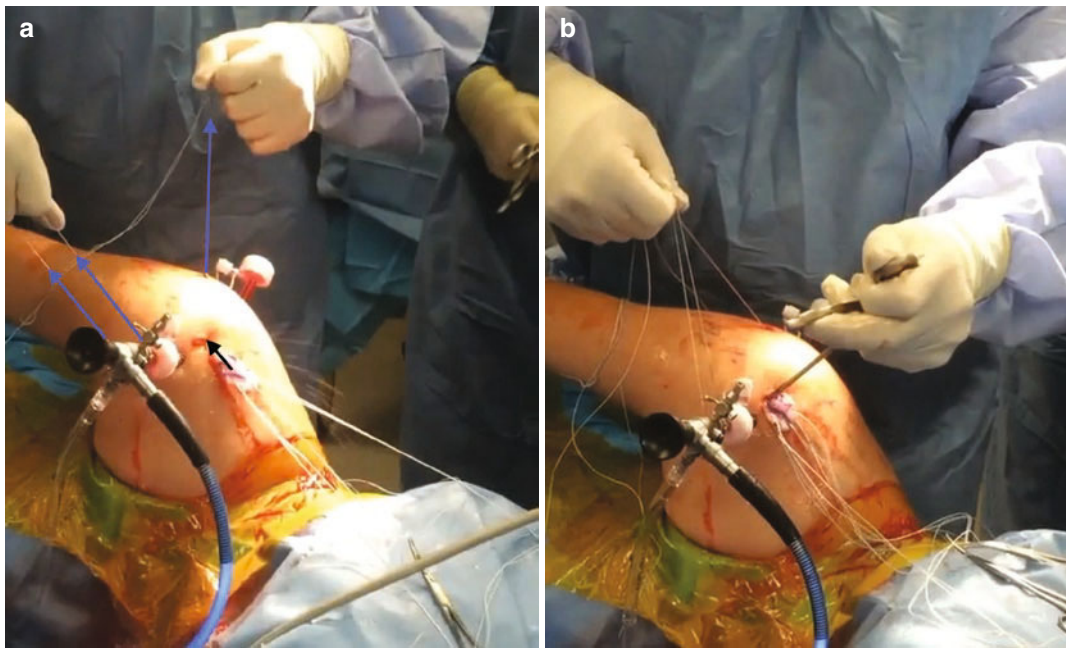

Fig. 34.14 Right shoulder external views—(**a**) graft shuttling is accomplished by pulling the graft into the shoulder (black arrow) using the inferior anchor suture limbs (blue arrows) that had remained out of their original working portals. (**b**) Pushing the graft inward with an instrument from the ASL portal also can be used to aid passage

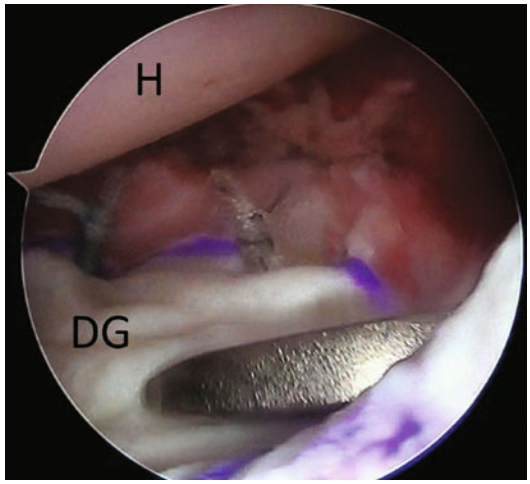

Fig. 34.15 Viewing from ASL, the graft (DG) has been brought into position, and the mulberry knots are seen on the dermal surface of the graft. An instrument through the posterior portal is used to spread out the graft onto the glenoid surface in preparation for final fixation. *H* humeral head

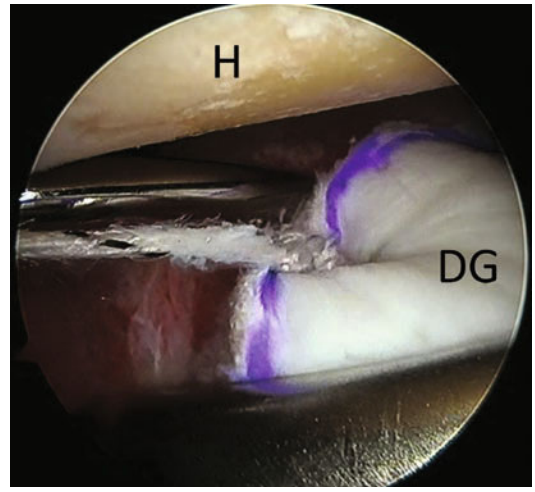

Fig. 34.16 Viewing from anterosuperolateral, the anteroinferior suture is tied using a knot pusher (sixth Finger, Arthrex, Inc., Naples, FL) through an anterior portal

Once the pulling sutures have been made tight, the graft should lie in the correct position inferiorly. An instrument can then be used to "smooth out" any remaining folds in the graft (Fig. 34.15) in preparation for final graft fixation.

34.7.8 Graft Fixation

Graft fixation begins by sequentially retrieving and tying the inferior suture limbs (mulberry knots and pulling sutures). Typically, suture retrieval and tying are performed through an anterior portal (Fig. 34.16) for the anteroinferior anchor and through a posterior portal for the inferior and posteroinferior anchors.

After the graft has been secured by the inferior anchors, another 3–5 fixation points should be established anterior, posterior, and superior. If the labral tissue is robust, labral fixation is an option. However, we have noticed the best results when at least six points of fixation are anchor-based. Fixation should proceed from inferior to superior. Viewing is primarily done through the ASL portal, but cannulated portals facilitate switching the scope to other viewing portals, which is often necessary.

Many options exist currently for anchor fixation of the graft to the glenoid. Knotless, push-in style anchors (2.9 mm PushLock, Arthrex, Inc., Naples, FL) can be used to fix any of the sutures that were preplaced during graft preparation. The repair suture from a knotless, self-cinching anchor (knotless 3.0 mm SutureTak, Arthrex, Inc., Naples, FL) can also easily be shuttled through the graft using the preplaced sutures. Lastly, if the preplaced sutures are not in the ideal location in the graft, a traditional push-in anchor (3.0 mm SutureTak, Arthrex, Inc., Naples, FL) (Fig. 34.17a) requiring suture passage (Fig. 34.17b) and knot tying (Fig. 34.18) can be employed.

In addition to marrow stimulation from drilling, we recommend injecting platelet-rich plasma (ACP, Arthrex, Inc., Naples, FL) at the graft-glenoid interface after final graft fixation has been completed (Fig. 34.19).

34.8 Postoperative Care

Although some patients undoubtedly avoid reoperation and experience improvement with a non-healed AGR, our best results have been seen in the setting of a fully healed graft (Fig. 34.6).

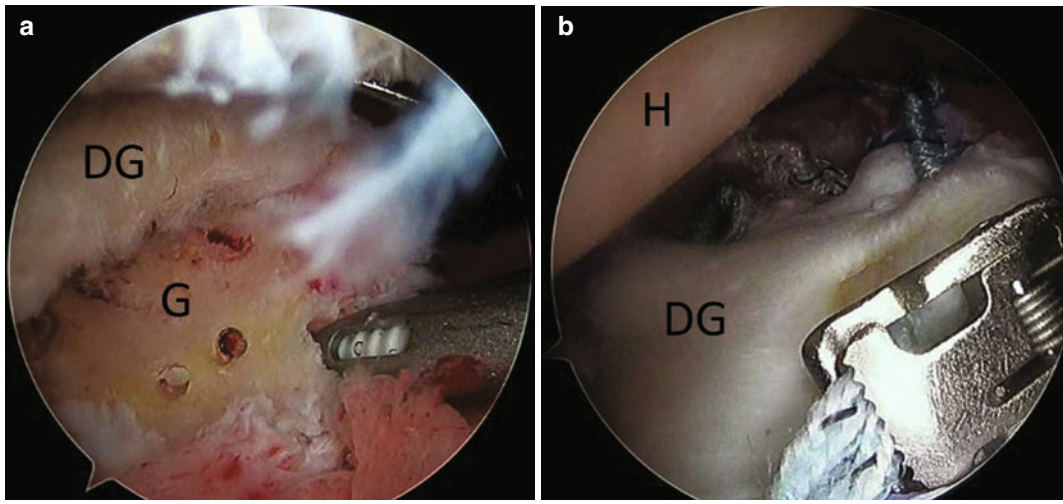

Fig. 34.17 (**a**) Viewing from anterosuperolateral, a posterosuperior anchor is being placed through a percutaneous portal. (**b**) A posterosuperior anchor suture is being placed using a self-retrieving anterograde suture passer (Scorpion, Arthrex, Inc., Naples, FL). *DG* dermal graft, *G* glenoid

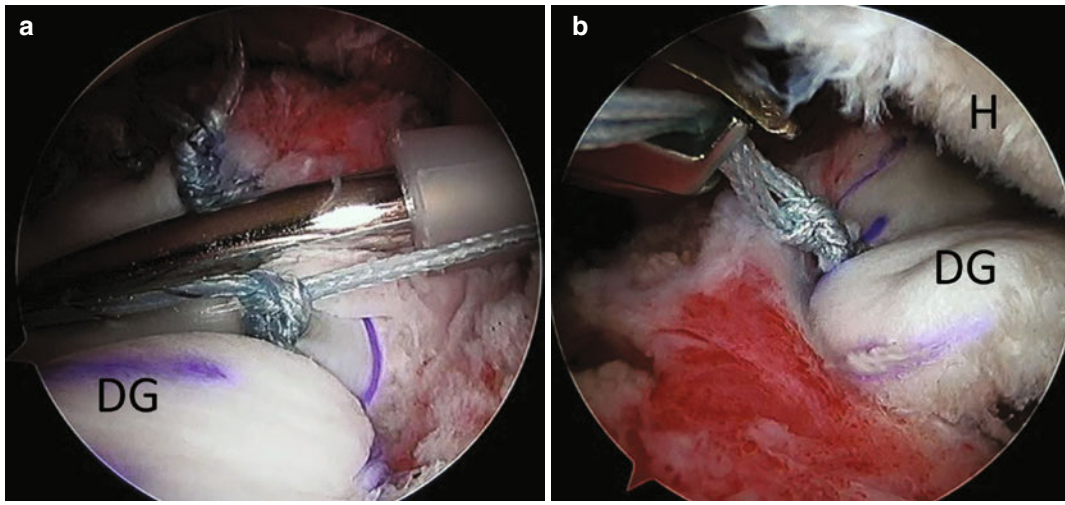

Fig. 34.18 (**a**) Viewing from anterosuperolateral, the posterosuperior anchor is being tied using a double-diameter knot pusher (Sixth Finger, Arthrex, Inc., Naples, FL). (**b**) An anterosuperior suture is being cut as fixation proceeds from inferior to superior. *DG* dermal graft, *H* humeral head

Furthermore, for most of our AGR patients, the operation represents their last chance to avoid a prosthetic arthroplasty. Thus, graft healing is prioritized in the postoperative setting. For most patients, immobilization is prescribed postoperatively for 6 weeks in a sling, with only elbow, wrist, and hand range of motion allowed. After 6 weeks, passive shoulder range of motion exercises are allowed, and the arm can be used for light activities of daily living. After 12 weeks,

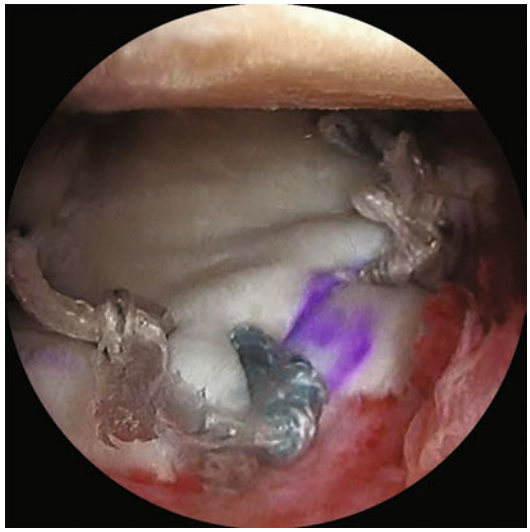

Fig. 34.19 Final appearance of the right shoulder AGR from an anterosuperolateral portal

active overhead use of the arm and TheraBand strengthening begin. Return to full activities such as sports or the gym is delayed until 6 months postoperatively.

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The Comprehensive Arthroscopic Management (CAM) Procedure

35

Emilio Calvo, Carlos Rebollon Guardado, Marina Acebal, and Kevin P. Shea

35.1 Introduction

Glenohumeral osteoarthritis (OA) is a common condition typically associated with elderly and often with a previous trauma. Typically OA is characterized by symptoms of weakness, decreased range of movement, and pain [1]. The initial treatment typically consists of nonoperative measures including physical therapy, pharmacotherapy, injections, and activity modifications [2, 3]. When standard nonsurgical methods are unsuccessful, the joint arthroplasty is the standard of surgical management of in an advance osteoarthritis [4]. The treatment with total shoulder arthroplasty (TSA) provides predictable clinical outcomes with low revision rates and high patient satisfaction in elderly or low-demand population [4, 5]. However, in a younger patient (age less than 55 years) or symptomatic patients but with less radiographically advanced disease, TSA may not be the best option [6]. Recent publications have shown unacceptable outcomes of TSA in younger patients because of the higher risk of revision [7], decreased component survival [8], and highest rates of component loosening [5, 9–11]. As arthroscopic technique has evolved, it has been included in the low-risk management options that can provide pain relief before arthroplasty [12, 13]. Arthroscopic treatment options have been used in an attempt to delay the need for arthroplasty in younger, more active patients or in those patients in whom arthroplasty is otherwise not an acceptable treatment option. More recent evidence suggests that carefully selected patients may benefit from arthroscopic management of osteoarthritis [12, 13]. The first reports of arthroscopic management of osteoarthritis of the glenohumeral joint were published in the 1980s [14–16]. These procedures primarily consisted of glenohumeral lavage, debridement of torn labral tissue and cartilage flaps, and removal of loose bodies. Given the available literature, arthroscopic management of osteoarthritis of the shoulder appears to have more validity than in the knee. Millet and coworkers described a joint-preserving arthroscopic treatment approach for young, active patients with advanced shoulder osteoarthritis [17]. They called this technique the CAM procedure, which is an acronym for comprehensive arthroscopic management. Because patients with advanced osteoarthritis frequently have a number of different pain generators and various pathoanatomic features that lead to functional deficits, all of

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these pathoanatomic factors need to be considered and addressed to optimize outcome. The CAM procedure therefore entails similar arthroscopic debridement procedures such a chondroplasty, synovectomy, loose body removal, and subacromial decompression but also involves [17]:

1. An extensive capsular release to restore glenohumeral motion.
2. Humeral osteoplasty and osteophyte excision to recontour the humeral head, restore abduction, and potentially decompress impingement on the axillary nerve.
3. Axillary nerve neurolysis when scarring is seen around the nerve or there is significant compression from an inferior humeral osteophyte.
4. Biceps tenodesis when there is a significant biceps tenosynovitis, a degenerative SLAP tear, an hourglass deformity, or a pulley lesion.

These are the features that distinguish the CAM procedure from previously described debridement procedures. In spite of encouraging outcomes described by Millett and coworkers, the reports of the CAM procedure in the literature are very scant [17–19]. The purpose of this chapter is to describe the CAM procedure and to review our experience with the clinical results following arthroscopic joint-preserving approaches for glenohumeral osteoarthritis.

35.2 Patient Selection

The appropriate patient selection is critical to achieve a successful outcome following the CAM procedure [20, 21]. The procedure is generally indicated for young, active patients with glenohumeral OA who we wish to delay glenohumeral arthroplasty. Several studies have shown unacceptable outcomes of TSA in younger patients (age less than 55 years), including increased rates of prosthesis component loosening, decreased prosthesis component survival, and significantly higher risk of revision, increasing the risk of infection [5, 6, 9–11]. A recent Markov decision analysis published by Spiegl et al. found that arthroscopic management of glenohumeral OA was the preferred treatment strategy for patients younger than 47 years, while TSA was preferred for patients older than 66 years [20]. Between 47 and 66 years of age, there was no clear advantage for one technique over the other, highlighting the need for individualized treatments based on a number of patient-specific factors in this age group [20]. Identifying the factors that are predictive of early failure is paramount for proper patient selection for those who will do well with joint preservation versus replacement. Mitchell et al. identified several preoperative factors that were found to be associated with failure of the CAM procedure [19]. These factors included age older than 50 years, radiographically more severe arthritis as measured by the Kellgren-Lawrence grade, narrower joint space less than 2 mm, and Walch B2- or C-type glenoid anatomy. The relative risk of progression to TSA was nearly six times higher in patients with a Walch type B2 or C glenoid compared with patients with Walch A1, A2, or B1 glenoid types.

35.3 Surgical Technique

An interscalene catheter is placed before the general anesthesia, which provides analgesia during the beginning of the postoperative rehabilitation. General anesthesia is then administered, and the patient is placed in the beach chair position. It is very useful to carry out a complete intraoperative examination of the bilateral shoulders under anesthesia to identify the specific angles at which shoulder mobility is restricted. A fluoroscopic C-arm is also draped into the surgical field using sterile techniques to assist with visualization and resection of the inferior osteophyte. The surgical procedure begins with a standard posterior arthroscopic portal and a 30° arthroscope to undertake a complete arthroscopic glenohumeral examination. Degenerative labral tissue and unstable chondral injuries are debrided, loose bodies are removed, and areas of synovitis are also addressed with either a mechanical shaver or radiofrequency device. The long head

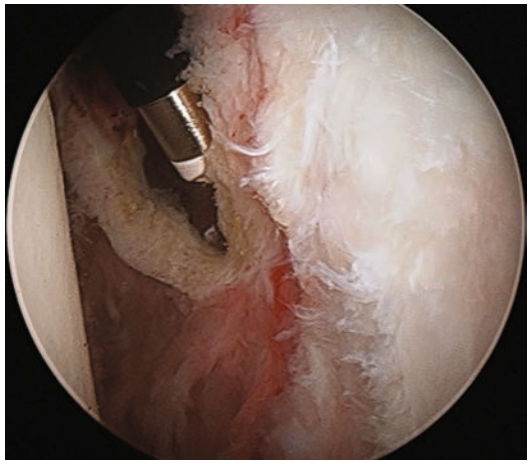

Fig. 35.1 Posterior capsulotomy using a radiofrequency probe and visualized from an anterior superolateral portal

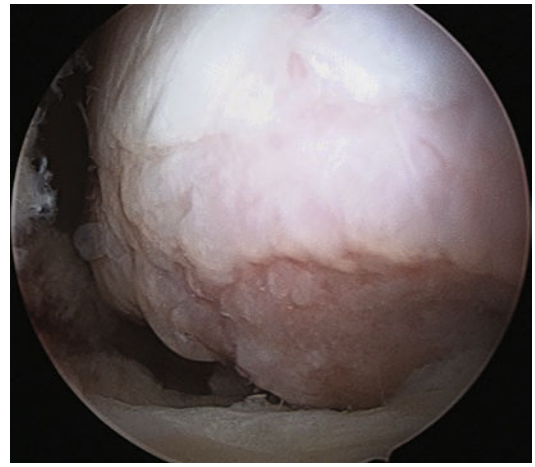

Fig. 35.2 Arthroscopic imaging of the humeral head showing an inferior osteophyte

of the biceps tendon was then examined, and if an injury was noted, it was released at its origin and later secured distally utilizing open subpectoral tenodesis or tenotomy. The anterior and posterior capsules are then released (Fig. 35.1). The rotator interval must be completely released, and the subscapularis recess is inspected at this point for loose bodies. Some authors perform the capsular releases after the osteophytes have been removed. In our experience, performing complete rotator interval opening as well as anterior and posterior capsular releases before osteophyte removal permits easy intra-articular excursion of arthroscopic instruments and shoulder mobility, which facilitates further osteophyte removal. In addition to anterior or posterior osteophytes, in many cases of glenohumeral OA, an inferior humeral osteophyte is present (Fig. 35.2). Previous literature has shown that this can affect the course of the axillary nerve and may contribute to pain. Therefore, inferior humeral osteoplasty is performed whenever this deformity is present. For this purpose, an accessory posteroinferior portal is established under spinal needle localization, and through this portal, the symptomatic osteophytes are resected with a high-speed shaver and burr (Figs. 35.3 and 35.4). Fluoroscopy is very helpful to confirm adequate resection of the inferior humeral osteophyte. Once the bony resection is completed, the inferior capsule is released (Fig. 35.5). Axillary nerve neurolysis and decompression are performed in the event that bony encroachment had changed the course of the nerve. Preoperative symptoms considered consistent with axillary nerve impingement or compression are posterior and lateral shoulder pain, atrophy of the teres minor or posterior deltoid, and weakness in

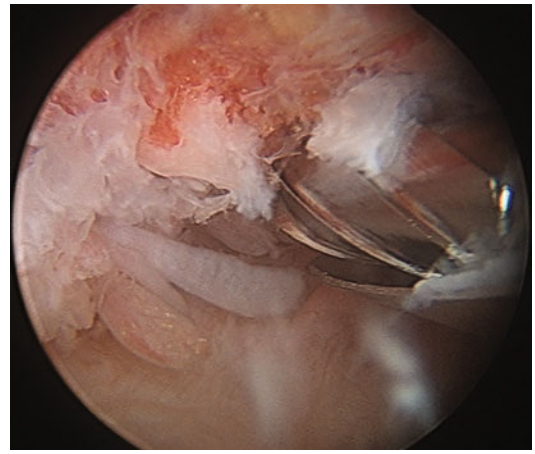

Fig. 35.3 Arthroscopic resection of the inferior osteophyte in a right shoulder. The arthroscope is inserted through a conventional posterior portal, and the burr is inserted through an accessory posteroinferior portal

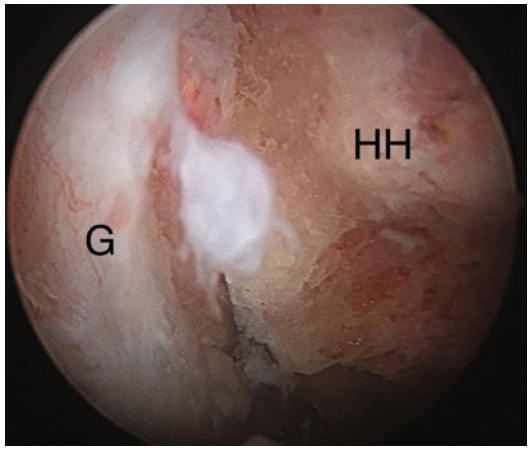

Fig. 35.4 Imaging of the posterior aspect of the glenohumeral joint after resection of the inferior osteophyte. *G* glenoid, *HH* humeral head

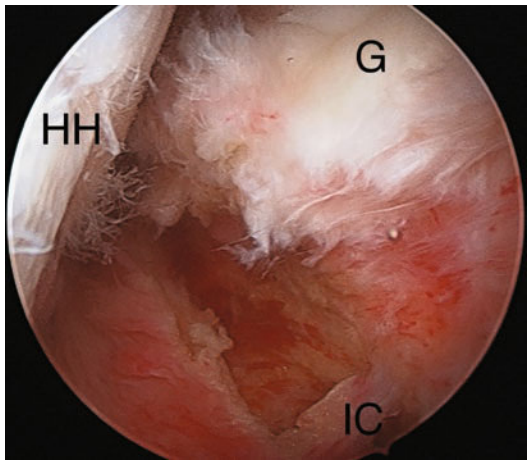

Fig. 35.5 Inferior capsule division. *G* glenoid, *HH* humeral head, *IC* inferior capsule

external rotation without the presence of a rotator cuff tear. The nerve should be carefully decompressed from proximal to distal, taking great care to identify and preserve all arborizing branches. Subacromial and subcoracoid decompressions are performed next. Bursectomy and resection of subacromial adhesion are mandatory, but acromioplasty is only performed if a Bigliani type 3 acromion is present or an impingement lesion is noted. We performed an arthroscopic suprapectoral biceps tenodesis with unicortical fixation with a polyetheretherketone (PEEK) tenodesis screw (Arthrex Inc.).

35.4 Postoperative Management

The main goals of postoperative treatment after CAM procedure are to prevent recurrent scarring, improve and maintain motion, and improve shoulder mechanics. Patients were placed in a sling for 1 or 2 days. Postoperative rehabilitation is divided into three phases, beginning with immediate active and passive range of motion for the first 4–6 weeks to maintain the gains achieved through osteoplasty, debridement, manipulation, and capsular release. Nonsteroidal anti-inflammatory medications were also used to help reduce inflammation during the initial postoperative period. The second phase began at 6 weeks and progressed until approximately week 12. During this time, rehabilitation is focused on strengthening of the rotator cuff, peri-scapular musculature, and core. The final phase was initiated at 12 weeks and focused on return to normal activities. Maximum recovery is expected by 4 to 6 months.

35.5 Results of the CAM Procedure

Mitchell et al. published the report of the midterm outcomes and survivorship for the CAM procedure for the treatment of GHOA at a minimum 5-year follow-up [18]. The survivorship found is around the 95.6% at 1 year, 86.7% at 3 years, and 76.9% at 5 years [18]. Factors associated with failure and progression to TSA were a Walch type B2 or C glenoid shape ($P = 0.006$) and preoperative joint space narrowing defined as less than 2 mm of joint space remaining as seen on a Grashey or true anterior-posterior radiograph of the glenohumeral joint ($P = 0.032$) [18]. Patients also reported a high median satisfaction of 9 of 10 (range, 2–10) [18]. Pain with work, activities of daily living, recreation, sleep, and use of the arms, all significantly improved from preoperative to postopera-

tive levels ($p<0.001$). Patients reported significant pain relief ($p<0.01$) and improved outcome scores at 2 years postoperatively, which they were able to maintain over time. Postoperative improvements in the ASES score ($r = 0.474$; $P = 0.013$) and satisfaction ($r = 0.397$; $P = 0.037$) were positively correlated with age. To summarize, older patients, those with higher preoperative ASES scores, and those with a larger joint space had improved results at a minimum 5-year follow-up [18].

The senior author has assessed the outcome of the CAM procedure in a consecutive series of 14 patients with advance glenohumeral OA. The mean age at surgery was 46 years (range 33–66) in 11 males and 3 females; the dominant extremity was involved in 57% of the cases (8 right shoulders). The mean follow up was 16 months, with a range of 6 to 36 months. Preoperatively, all patients complained of chronic aching pain exacerbated by activity. The procedure included glenohumeral chondroplasty, capsular release, synovectomy, biceps tenodesis or tenotomy, body loose removal, and subacromial decompression. The preoperative and postoperative evaluation consisted of patient interview and evaluation. Patients were questioned regarding changes in pain and an overall subjective satisfaction with the results of the treatment with The Western Ontario Rotator Cuff (WORC) Index. Patients showed a preoperative mean WORC index of 52%, with a range from 26 to 77%, while postoperatively the mean value was 36%, with a range from 1.9% to 87.6%. The preoperative results in Visual Analog Scale for Pain (VAS pain scale) were a mean of 6 with a range 1–10, and in postoperative, the VAS was a mean of 4 with a range of 0–10.

35.6 Risks and Complications

There are several surgical risks and potential complications that can be avoided when the procedure is performed systematically using meticulous surgical technique. The axillary nerve is particularly susceptible to iatrogenic injury during inferior capsular release and during the neurolysis of it because they are typically difficult to observe during the arthroscopy. Anterior and posterior capsular releases should always be performed after addressing the axillary nerve to prevent fluid excursion or leakage into the axillary space. The inferior capsular scar tissue that often develops postoperatively may involve the axillary nerve, potentially resulting in recurrent posterior and lateral shoulder pain.

35.7 Conclusion

These are the preliminary results of small series published. It seems to be a promising procedure for the glenohumeral osteoarthritis in young patient. This procedure is especially useful in younger patients who wish to remain active and yet avoid prosthetic replacement improving its quality of life. CAM constitutes a safe technique that utilizes additional procedures like the humeral osteoplasty and neurolysis of the axillar nerve for a additionally reduces of pain. In addition, if the arthroscopic technique fails to relieve the patient's symptoms, the procedure does not compromise any future surgical treatment. Patients who underwent the CAM procedure demonstrated significant improvements in the American Shoulder and Elbow Surgeons (ASES) score, VAS scores, and WORC Index. However, it is always necessary to ensure the patient and physician expectations coincide before undertaking operative management. The midterm clinical outcome seems to be around the 76.9% survivorship at 5 years follow-up.

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Partial Replacement (Partial Eclipse/HemiCAP)

36

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36.1 Indication

The main indication is for patients with symptomatic focal chondral and osteochondral lesions of the humeral head, circumscribed avascular osteonecrosis, and Hill-Sachs and reverse Hill-Sachs lesions, who are biologically young and have a high functional demand.

36.1.1 Specific Contraindications

- Advanced osteoarthritis with loss of humeral head centralization and rotator cuff tears.
- Shoulder stiffness with limitation of passive shoulder joint mobility.

36.2 Operative Principles

Arthroscopically assisted minimally invasive (Partial Eclipse, Arthrex) or open (HemiCAP, Arthrosurface) congruent focal surface replacement on the humeral head. The implants consist of two components:

1. Fixation screw for osseous fixation within the humeral head.
2. Final surface implant with a special designed back surface to ensure permanent osseous integration.

Due to the little bone resection, the transfer to a total shoulder prosthesis (anatomical or reversed) can be performed without any problems.

36.3 Preoperative Assessment

36.3.1 Diagnosis

36.3.1.1 Clinical Examination

Prior to the physical examination, a detailed anamnesis is essential to find out about the patients' symptoms, duration of the complaints and previously performed therapies or surgeries (intra-articular injections, e.g., with steroids), subjective instability, metal allergy, and relevant comorbidities (e.g., chronic polyarthritis). Furthermore, it is important to find out the patients' expectations to their shoulder function.

Several tests have been described to examine shoulder function; therefore, those tests should be used who the examiner is familiar with.

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Additionally, passive and active shoulder motion should be documented.

36.3.1.2 Neurological and Vascular Status

To meet the criteria for a partial replacement, the examination of peripheral neurology, especially the axillary nerve, is important.

36.3.1.3 Imaging: X-Rays

A series of three shoulder X-rays should be performed (true AP, y-view, axial) to assess the bony conditions (osteochondral lesion, Hill-Sachs or reverse Hill-Sachs lesion), centering of the humeral head, and to exclude an advanced glenohumeral osteoarthritis.

36.3.1.4 Imaging: MRI

Arthro-MRI with high resolution, in order to visualize the defect localization, size, and osteochondral environment (bone edema, necrosis). Additionally, the MRI can show any accompanying lesions (e.g., traumatic lesions) (Fig. 36.1).

36.3.1.5 Imaging: CT

CT (with intra-articular or intravenous contrast medium) for specific questions (e.g., exact localization and size of an osteochondral lesion or Hill-Sachs lesion, extent of a humeral head necrosis).

36.3.1.6 Preoperative Patient Information and Consent

Surgery-specific risks:

- Incorrect implantation (size, angle, height, depth)
- Risk of glenoid and additional humeral head cartilage damage
- Material failure (breakage, disconnection)
- Material wear
- Early loosening
- Shoulder dislocation
- Nerve lesion (in particular the axillary nerve)
- Fracture
- Infection
- Allergy/hypersensitivity reaction
- Switching from arthroscopically assisted minimally invasive to open technique (partial eclipse)
- Progressive joint wear
- Need for a total shoulder prosthesis in the course

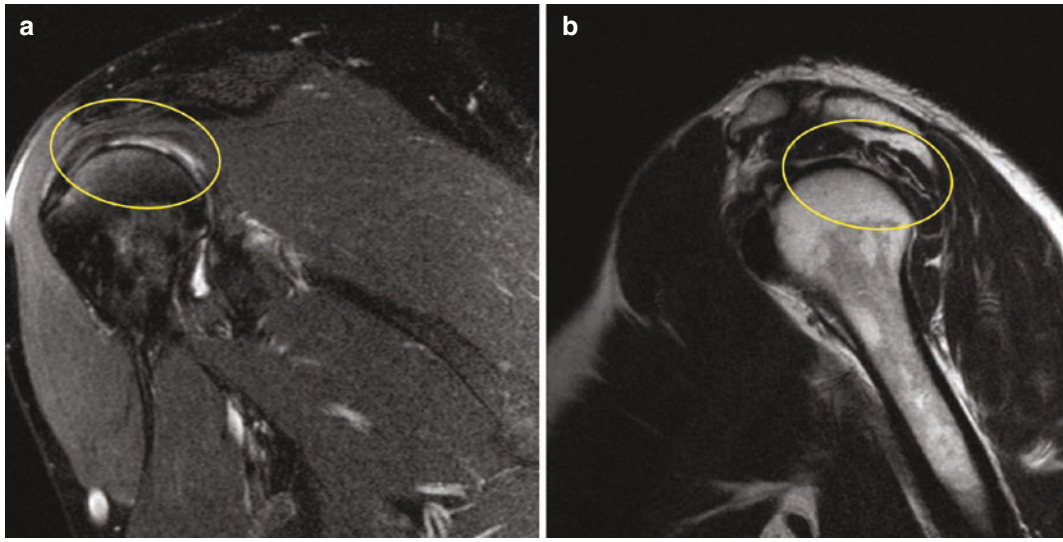

Fig. 36.1 MRI images of posterosuperior cartilage lesion. (**a**) Coronal and (**b**) sagittal view

36.4 Operative Technique

36.4.1 Positioning and Preparation

A beach-chair position with the use of an arm holder is recommended. If a arthroscopically assisted technique is performed, the shoulder pad of the OR table should be removed to have access to all shoulder portals needed. Prior to surgery, an examination during anesthesia is recommended.

36.4.2 Arthroscopically Assisted Partial Surface Replacement (Partial Eclipse)

Before resurfacing, a diagnostic arthroscopy is performed. Subsequently a probe is inserted to accurately measure the defected size and to check the stability of the surrounding healthy cartilage on the humeral head. Through an anterosuperior portal, the drill guide is inserted, and through the tip of the drill guide, the necessary implant diameter can be measured. Once the drill guide is in the right position, the drill sleeve is placed on the lateral side of the drill guide. Through a small incision followed by a blunt soft tissue preparation, the sleeve is advanced until cortical bone contact (protection of axillary nerve). A guide wire is drilled transhumeral until it hits the drill guide tip following a 4 mm cannulated drill to prepare the final transhumeral canal (Fig. 36.2). The retro-reamer is inserted and the humeral head surface is reamed (Fig. 36.3). Through the anterosuperior portal, the final implant is inserted and screwed into the humeral head by turning it counterclockwise. The position of the implant can be checked arthroscopically.

36.4.3 Open Partial Surface Replacement (HemiCAP)

The implantation is carried out through the delto-pectoral access and the detachment of the subscapularis tendon. Optimal visualization is essential to measure the defect and check the stability of the surrounding cartilage. Subsequently, a guide wire is put perpendicular to the surface right in the center of the cartilage defect and overdrilled, and a fixation screw is brought down to the cartilage level.

Using the measuring instrument, the size and radius of curvature of the defect can be measured, and thus the appropriate reamer and implant are determined.

Once a sharp cartilage edge is prepared, the reamer is brought down to the head of the inserted fixation screw, following a cold welding of the definitive implant and fixation screw with an impactor.

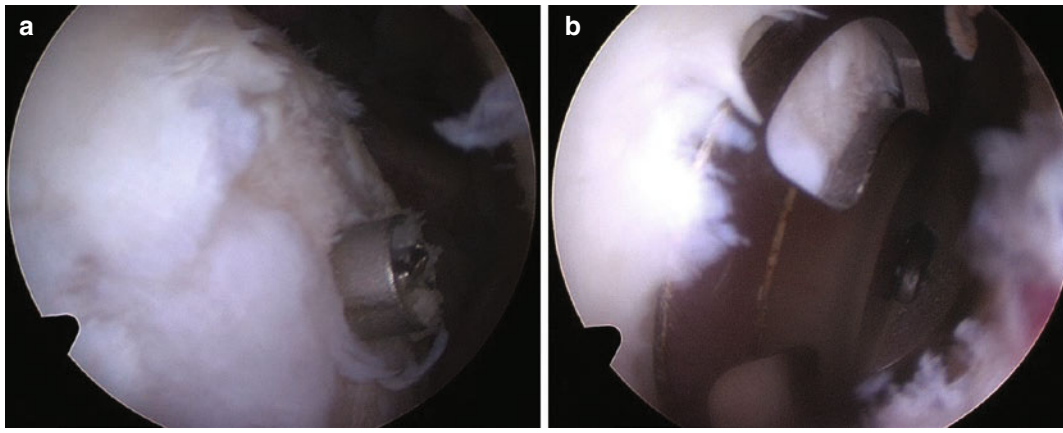

Fig. 36.2 (**a**) Drill guide and drill sleeve placed in the center of the cartilage lesion. (**b**) Mounted retro-reamer to prepare the surface of the humeral head

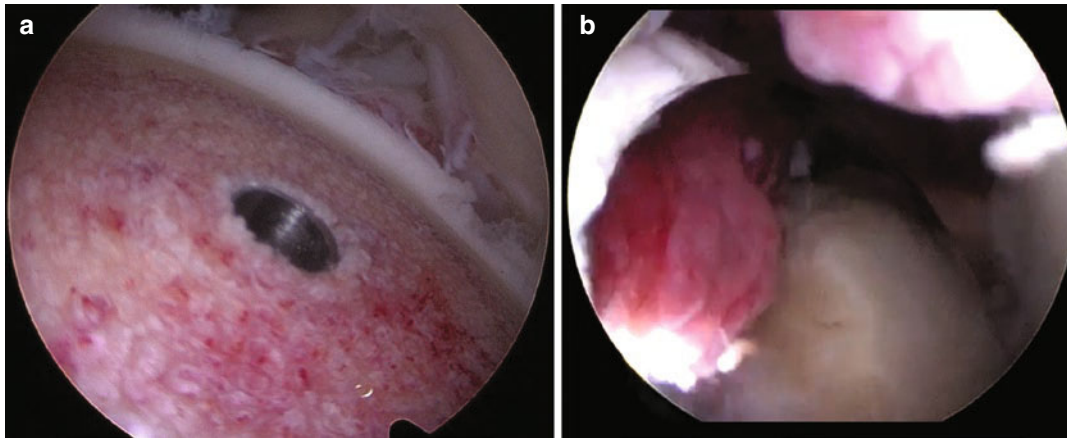

Fig. 36.3 (**a**) Prepared implantation side with intact cartilage borders. (**b**) Intra-articular view after Partial Eclipse implantation

36.5 Postoperative Management

Still within the operation room and during anesthesia, a shoulder sling/brace should be mounted. Additionally, control of peripheral circulation, motor activity, and sensitivity is essential. To ensure a correct procedure, an X-ray control should be performed (Figs. 36.4 and 36.5).

36.6 Follow-Up Treatment

36.6.1 Partial Eclipse

Shoulder sling immobilization for 2 weeks.

Week	Motion	Int. rotation/ ext. rotation	Abduction/ adduction	
1–6 post-operative weeks	Passive	Free	Free	
>7 post-operative weeks	First active assisted, then active	Free	Free	
>12 post-operative weeks	Strengthening	Free	Free	Beginning of sports

36.6.2 HemiCAP

Shoulder brace in 15° abduction for 6 weeks.

Week	Motion	Int. rotation/ ext. rotation	Abduction/ adduction	Flexion/ extension
1–3 post-operative weeks	Passive	80–0–0	90–0–0	90–0–0
4–6 post-operative weeks	Active assisted	Free–0–0	90–0–0	90–0–0
>7 post-operative weeks	Active	Free	Free	Free

36.7 Tips, Tricks, and Pitfalls

Care must be taken with diffuse cartilage damage, bipolar cartilage lesions, generalized osteoarthritis, or humeral head deformities as these entities are a contraindication for the implants. When resurfacing the humeral head, care must be taken to surrounding cartilage as the implant should sit underneath the cartilage

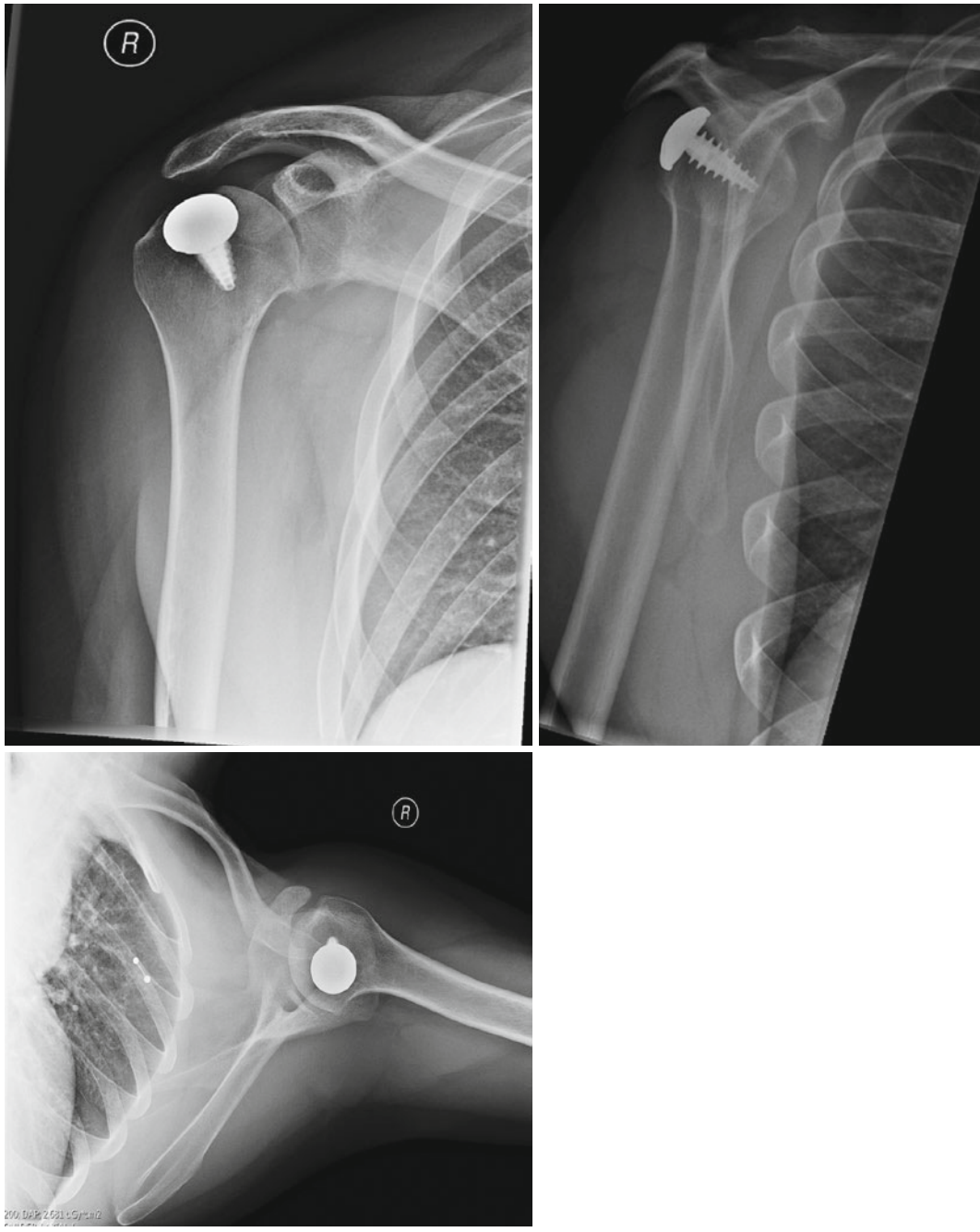

Fig. 36.4 Postoperative radiographs of HemiCAP implant covering a huge Hill-Sachs lesion after shoulder dislocation

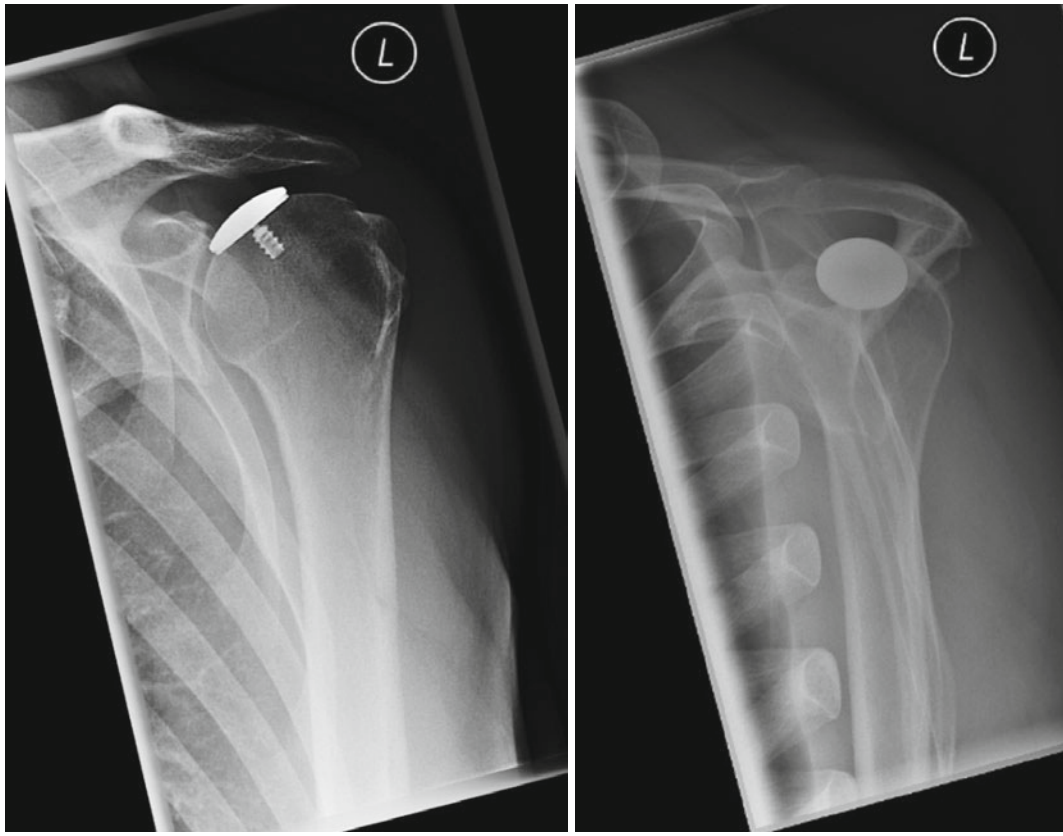

Fig. 36.5 Postoperative radiography after Partial Eclipse implantation with a posterosuperior cartilage lesion

boarder. An implant overlap must be avoided in any case as this can lead to a glenoid erosion. Additionally, the overlap can lead to notching or impingement.

In the case the Partial Eclipse system is used for a very cranial defect, the transhumeral drill hole must be placed very low. Therefore, the insertion point of the drill should be prepared over a small incision before inserting the tissue protection sleeve, in order to protect the axillary nerve. Uncontrolled drilling through the soft tissue should be avoided.

In case of HemiCAP implantation, the joint must carefully be rinsed, and the inner cone of the fixation screw must be cleaned using the specific cone cleaner which comes with the system. This is essential to allow the safe connection between both implant parts.

Further Reading

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Part IV

RC in the "Older" Patient (Age 50–70)

Rotator Cuff Pathology in the Older Active Patient

37

Matthew R. Zapf and Dan Guttmann

37.1 Introduction

Our population is aging, and many individuals are increasingly active as they get older. The demographic once thought to be "elderly" now contains a significant component of physiologically youthful and active patients. The orthopedic surgeon is challenged with offering more minimally invasive options to this population. Several authors have demonstrated the impact of rotator cuff disease on general health in the aging population. As patients age, comorbidities accumulate, thus amplifying the effect of rotator cuff pathology. Tashjian et al. conclude patients with rotator cuff disease and medical comorbidities have decreased DASH and SST scores, but more importantly, they have worse general health status [1]. MacDermid et al. mirror these results, concluding the presence of rotator cuff pathology is highly predictive of impaired physical health and quality of life. They go further, stating "the size of this impact is comparable to effects of conditions such as hypertension, congestive heart failure, diabetes mellitus, myocardial infarction and clinical depression" [2].

Interestingly, this decline in general health does not translate into inferior clinical outcomes after surgical intervention for rotator cuff pathology. In a later study, Tashjian et al. illustrate a greater improvement in pain score, function, quality of life, and DASH scores in patients with more comorbidities after rotator cuff repair. At 1 year postoperative follow-up, there was no significant correlation between comorbidities and pain, function, and quality of life. They conclude the presence of multiple comorbidities is not a negative prognostic factor in determining surgical candidacy for rotator cuff disease [3].

It is generally known rotator cuff pathology increases with age. In combination with an aging demographic and maintenance of an active lifestyle later into life, the prevalence of rotator cuff pathology will only increase. Current estimates of full thickness rotator cuff tear prevalence in patients 65 years and older range from 22% to 62%, which only increases with advancing age [4–11]. These statistics demonstrate a significant opportunity for orthopedic surgeons to impact public health and quality of life for our aging population.

During the years surrounding the turn of the century, the debate between open and arthroscopic procedures demonstrated arthroscopic techniques produce at least equivalent results to open treatment, but with less morbidity. Techniques

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and understanding of rehabilitation improved and indications expanded. As providers, we are undergoing an evolution of surgical indications to consider not necessarily chronologic, but physiologic age. Initial concerns of low tendon healing rates in the elderly population have not resulted in worse clinical outcomes as once believed. These beliefs were rooted in evidence demonstrating increased likelihood of a degenerative etiology, large and massive rotator cuff tears, decreased bone quality, poor tissue quality, and decreased biologic response and blood supply to the repair site [9, 10, 12–17]. Despite these concerns, work performed in the 1990s and more recently, clearly indicate chronological age and comorbidities are not necessarily contraindications to surgical treatment. Surgical repair has proven to offer patients a significant chance at successful clinical outcomes and increases in quality of life. Unfortunately this concept is not prevalent among many referring providers and even patients. It is our charge as orthopedic surgeons to educate such providers and shift the paradigm to consider physiologic age over chronologic [18–20].

In the following chapter, we will review the current evidence regarding the natural history, pathophysiology, treatment options and treatment outcomes in the management of rotator cuff disease in patients older than 65 years of age.

37.2 Natural History

The large prevalence of rotator cuff tears in patients over the age of 65 years has a significant effect on general public health, with most reports citing between a 22% and 51% prevalence. Further, recent data demonstrate a 78% prevalence of rotator cuff tears in the contralateral asymptomatic shoulder. The study by Yamaguchi et al. informs us patients over 66 years of age have a 50% likelihood of having bilateral rotator cuff tears. Further, symptomatic tears were larger by an average of 30% in size compared to asymptomatic contralateral tears. Orthopedic surgeons are charged with preserving function, mobility, and active lifestyles. It has become clear rotator cuff pathology produces declines in general health and vitality; thus orthopedic surgeons are offered an opportunity to impact the overall health of a significant number of patients [4–7, 9, 10, 21, 22].

It is critical for orthopedic surgeons to have a comprehensive understanding of the natural history of rotator cuff tears in order to determine the most appropriate and effective treatment recommendations. Recent evidence suggests adequate results may be achieved with non-operative management of certain rotator cuff tears. However, it must also be emphasized this research was performed on patients less than 65 years of age with small tears. Additionally, the short-term follow-up of these same studies must be emphasized; only one has a follow-up beyond 12 months [23–26]. Several prominent studies note the increase in prevalence, size, degeneration, and associated symptom development as follow-up increases beyond these short periods. An odds ratio of 2.1 for tear progression was calculated in one such study when follow-up duration is doubled [5, 25, 27].

Tear patterns in the elderly must be understood to be distinct from tears in patients younger than 65 years of age. We will discuss these differences below and their clinical relevance and identify factors to best inform patients on potential treatment outcomes.

Current surgical indications for the treatment of rotator cuff pathology are variable. The most consistently cited indication is failure of conservative management for 3–6 months. The logical basis of early surgical intervention is to maximize the likelihood of a successful repair [28]. Thus we must determine factors identifying patients responsive to non-operative treatment and those in which expedited surgical treatment is warranted to reduce likelihood of failure as tissues degenerate.

Older patients have been noted to present with larger tears, greater tissue degeneration, and higher retear rates with significant interplay among all factors [10, 29–32]. One such study stated patients older than 60 are twice as likely to experience a large tear and three times as likely to experience massive tears [10]. However, despite increased

retear rates, the literature supports successful outcomes with surgical intervention in this age group [33–36]. It is important to note, although results are satisfactory even in the presence of a retear, intact repairs are preferred and produce improved strength consistently across the literature.

37.2.1 Patient Presentation

Consider this common scenario we face in our clinical setting. A 70-year-old avid skier presents after the conclusion of the ski season with persistent and increasing shoulder pain incited by a fall 3 months earlier in the season. His pain is worsened by overhead activities and awakens him at night. As his fall occurred at the beginning of the season, he has only now been referred by his primary care physician. As is common his referring provider told him he is "too old for surgery."

The clinical questions posed are the following: (1) What are the indications for non-operative or operative management for this patient? (2) What is the timeline for surgical intervention to maximize "healability" of the tear if non-operative management is attempted and fails? (3) What clinical signs exist for us to determine if the tear is enlarging and/or tissue is degenerating? (4) Will delay in surgical intervention compromise the result?

It is imperative in this situation we focus not only on the reparability of a likely tear but the "healability" of the tear. Both are crucial for a successful result. Reparability, however, does not necessarily translate to "healability."

37.2.2 Symptomatic Progression

Asymptomatic rotator cuff tears are common in the population over the age of 65 years as determined by several studies investigating both shoulders in patients presenting with shoulder pain [5, 22, 37]. Patients with larger tears at baseline, however, are more likely to develop symptoms. Symptomatic development has been linked to tear progression and tissue degeneration in several studies as will be discussed below.

In the study by Keener et al. of patients with a mean age of 62 years, they noted 49% of patients with previously asymptomatic rotator cuff tears developed pain at a mean of 2.6 years. Development of pain was influenced by tear magnitude with pain developing in 50% and 46% of patients with full and partial thickness tears, respectively, compared to 28% of controls. The onset of pain was highly correlated with tear enlargement. Patients who developed pain had a 1.66× greater prevalence of tear enlargement compared to those who remained pain free [22].

These findings are supported by the study of Moosmayer et al., where 36% of previously asymptomatic patients developed pain. Pain onset was again associated with tear enlargement, although in their cohort onset of pain occurred earlier at a mean of 18 months [38].

Mall et al. determined patients with larger full thickness tears at baseline were more likely to become symptomatic at a mean of 1.93 years. Additionally, the symptomatic group had significant increases in both size and progression from partial to full thickness tears compared to patients who remained asymptomatic. Pain development led to compensatory scapulothoracic motion in early abduction, significant decreases in ASES score by 28 points, and declines in ROM in all planes with the exception of external rotation at 90° of abduction [37].

Keener et al. also demonstrated similar, significant deterioration in ASES and SST scores (by 31.9 and 14.8 points) occurred in nearly all patients who developed pain [22]. Moosmayer et al. also noted significant functional decline with ASES scores deteriorating by 29.4 points and VAS increasing by 3.6 points in the newly symptomatic group compared to 2.6 and 0.3 points, respectively, in the asymptomatic group. Active shoulder abduction and flexion range of motion and strength were also significantly decreased in the newly symptomatic group [38].

Development of pain in a previously asymptomatic shoulder with a known rotator cuff tear should be taken as a sign of tear progression and functional decline. As we will see, tear size has a significant impact on the "healability" of a tear

and treatment management strategies. Thus in patients prone to tissue degeneration and enlargement, i.e., the patient over the age of 65 years with known tears, close clinical follow-up is mandatory. We know risk of tear progression and decline in "healability" grows linearly with duration of follow-up; thus long-term follow-up is recommended.

37.2.3 Tear Progression

The relationship between baseline tear size and increased risk for progression is noted by several authors [22, 25, 28, 38, 39]. Determining in whom and when a tear is likely to progress is a critical component of the clinical course for rotator cuff pathology. Several studies point to the onset of pain as a marker for tear progression; thus we must also understand how rapidly and to what extent tear progression and tissue degeneration is likely to proceed.

Maman et al. determined the rate of progression doubles as follow-up duration doubles. They reason most progressive changes in patients with full thickness tears occur after the first 18 months of follow-up, well beyond short-term follow-up noted in many studies. In their study, progression at 18 months was seen in 12–25%; however, with longer follow-up this increased to 40–60%. These figures correspond to the findings of Yamaguchi et al. in a study with 5.5-year follow-up demonstrating a 40% progression rate [25, 40].

Hebert-Davies et al. determined older patients with larger tears were at significantly higher risk for tear enlargement. The average age of patient with tear enlargement and fatty degeneration progression was 65.8 years at time of enrollment compared to those with stable tears of 61.6 years. Comparing tear grade with enlargement found 67% of full thickness tears enlarged at least 5 mm, which occurred on average 2 years after identification [28].

Tear progression is significantly influenced by baseline size with a 4.2 and 1.5× greater likelihood of tear progression in full thickness and partial thickness tears, respectively, compared to controls as determined by Keener et al. Risk for tear enlargement was greater in the dominant shoulder in this study, a finding repeated in a follow-up study by the same group [41]. The key finding to guide clinicians appears to be the relationship between tear enlargement and pain onset. The mean time to develop pain was 2.6 years in their investigation, while mean time to enlargement was close behind at 2.8 years. These findings are consistent with earlier work by Moosmayer et al. where tear enlargement was more likely in the newly symptomatic group [22, 38].

Recent work by Kim et al. demonstrated a 41.8% overall tear progression rate, again with significantly greater tear progression seen in full versus partial thickness tears. The discrepancy between enlargement rates also significantly progressed as follow-up duration increased. Full thickness tears were found to be the most important risk factor for tear progression [39].

Ample evidence exists to support onset, increase and recurrence of pain are markers for tear progression. A full thickness tear is a key risk factor for tear enlargement in several studies with key time periods of 18–24 months and beyond. For the symptomatic shoulder, several other risk factors must be monitored. In their 2017 investigation, Yamamoto et al. identified tear progression in 47% of shoulders at a mean of 19 months. Key risk factors were medium-sized tears, full thickness tears, and smoking [42]. Interestingly we will see medium-sized tears appear to be a tipping point for both progression and treatment outcomes and thus must be viewed as a "tear at risk" for both.

An additional question is can we derive the size of tear based on symptomatic progression? Some studies say yes. In a large cohort of patients, those with pain had a tear size mean of 22.7 mm compared to 17.4 in those where asymptomatic tears were discovered [5].

Tear progression is significantly associated with muscle degeneration. Thus it is imperative to track the development of clinical symptoms in previously asymptomatic shoulders as these serve as indicators for tear enlargement, tissue

degeneration, and subsequent decline in healing rates for surgical repair [22].

37.2.4 Tissue Degeneration

Several mechanisms are proposed to contribute to tissue degeneration. Tendon retraction in full thickness tears produces changes in muscle pennation angle [43]. Several molecular mechanisms have been postulated to contribute, yet these are beyond the scope of this chapter [44]. Suprascapular neuropathy associated with tendon retraction has also been cited as a cause [45]. What is common among all studies is tear size is associated with increased tissue degeneration. Most importantly, advanced tissue degeneration is a marker of a poor biologic environment and reduced "healability" which compromises outcomes. Several studies note fatty degeneration greater than Goutallier stage 2, and even a more recent study citing degeneration greater than Goutallier stage 1, is a significant risk factor for poor healing of repair. Thus to optimize the "healability" of tendon repair, surgeons must have a strong understanding of tissue degeneration in order to intervene before such a point is reached [14, 30, 34, 46–54].

Melis et al. published a large case series of 1688 patients and identified three key risk factors for tissue degeneration. They include increasing patient age, delay between onset of symptoms and diagnosis, and number of tendons involved. Age was the most reliable predictor. Degenerative tears were more forgiving in that moderate (Goutallier stage 2) fatty infiltration did not appear until an average 4 years after symptom onset with severe stages (Goutallier stages 3 and 4) appearing at 6 years. These numbers are more conservative than those published in more recent, albeit smaller, studies. Traumatic etiology of tears produces a tighter timeline as we will discuss in a following section. Muscular atrophy, as determined by the tangent sign, correlated with degree of fatty infiltration and was more pronounced in tears involving both the infraspinatus and supraspinatus (28%) compared to isolated supraspinatus tears (11%). This pattern continued with the increasing degree of tears, i.e., partial to full thickness, and with involvement of more tendons [55].

In the only study providing prospective data on fatty degeneration progression, Hebert-Davies et al. investigate factors contributing to degeneration. Patients with fatty degeneration were older, more likely to be female, had larger tears at baseline, and had a larger magnitude of tear progression. Tear enlargement remained a risk factor for degeneration independent of age. Degeneration of both the supraspinatus and infraspinatus was the most common presentation, representing 49% of patients with tissue degeneration, compared to isolated tears of the supraspinatus and infraspinatus with rates of 27% and 24%, respectively. Baseline tear size again proved to be a risk factor for tissue degeneration as did tear stability. Tear size greater than 15 mm at baseline and those with enlargement more than 9 mm demonstrated greater tissue degeneration. In tears involving both the supraspinatus and infraspinatus, the median time for fatty degeneration progression of each muscle was 1 and 1.1 years. For isolated tears the timeline was more forgiving for the infraspinatus with fatty degeneration occurring at a median time of 3.1 years but for the supraspinatus remained short at 1.4 years. Involvement of the anterior supraspinatus demonstrated a 53% rate of progression to degeneration compared to 17% with tears in other regions; however, this did not reach statistical significance. Importantly tear enlargement preceded degeneration in the majority of tears going on to degeneration [28]. This may be explained by the larger infraspinatus footprint in more recent investigations. This suggests involvement of both the infraspinatus and supraspinatus is more common than once believed [56]. In tears demonstrating degeneration progression, Goutallier stage advanced at least two grades in many shoulders.

Keener et al. demonstrated a significant increase in muscle degeneration progression as tears enlarge in 8% and 30% of unstable tears involving the infraspinatus and supraspinatus, respectively. They conclude "The progression of muscle degeneration is a very relevant consideration when counseling subjects with an enlarging rotator cuff tear as both factors are

associated with lower rates of tendon healing following surgery." [22]

The investigation by Moosmayer et al. determined increased muscle atrophy and fatty degeneration, as defined by progression from Goutallier stage ≤1 to >1, were also more likely in the newly symptomatic cohort. The newly symptomatic group had an odds ratio of 13.1 for the progression of fatty degeneration. Additionally they calculated a 7.5 odds ratio for long head of the biceps tendon pathology in those with new onset of symptoms. They conclude while not all asymptomatic full thickness tears develop symptoms, those that do show a higher rate of structural deterioration [38].

37.2.5 Tear Location

Tear location has also been implicated as a risk factor for fatty muscle degeneration. Work by Mochizuki et al. in 2008 presented a modern perspective to the rotator cuff footprint anatomy. Traditionally the supraspinatus insertion occupied the majority of the highest impression of greater tuberosity, and the infraspinatus insertion was limited to the middle impression. However, the traditional view of this anatomy does not explain the common clinical observation of infraspinatus degeneration in the presence of what are perceived to be isolated supraspinatus tears. Cheung et al. published this observation in 2010 noting severity of supraspinatus tear correlated with fatty infiltration of the infraspinatus even when there was no perceived infraspinatus tear [45]. The findings of Mochizuki may provide insight into this process where the supraspinatus footprint was found to be smaller than previously described and the infraspinatus extended further anteriorly on the greater tuberosity. Thus, significantly greater overlap, as proposed earlier by Minagawa and Clark, of the supraspinatus and infraspinatus insertions may exist [56–58]. Given this evidence, previously thought to be isolated supraspinatus tears are more likely to involve the infraspinatus as well.

Kim et al. demonstrated full thickness tears involving the anterior aspect of the supraspinatus tendon were especially at risk for tissue degeneration. They conclude tears that do not involve the anterior supraspinatus insertion are 96% less likely to develop fatty degeneration. They advocate for earlier surgical intervention for full thickness tears involving this region to prevent such fatty degeneration. These findings corroborate those of more recent investigations [59]. Namdari et al. conclude disruption of the anterior supraspinatus tendon also was associated with greater tear size and more pronounced tissue degeneration [60]. Hebert-Davies et al. determined a threefold increased risk for fatty degeneration development existed for tears involving the anterior insertion of the supraspinatus when compared to tears that enlarged yet spared this region [28]. The increased risk for degeneration and enlargement for tears involving this area may be explained by the anatomic evidence presented above and can assist the clinician in determining the appropriate monitoring and treatment protocols for such patients.

37.2.6 Tear Etiology

It is known that degenerative tears in older populations are typically larger with lower quality tissue. The clinician must also be aware that patients in this demographic with a traumatic tear etiology are at an increased risk of sustaining large and massive tears [61]. Trauma may amplify the injury to tissue more likely to be less robust and resistant to insult. Traumatic tears have a different timeline to degeneration and thus must be managed with a different strategy. Unlike degenerative tears, the onset of a traumatic tear can be accurately determined. Such tears are noted to more rapidly develop degeneration in several studies [52, 55]. Thus, it is our view traumatic tears in this population are less likely to respond to non-operative measures and thus a more aggressive evaluation (e.g., MRI) and shorter timeline to operative intervention may be warranted.

37.2.7 Summary

In conclusion, patients older than 65 years of age are more likely to sustain larger tears at baseline and are at increased risk for tear progression and tissue degeneration. However, we must not confuse chronologic with physiologic age. The biology of the healing environment must be optimized in order to maximize repair "healability." Close clinical monitoring of patients with rotator cuff tears can provide significant information as to the status of the tear. Full thickness tears, tear size greater than 15–20 mm and location involving the anterior aspect of the supraspinatus, and, based on recent anatomic evidence, infraspinatus tendons represent tears at risk for progression and degeneration. Pain onset, or recurrence, is a reliable marker for tear progression and thus, tissue degeneration. Tissue degeneration closely follows tear progression, and timelines for both have been noted to be from 18 to 24 months after symptom onset or recurrence. Close clinical monitoring is warranted in such situations such that intervention can be offered before biologic deterioration compromises outcomes. Further, traumatic tears follow a more accelerated timeline to degeneration, and thus more rapid intervention is often warranted.

37.3 Non-operative Management

Non-operative management is a reasonable first approach in the majority of patients with degenerative, atraumatic rotator cuff tears with wide ranges of success published. Below we discuss the recent literature pertaining to degenerative rotator cuff tear non-operative management in the context of the natural history.

Non-operative management success rates in all patients are quoted with a wide range between 53% and 80% [62–64]. Determining patients which will respond to non-operative management is vital to both surgeons and patients. These factors may help better inform patient counseling, treatment strategy, patient satisfaction, economic impact, and ultimate outcomes.

As discussed previously, the natural history of degenerative rotator cuff tears from identification to progression, as marked by pain onset or symptom recurrence, can take 1.5–3 years [22, 28, 38, 42]. Pain onset is a reliable marker for tear progression, with larger tears at an increased risk of progression [42]. Further, tear progression is associated with increased tissue degeneration and thus decreased healing rates [22]. Moving forward the challenge to optimize patient outcomes and satisfaction, we must identify those factors which identify patients who will respond to non-operative management and those in whom early surgical intervention may produce superior results.

One author states, "Patients with well-preserved function of the supraspinatus and infraspinatus are the best candidates for conservative treatment." [62] However, anatomic factors do not exist in isolation. Dunn et al. highlight the importance of nonstructural and nonclinical factors in determining surgical candidacy. In their analysis of 433 patients with a median age of 62 years, they determined low patient expectation regarding the benefits of physical therapy to be the strongest predictor for non-operative treatment failure. Logically non-smokers and more active patients were also more likely to proceed with surgery. Perhaps the most important findings in this report were those factors not associated with progression to surgery. Neither tear size, retraction magnitude of tear, pain, nor weakness were predictors of progression to surgery. Further they found patients who failed rehabilitation and went on to surgery did so within 12 weeks; those who avoided surgery for greater than 12 weeks were unlikely to go onto surgery at the final 2-year follow-up. This finding suggests surgical treatment especially if no improvements are seen after 12 weeks should be considered.

Henn et al. looked at similar expectations relating to outcomes of surgical repair. They analyzed the expectations of 125 patients undergoing rotator cuff repair in addition to demographics, symptom duration, prior treatment, comorbidities, tear characteristics, and repair technique in relation to patient-reported outcomes. Although

this patient cohort was younger, average age at time of surgery was 56.2 years, their results demonstrated superior self-assessed results on all measures in those patients with more optimistic expectations [65].

The interplay between patient expectation and results is powerful. Reimbursement for our services is becoming increasingly linked to patient satisfaction; thus patient expectations must be linked to our treatment plans. Such reports justify including nonstructural and nonclinical parameters, e.g., the SANE rating, into discussions evaluating for non-operative and operative candidacy [66].

Tanaka et al. analyzed 128 patients with symptomatic full thickness rotator cuff tears managed non-operatively for factors predicting non-operative treatment success. They demonstrated a success rate of 52.8% for conservative management with an average age of 68 years. Conversion to surgery occurred after failure of no less than 3 months conservative management in the remaining 47.2% with an average age of 67 years. Four factors significantly associated with successful conservative management were identified: passive external rotation greater or equal to 52°, negative impingement sign, supraspinatus occupancy ratio exceeding 78%, and an intact intramuscular supraspinatus tendon. If a patient exhibited three of the four factors, they had an 87% success rate with non-operative management. Further, those patients with acute tears (traumatic origin) exhibiting all four factors above responded well to conservative management [63].

Conservative management may be effective in a large proportion of patients; however, symptom recurrence may imply tear progression and further tissue degeneration. Therefore, when managing patients non-operatively, one must pay careful attention to the responsiveness to treatment and symptom recurrence [62]. These patients must be closely monitored during this period and instructed to follow-up if symptoms fail to improve or worsen. Even in those with initial success with non-operative management, annual follow-up has been recommended [42, 67]. Also, patients who are protective of their shoulder may not volunteer complaints of pain, and thus, the surgeon must be diligent in their questioning of symptoms.

Boorman et al. further demonstrate that durable results can be achieved with conservative management of small, full thickness rotator cuff tears in a study including 93 patients with an average age of 60 years at diagnosis. They achieved 75% successful results as judged by conversion to surgery. They reported only three patients converting to surgical treatment throughout the study period. Most importantly, outcomes as measured by the rotator cuff quality of life index demonstrate durable results in the non-operatively managed group without signs of deterioration at a 5-year follow-up [67].

In a 2018 meta-analysis of Level I and Level II evidence, Piper et al. compare operative to non-operative management; only three studies met inclusion criteria. These papers reviewed 269 patients with only a 1-year follow-up. Statistically significant improvements were noted in the operative group in both Constant scores and Visual Analog Scale scores. However, the differences failed to meet published minimal clinically important differences of the Constant and Visual Analog scores [23, 68, 69].

Heerspink et al. performed a randomized controlled trial of 56 patients comparing mini-open surgical repair with conservative treatment for degenerative rotator cuff tears with a 1-year follow-up. Of note the study enrollment was terminated early resulting in a significantly smaller study population. Additionally only 20 of the 25 planned surgical patients underwent final analysis; in 30% of these, a side-to-side repair only was performed, suggesting these were small tears. The conservative management group experienced similar attrition with only 25 of 31 patients undergoing final analysis. Their results demonstrate a trend toward improved Constant-Murley score and statistically significant VAS pain and VAS disability scores in the surgical group. Neither parameter reached accepted minimal clinically important differences as outlined above. They noted a significant difference in improvement in the Dutch Simple Shoulder Tear and VAS pain parameters between surgical and conservatively managed patients. Given the high reported retear

rate at 1 year of 73.7%, a subgroup analysis was performed. In the intact repair group, a statistically significant improvement exceeding MCIDs in CMS, VAS pain, and VAS disability favored the surgical group. This study exemplifies the difficulty in orthopedic research where enrollment was limited by patient expectations as they were referred for surgical intervention and conservative management beginning prior to initial consultation. Unfortunately, the resulting small sample size reduces the impact of an otherwise well-performed study [26].

Kukkonen et al. performed a well-designed randomized controlled trial of 167 patients with degenerative, small (<10 mm), isolated supraspinatus tears comparing physiotherapy alone, physiotherapy and acromioplasty alone, and physiotherapy and rotator cuff repair. Per intent-to-treat outcome, the Constant score failed to reach minimal clinically important differences between groups at a 2-year follow-up. The pain sub-score did favor the surgical groups at final follow-up. At 2 years the surgical group had a significant decrease in tear size. However, analysis of atrophy and Goutallier stage did not reveal differences between groups. Of note, a high prevalence of osteoarthritis, 38–42% at baseline and 57–65% at final follow-up, existed among all groups, and 9% of nonsurgical patients crossed over to surgical repair. This examination does well to inform treatment options for the small, isolated degenerative supraspinatus tear. Non-operative management had a high success rate, and no significant advantage was demonstrated in the surgical groups, supporting conservative management for small, isolated, degenerative tears [24]. However the tear size is not representative of all degenerative tears in older patient cohorts which are noted to be larger, of poorer tissue quality, and thus more likely to progress [22, 25, 28, 42, 70]. Although the crossover rate from nonsurgical to surgical groups was lower than earlier studies, an as-treated analysis would be informative.

An earlier randomized controlled trial by Moosmayer et al. compared non-operative and operative treatment of small- to medium-sized rotator cuff tears in 103 patients with a slightly younger average age of 61 and 59 years, respectively. The mean improvement in VAS pain, Constant scores and ASES between groups favored the surgical group and reached both statistically significant and minimal clinically important differences at 12-month (final) follow-up. Patient satisfaction was also found to be higher in the surgical group. Nine patients in the conservative group underwent surgical repair [71].

The evidence comparing non-operative and operative treatment is conflicting on the surface. Further analysis, however, reveals informative trends. First, the management of patient expectations can greatly assist with developing treatment strategies. When discussing treatment options with patients, it is important to create a team atmosphere along with physiotherapists and gauge patient beliefs regarding effectiveness of treatment. This collaboration can impact patient outcomes and satisfaction. Second, non-operative management has acceptable and durable success rates in the properly selected patients. The parameters set forth by Tanaka et al. are excellent starting blocks to assess the viability of non-operative treatment. For patients with small rotator cuff tears exhibiting at least three of the four factors outlined above, literature supports likely success with non-operative management, and this should be pursued until results deteriorate below acceptable levels to the patient. Finally, much attention has been recently placed on randomized trials comparing non-operative to operative management of degenerative rotator cuff tears. The evidence to support physical therapy over surgical intervention in all patients is inadequate. The study by Kukkonen et al., while adequately powered, analyzed only small tears isolated to the supraspinatus, excluding the larger multi-tendon tears more common to older patient populations. In the well-designed study by Heerspink et al., few conclusions can be made due to varying surgical techniques, high retear rate, and limited enrollment. It should be noted, however, that trends in Constant score and statistically significant improvements in VAS pain and disability scores and Dutch Simple Shoulder Test favoring the surgical group were noted despite these limitations. The final randomized trial by

Moosmayer et al. did demonstrate improvements in Constant, ASES, and VAS pain scores which were both statistically significant and exceed published minimal clinically important differences favoring the surgical group. Importantly the duration of follow-up must be taken in to consideration. Functional and strength gains are noted to extend beyond the common 1 year time point used in studies [72].

Evidence suggests successful, durable outcomes can be produced with non-operative management in the properly selected patient. However, such literature often fails to provide details pertaining to patient activity levels and tissue quality and mostly exclude patients with subscapularis tears. It is our experience the prevalence of subscapularis tears is quite high. Subscapularis involvement may dramatically affect the ability to maintain appropriate force couples and impact the success of non-operative management. Several high-level evidence meta-analyses comparing operative to non-operative management have been completed recently on this matter.

"In summary", the available evidence does well to inform treatment of degenerative rotator cuff tears. Non-operative management of small, isolated tears can be performed with a likely successful result and should be pursued as a primary intervention in the majority of patients. If patients fulfill the criteria set forth by Tanaka et al., an increased likelihood of success can be anticipated. Careful scrutiny of the literature does not support the claim that no difference exists in non-operative and operative management of all patients with rotator cuff tears. One must take a global view of individual patient characteristics, treatment strategies, and goals.

37.4 Surgical Management

Debates persist regarding the ideal surgical technique for rotator cuff repair; therefore, we will limit the following discussion to the literature examining large to massive tears with poor tissue quality. Degenerative tears have often been shown to be larger, of lesser quality tissue, and exhibit more retraction with higher retear rates. Thus we will focus on recent literature pertaining to techniques for repair of large or massive rotator cuff tears, specifically those comparing traditional single-row and unlinked double-row techniques to modern transosseous equivalent or double-row linked compression techniques.

37.4.1 Single vs. Double Row Repair

Prior literature has demonstrated debridement alone leads to inferior outcomes compared to repair and may lead to progression of glenohumeral arthritis [19, 73–76]. Repair techniques should aim to restore the anatomic footprint in a tension-free manner to create the most durable construct possible. Complete repair of large and massive rotator cuff tears can be reliably achieved in up to 80% of tears [77]. Compared to single-row (SR) techniques, double-row (DR) repairs have the potential advantages in restoration of anatomic footprint and biomechanical superiority [78–80]. Earlier studies analyzing unlinked DR repairs concluded no clinical advantage was gained over SR techniques. However, the DR repairs in these studies used non-linked sutures tied with no compression of the repaired footprint [81–83]. Recent reviews and meta-analyses include these same studies using non-linked DR techniques repeating the conclusion no clinical advantage is conferred by DR techniques. These reviews and meta-analyses do, however, consistently report improved tendon healing and retear rates using DR techniques, especially in large tears [84–86]. Current techniques use a transosseous equivalent (TOE) repair with wider fiber and suture tapes with footprint compression. Thus, many prior study conclusions may not apply to the surgical techniques used today.

Denard et al. demonstrated clinical advantages can be gained with non-linked repair techniques as used in older studies referenced above when repairing massive tears. Multivariate analysis concluded double-row repair is 4.9 times more likely to produce a good or excellent functional outcome by the UCLA score. Perhaps one of the most important conclusions from this study is the ability to mobilize tendon tissue using advanced

techniques, i.e., interval slide release, may be critical to a successful repair. They conclude a DR repair is preferred when sufficient tendon mobility can be achieved [87]. When analyzing results by tear size, DR repair demonstrated superior, durable, clinical results in several other studies during the same time period in tears greater than 3 cm [88, 89]. A meta-analysis by Xu et al. in 2014 supported the above findings for tears greater than 3 cm in size. Improved overall ASES scores, retear rates, and internal rotation were found for the DR repair groups. Clinical outcomes for DR repair were superior to single row in tears greater than 3 cm in size [90].

Recent studies comparing SR repairs with modern TOE techniques demonstrate advantages exist for TOE repairs, especially in large tears. Functional outcomes have been noted to be improved for TOE repairs compared to SR repairs [91]. Significantly decreased retears and improved healing rates using TOE or DR compression repair techniques (e.g., Suture Bridge) for large tears have been demonstrated in multiple studies [91–93]. Improved healing has also been noted in smaller tears using TOE techniques, although the advantage is of smaller magnitude [93, 94].

37.4.2 The Irreparable Tear: Partial Repair

For large and massive rotator cuff tears which cannot be completely repaired due to poor tissue quality and excessive retraction, surgical management options remain. The classic article by Burkhart et al. demonstrates complete defect coverage was not essential for patient satisfaction and good clinical outcome. If normal mechanics and restoration of force couple balancing can be achieved, improvements in strength, ROM and UCLA scores can be dramatically improved even with persistent defects [95]. Similar improvements were seen in more recent papers using the validated RC-QOL, Constant-Murley Score, ASES, VAS, and Simple Shoulder Test. Patients with lower functional scores, night pain, and higher VAS score achieved greater functional improvements from surgical intervention [76, 96, 97].

37.4.3 Superior Capsule Reconstruction

In a recent publication, disruption of the superior capsule has been considered one of the essential lesions in rotator cuff pathology. As described by Adams et al., the rotator cable attachments are superior capsular thickenings, and the superior capsule is confluent with the undersurface of the superior cuff. Thus the integrity of the capsule is linked to that of the cuff and becomes essential for normal shoulder biomechanics and kinematics. Further, they conclude the superior capsule is the primary restraint to proximal humeral head migration and responsible for providing a stable fulcrum for shoulder biomechanics. Large and massive rotator cuff tears represent complete disruption of rotator cuff tendons and the underlying superior capsule. In small and medium tears, capsular integrity may still be preserved. Thus in larger tears with the disruption of the superior capsule, such restraint is lost. Linked double-row repair techniques can repair both the cuff and the capsule and may help explain recent data that has demonstrated superior outcomes over single-row repairs [98].

Since Mihata et al. in 2013 demonstrated superior capsule reconstruction (SCR) restored superior stability of the glenohumeral joint, the procedure has gained immense popularity for the management of “irreparable” (unhealable) rotator cuff tears [99]. Early studies have reported significant and durable functional gains for those with massive irreparable tears, reversal of pseudoparalysis, and reliable increases in acromiohumeral interval distance [100, 101]. More recent studies support these significant improvements in VAS, ASES, and ROM in the majority of patients [102].

Return to recreational activities, including overhead sports, is a common goal of many patients. In cases of massive, irreparable rotator cuff tears prior to the introduction of superior capsular reconstruction, treatment options for many patient were limited to “live with it,” debridement, or shoulder arthroplasty [103]. SCR has been demonstrated to reliably return patients to the same pre-injury level of physical work and sport participation in one recent

study. Interestingly, those who participated in sports prior to injury demonstrated increased gains in active elevation and ASES score without increases in graft tear rates compared to patients who did not participate in sports [104].

Orthopedics is a specialty in which new, often sexy, surgical techniques should be used with caution. Until long-term outcome data and proper indications are established, surgeons must use caution in performing such procedures. Recent literature provides clarification of indications and technical pearls. A significant decline in results is seen in patients with Hamada rotator cuff arthropathy grade 3 and above; thus SCR is recommended in patients with Hamada 1 or 2 only. Adequate deltoid function has consistently been reported to be necessary for SCR candidacy. The subscapularis is important for restoration of force couples, and thus if the subscapularis is torn and irreparable, SCR is best avoided. Pseudoparalysis is not a contraindication to SCR, rather it has the potential to be improved. Advanced Goutallier staging does not necessarily preclude a good outcome. However, patients with Hamada stages ≥3 have been shown to have decreased rates of success. Technical pearls include the use of three independent anchors medially on the glenoid, a transosseous equivalent repair laterally and grafts thickness ≥8 mm [102, 105–107]. Several excellent technical articles have been published recently describing additional pearls including: circumferential cerclage suture around the graft to prevent cut out, graft pretensioning, attaching the graft in approximately 15–45° of shoulder abduction and using the expansion bridge technique humeral head (three anchors medially and three anchors laterally) [101, 106, 108].

37.4.4 A Word on the Subscapularis

Review of the literature has demonstrated a high rate of subscapularis tears. "You may not have seen it, but it has seen you" [109]. In our experience subscapularis tears are common, and certain intraoperative maneuvers are needed to properly diagnosis them. The over the top view from the anterolateral portal, or use of a 70° scope from the posterior viewing portal, in combination with internal rotation and a posterior translation of the humerus maneuver or "posterior lever," can significantly enhance the recognition and diagnosis of subscapularis pathology [110].

A recent study with 10-year follow-up concludes healed subscapularis repairs, results in a greater degree of successful supraspinatus repairs. It was demonstrated that repairs of tears limited to the upper third portion of the subscapularis have improved outcomes and are associated with less fatty infiltration than those extending into the inferior and more muscular components [111]. These long-term results reinforce prior work demonstrating the importance of re-establishing force couples in preventing joint imbalance which can lead to further tendinous and cartilage degeneration. Force couple restoration has also been demonstrated to improve shoulder function in animal models [112, 113].

37.4.5 Double-Row Repair May Be More Cost-Effective

DR repairs are more expensive initially and thus may be avoided in cost sensitive settings such as independent surgery centers. A recent study by Huang et al. concludes that although initial cost of DR repairs is indeed higher, DR techniques are more cost-effective in the long term than SR. A further economic advantage is gained when using DR repair techniques in rotator cuff tears equal to or greater than 3 cm in size [114].

37.4.6 Key Points

1. Recent literature supports the use of double-row techniques when managing large and massive tears.
2. Improved healing rates and clinical outcomes are reported when double-row techniques are used in large and massive tears.
3. Maximizing tendon mobility is crucial for repair success.
4. Partial repair, if able to restore force couple balance, is a viable option producing good

results when complete repair cannot be achieved.
5. Superior capsular reconstruction is supported by the literature with an increasing amount of studies demonstrating excellent clinical and functional outcomes with reliable return to activity.
6. SCR may be more successful with Hamada Grade 2 or less; pseudoparalysis may be reversed; Hamada grades 3 and 4 are not absolute contraindications but have less predictability in outcome.
7. Double-row repair may be more cost-effective, especially in tears greater than 3 cm in size.

37.5 Surgical Outcomes

As recently as 1998, rotator cuff repair was discouraged in the patient older than 65 years. With the advent of new technology, new techniques and a better understanding of the natural history of degenerative tears multiple studies have demonstrated superior results for repair compared to non-operative and limited operative management of the properly selected patient. As is apparent in these studies, the ability of a repaired tear to heal is the most impactful on patient-reported outcomes [18, 20, 30, 33, 115]. One study concludes, "tendon healing is the main determinant of outcomes after rotator cuff repair" [33]. Evidence provided by Fehringer et al. demonstrate a healed rotator cuff repair can impart comparable shoulder function to age-matched individuals with intact rotator cuffs [115].

Reported healing rates vary widely from 13.3% to 88% [7, 18, 26, 30, 33, 34, 48, 115, 116]. Determining factors with causal relationships to tear "healability" is crucial. While no conclusive evidence exists, the commonly cited factors include tear size, fatty degeneration, overall tissue quality, patient age, and bone quality [30]. It is the opinion of the authors that age alone may not be the best predictor of outcome. Therefore looking solely at age may be too simplistic in decision-making regarding non-operative versus operative treatment. Additionally, chronologic age has become less important than combining physiologic age with activity level in making treatment decisions.

Degenerative tears encountered in patients over the age of 60 are more likely to be larger with poor tissue quality [10, 15, 30, 40, 61, 70]. Thus, it is no surprise recent prospective trials fail to demonstrate a difference between operative and non-operative management in small tears. While tear characteristics in these studies may not be representative of degenerative tears in which surgical intervention is beneficial, they identify tears more likely to benefit from non-operative treatment [23, 24, 26, 71, 117]. Existing studies demonstrate significant improvements in pain, quality of life, and functional outcomes after surgical repair of degenerative tears. However, this is not a widespread belief in the referral physician population as patients are often told they are not surgical candidates due to their age by nonsurgical professionals. It is our duty to determine those patients and tear characteristics to which modern evidence applies. The discussion below focuses on literature published in the last 10 years to provide the most relevant support for contemporary practice.

37.5.1 Surgical Outcomes in Patients Over 65

Several papers support surgical candidacy is not impacted by comorbidities nor age [3, 118]. Further, successful surgical outcomes of patients over the age of 65 years compared to those under 65 years are similar. Osti et al. performed a comparative analysis addressing such an issue. At minimum 2-year follow-up, both groups exhibited significant improvements in the modified UCLA score, range of motion, and SF-36 scores. This study included predominantly medium and large tears with up to 36% of tears involving both the supraspinatus and the infraspinatus. The evidence does not support age cutoffs for surgical candidacy. Rather, favorable surgical outcomes are consistently reported in the appropriately selected patient regardless of age.

A recent systematic review by Silva et al. asks the questions, "Is it really worthwhile to surgically repair rotator cuff tears in patients of 65 years and above?" and "Is there improvement of functional outcome despite worse tendon and bone quality?". Their conclusion is in the affirmative to both. The review includes predominantly level IV evidence with varied clinical outcome scores used, yet the outcomes consistently produce clinically significant improvements in function, pain, and quality of life compared to preoperative levels [35].

A randomized trial by Jacquot et al. analyzed outcomes in a patient cohort with degenerative rotator cuff tears treated with repair compared to acromioplasty and biceps tenotomy alone. The overall average patient age was 68 years. No difference in preoperative Constant score nor activity level was found between groups. While functional outcome at a final 4-year follow-up favored the repair group statistically, it did not exceed MCID established for the Constant score. However, when analyzing for tear size, those with intermediate and retracted tears and healed repairs demonstrated improvements exceeding MCIDs. Additionally, the repair group had significantly less progression to rotator cuff arthropathy as determined by eccentric humeral head position and acromiohumeral interval. They concluded the low complication rate, 4%, high patient satisfaction, and superior clinical results in the healed repair groups strongly support tendon repair in active patients. They reiterate the importance of identifying factors associated with tendon healability to maximize outcomes [33].

In a case series of 58 patients older than 65 years, Djahangiri et al. report significant improvement in Constant scores, range of motion, strength, and satisfaction after repair of isolated supraspinatus tears. They report a healing rate of 70% with a 93% satisfaction rate. As noted in other reports, those without healed tendon repairs had smaller improvements in Constant scores, strength, and pain reduction. Importantly they note preoperative Constant score was not associated with repair healing. They conclude the beliefs that patients older than 65 years have decreased ability to heal repairs and are not surgical candidates are not supported by available evidence. Further, the surgical repair of single tendon tears with fatty infiltration less than Goutallier stage II is a highly successful procedure [34].

Charousset et al. examined a cohort with mean age of 70 years after arthroscopic rotator cuff repair. Those with glenohumeral arthritis and Goutallier stage 3 or 4 fatty infiltration were excluded. The predominant tear type was isolated supraspinatus in 49%, yet the remainder consisted of multi-tendon involvement. Postoperative Constant and Simple Shoulder Test scores both improved beyond accepted MCIDs for both measures. Full retear rate was 42%, with partial retears in 24.7% and healed repairs in 33.3%. Analysis of outcomes showed significantly decreased Constant scores in those with full retears; however, Constant score improvements were retained in partial retears and were not statistically different than outcomes in healed repair patients [30].

Fehringer sought to determine the relative shoulder function of patients over 65 years undergoing surgical compare compared to an age-matched cohort. Patients who can achieve rotator cuff repair healing demonstrate comparable shoulder function to their age-matched pairs with intact rotator cuffs. Clinically significant improvements, as measured by the Constant score and Simple Shoulder Test, were demonstrated in those with repaired tears compared to patients with unrepaired tears. While significant improvements can still be expected in the patient without repair healing, these are not as pronounced as those with healed repairs [115].

37.5.2 Do Results Deteriorate with Age?

Further questions remain regarding the candidacy of patients as they advance beyond the age of 70. Soon after the investigation led by Flurin, results of arthroscopic repair of full thickness rotator cuff repairs in patients older than 70 years were compared to age-matched controls. Verma et al. analyzed the results of 39 such patients with mean 36.1-month follow-up. As with many stud-

ies patients with tears of the subscapularis, irreparable tears and Goutallier stages 3 and 4 fatty infiltration were excluded. The mean tear size was 3.24 cm in the anterior-posterior dimension with the majority being medium (48.7%) and large/massive tears (17.9%). Significant improvements were noted in all measures. Mean ASES score improvement was 41.7 points leading to a final mean score of 87.5. Pain as measured by VAS improved from 4.6 preoperatively to 0.5 postoperatively. Simple Shoulder Test scores improved from 3.9 to 9.8. Patient satisfaction averaged 94.3%. Most importantly, mean age- and sex-matched normalized Constant scores ranged from 81.7% to 88.8% in female patients and 88.3% to 97.2% in males [36].

Flurin et al. performed a randomized controlled trial comparing simple subacromial decompression with decompression and rotator cuff repair in 154 patients with an average age of 74.6 years. Tears in this investigation were predominantly small to medium full thickness involving the supraspinatus with or without infraspinatus extension. The repair group demonstrated statistical significance in Constant score, ASES, and Simple Shoulder Test scores. While both groups gained significant improvements exceeding MCIDs compared to baseline, the between group difference failed to surpass such thresholds. Interestingly, however, the gap in improvements gained in the repair cohort older than 75 years continued to grow. Subgroup analysis demonstrated the differential gains were also greater in the repair group for more retracted tears. Tears with increased fatty degeneration improved in both Constant and ASES outcomes; however, the difference between repair and decompression diminished as fatty infiltration reached higher stages. The evidence presented demonstrate gains in surgical intervention for degenerative tears in patients of further advanced age are significant and durable [18].

Robinson et al. analyzed 61 patients over the age of 70 with full thickness tears failing nonoperative management. The majority of patients had large or massive tears. A retear rate of 32% was reported which was correlated with increasing size of tear. Functional improvements were clinically significant in both healed and retear groups, although as seen in other studies, gains in the healed group significantly surpassed those of the retear group. Interestingly they determined male patients fared better than their female counterparts. In their multivariate analysis, male shoulders were noted to have a 1-year score average 15.5 points greater than female patients [7].

Miyazaki et al. reviewed the results of 168 shoulders with a mean age of 71 years. Using the UCLA score, they found a 96.4% rate of excellent (80.4%) and good (16%) outcomes. More importantly the results did not deteriorate with advancing age. As demonstrated in prior work, only a minority of tears in this elderly cohort were small in size, 16%. The majority were medium or larger with 26.4% medium, 15.3% large, and 42.3% extensive—involving two or more tendons. Although past papers produced mixed results on the impact of duration of symptoms and outcome, they concluded delay in treatment was associated with declining results [61].

In a more recent case series, Jung et al. evaluated rotator cuff repair of large to massive tears in a population older than 75 years. Although the study is without a control group, significant improvement in functional outcomes and pain was again seen in an even older patient population. Clinically significant improvement in Constant score, ASES, and VAS were again demonstrated at mean 30-month follow-up. Healing rate was reported at 74% and over 70% of patients achieved an ASES score >80. Those with retears continued to gain significant improvement, although less than the intact group. They were not deemed statistically significant from those with intact repairs. As seen in prior studies, patients with retears demonstrated strength deficits in external rotation and of the supraspinatus. The above study does well to demonstrate excellent results can be achieved by repairing this subset of tears [116].

37.5.3 Return to Activity

Maintenance of an active lifestyle has become a key treatment goal in the contemporary patient of advanced age. As noted, patients are engag-

ing in recreational activities further into life than ever before. These patients are less concerned with simply performing ADLs but rather aim to continue participation in recreational endeavors. With younger athletes we focus on return to sport as a key determinant of treatment success, so too must we apply this criteria to the modern older patient.

Return to recreational sport can be achieved with reliable success in the older patient undergoing rotator cuff repair. Bhatia et al. analyzed 44 patients with a mean age of 73 with full thickness tears predominantly of the supraspinatus; however, nearly half of the cohort exhibited multi-tendon involvement. Tissue quality was predominantly Goutallier stages 0 and 1, but stage 2 patients were included albeit a significant minority. Functional and subjective outcomes, as measured by ASES, SANE, and VAS scores, all improved significantly. Return to sport at preinjury levels was achieved in 77% of patients, with average postoperative ASES, SANE, QuickDASH, and SF-12 physical component scores of 90.3, 85.1, 11.3, and 51.6 at a mean 3.6-year follow-up. All established MCIDs were surpassed. The evidence supports the use of surgical rotator cuff repair in the recreational athlete regardless of age. Durable and clinically significant improvements were achieved not only in self-reported functional outcome parameters but also in general health [9].

37.5.4 Results Improve Beyond One Year

Often studies conclude at 1 year; some even earlier. However, can we definitively say further improvement does not occur after these seemingly short periods? A study by Nho et al. says we cannot. Both healing percentage and clinical outcomes continued to improve beyond these short time periods. Healing rates as determined by ultrasound were 64% at 3 months and 1 year, increasing to 75% at 2 years. Clinical outcomes followed a similar trend. Average ASES scores continued to climb from 84.88 at 1 year to 92.65 2 years [119].

37.5.5 Summary

Review of surgical outcome literature supports surgical treatment of rotator cuff tears in patients over the age of 65 years. Exclusion from surgical intervention based solely on age and comorbidities is not supported by the literature and should be refuted. The single most impactful predictor of surgical success is repair healing. Preoperative shoulder function as measured by patient reported outcome surveys does not predict repair healing. While healed repairs produce universally superior outcomes, patients with only partial retears can expect results similar to those with intact repairs. Advancing age does not result in deterioration of results, and reliably high rates of return to recreational activities is possible. Beyond shoulder-specific functional gains, general health improvements have been demonstrated with rotator cuff repair. Finally, it is common practice to exclude patients with subscapularis tears from these investigations. It is the opinion of the authors this is a mistake. Subscapularis tears are an under-recognized pathology. The identification and treatment of subscapularis tears assist in force couple balance restoration and have the potential to further improve surgical success. This is supported by recent long-term evidence demonstrating inferior outcomes in patients with concomitant full thickness subscapularis tears, and increased healing rates can be expected with successful subscapularis repair [111].

37.6 Retear Factors

Surgical repair of degenerative rotator cuff tears in the aging population has been demonstrated to provide significant improvements in functional outcomes and patient satisfaction. Clinically significant improvements are seen even when repair fails to heal, yet healed repairs produce superior outcome consistently across all studies [120]. Treatment protocols may be altered based on identification of risk factors for tendon healing. Early surgical intervention to prevent tissue degeneration may be recommended in which different surgical techniques may be employed and more conservative approaches for others.

Age has long been identified as a risk factor for repair failure and thus has traditionally been used as an excuse to avoid surgical treatment for those of advanced age. We have seen surgical intervention be successful even with a history of previous surgical failure. Revision surgery may potentially provide functional improvements for these patients. In agreement with several investigators, it is the opinion of the authors that chronological age is not itself an independent risk factor for failure [32, 121]. While this can make surgical intervention more challenging, it is not a valid reason to deprive a patient population of an intervention proven successful in the literature. Further it is also not carte blanche support for surgical intervention in all patients. Careful patient selection is mandatory as with any surgical treatment.

37.6.1 Tear Size and Age

A recent current concepts review outlines various factors associated with rotator cuff tendon healing. Whether it be measured by tear dimensions or tendon involvement, tear size is consistently associated with healing. Size is not the only component; we must consider the healing environment, bone quality, patient comorbidities, social history, and tissue quality [121]. As age and tear size have often been shown to be linked, we will discuss them together.

In a large cohort study involving 1600 patients, Diebold et al. demonstrated a positive correlation between age and retear in degenerative rotator cuff tears addressed with single-row repair. For those patients less than 50 years, retear was very low at 5%; however, it increased to 15% in patients in their seventh decade of life, to 25% in their eighth, and to 34% in patients over 80 years of age. Other characteristics in the retear group included an average age of 65 years in the retear group, full thickness tears averaging 7.57 cm^2, and average anteroposterior size 2.8 cm and 2.3 cm mediolaterally [29]. Similar findings were demonstrated by Chung et al. where the average age and size of the initial tear in the retear group were 65 years and 2.77 cm in the anteroposterior dimension [14].

Park et al. provided additional information regarding several factors associated with decreased healing. They analyzed 339 patients undergoing repairs of small- to medium-sized tears. Single-row techniques were used for small tears and double row for medium tears and those with poor tissue quality. They identified a cutoff of 69 years and tear size of 2 cm in the anteroposterior dimension as inflection points for risk of decreased healing. They suggest tear size of 2 cm to be the critical size for healing and recommend repair prior to this size being reached [48].

Similar trends were noted by Rhee et al. They report retear rates of 39.8% and 51.1% in patients in their seventh and eighth decade of life, respectively. No statistical significance was found between the two groups. As with other studies, they noted a significant increase in retear rates based on intraoperatively determined tear size. Odds ratio for retear was 7.1 in large tears and 17.2 in massive tears. They conclude significantly increased retear rates are associated with increasing tear size, yet no significant association was found between retear and age.

Nho et al. assessed both size and magnitude of tendon involvement in relation to repair. For patients with multi-tendon tears, the healing rate was only 49% compared to 90% for single tendon repairs. Additionally the average preoperative size of tears that went on to healing was 2.8 cm compared to 4.4 cm that failed [119]. In a subsequent investigation by Nho et al., they determined progression from a single-tendon to a multi-tendon tears increased the likelihood of retear by a factor of nine and worsened clinical outcome. Their concluding recommendation was to consider early surgical intervention for single tendon tears to maximize healing potential and clinical outcome [122].

A review of 49 published studies provides an average healing rate of 68% in patients older than 60 years. Rashid et al. collected data from a randomized trial (UKUFF Trial) to assess differences between open and arthroscopic rotator cuff repair to identify factors impacting healing. Failure to heal occurred in 43% of patients at 12 months with escalating failure rates as tear size increased. A positive correlation between age and

tear size was found. Logistic regression analysis demonstrated age to be an independent risk factor for failure to heal. However when assessing if age or tear size had a greater impact, only massive tear size (defined as three tendon involvement and/or tear size >5 cm) remained an independent predictor of healing [31]. Unfortunately subgroup analysis by surgical technique was not provided. While evidence is conflicting regarding surgical technique superiority, evidence does exist to support double-row techniques in massive rotator cuff tears [87]. Logical application of this evidence to this demographic may support the use of double-row and double-row derivative techniques.

In a retrospective cohort study of 1000 patients, the best predictor of retear after repair was determined to be tear dimensions when single-row technique was used. Other factors such as age, operative time, and tissue quality were determined to be associated, however to a lesser degree. Average size of tears going on to failure was 2.8 cm anterior-posterior length, 2.2 cm medial-lateral length, and 7.5cm^2 surface area. Anterior-posterior length was determined to be the strongest predictor of repair failure of single-row repair [120].

Clear trends emerge when assessing literature published in the last 10 years focusing on degenerative rotator cuff tear management. While age has commonly been cited as a risk factor for decreased repair healing, not all authors agree. It is interesting to note tear size beyond 2 cm is consistently cited as a risk factor for healing failure. Park et al. conclude with a meaningful explanation using recent anatomic and biomechanical data. The work of Sano et al. demonstrates that tear propagation accelerates when tear size exceeds 2 cm, especially in L-shaped patterns. Further work by Oh et al. demonstrated progression into the infraspinatus was the critical factor producing changes in humeral head kinematics [48, 123, 124]. Mochizuki et al. determined the supraspinatus footprint is smaller than previously thought with an anteroposterior dimension of 12.6 mm and the infraspinatus footprint is much larger at 32.7 mm [56]. Using these parameters it is clear rotator cuff tears exceeding 2 cm will involve the infraspinatus and can contribute to fatty degeneration of the infraspinatus, cited by many as a key contributor to decreased healing. Additionally, it may disrupt force coupling necessary for normal glenohumeral kinematics.

37.6.2 Tear Retraction

Several studies have identified tear retraction as an indicator for retear [8, 14, 125–127]. Retraction proximal (medial) to the level of the glenoid is cited as a risk factor for poor tendon healing in multiple studies [8, 126, 128]. One study stated retraction medial to the glenoid imparted a 50% retear rate compared to only 10% if retraction was lateral to the glenoid using single-row techniques [8]. Minor improvements to 44% and 6% retear rates were seen using double-row techniques [126].

Two recent studies calculated cutoff values for tendon retraction predictive or retear between 2.2 and 2.8 cm [14, 125, 129]. Significant tear retraction places undue tension on repair attempts; such tension can compromise the healing capacity. Such retraction may also be a marker for a deteriorated biologic capacity for tendon healing.

37.6.3 Tissue Quality

As discussed in the prior section, baseline tear size predisposes tendons to accelerated degeneration. Several biomechanical and clinical studies indicate tear sizes beyond 2 cm in anteroposterior width are associated with accelerated tissue degeneration [29, 48, 120, 122–124]. In conjunction with this evidence, several authors point to fatty infiltration beyond Goutallier stage 2 as a risk for nonhealing repairs [14, 30, 34, 48–52].

Fatty infiltration of the infraspinatus has been repeatedly linked to healing failure [14, 48, 53, 54]. The majority of study findings fall in line with the traditional finding that fatty infiltration greater than Goutallier stage 2 is linked to healing failure. Recent evidence now exists suggesting Stage 1 fatty infiltration may also be a risk factor. Interestingly, age as an independent risk factor for healing failure is not a universal finding in these investigations [32].

Recent evidence also reinforces fatty infiltration of the supraspinatus may negatively impact healing rates [46]. A study evaluating isolated full thickness supraspinatus tears demonstrated long-term retear rates may increase with even minor amounts of preoperative degeneration [130].

In a retrospective cohort study of 105 patients with massive rotator cuff tears, infraspinatus fatty infiltration alone and the combination of infraspinatus fatty infiltration and the Patte classification were the most predictive for tendon reparability. Cutoff values for reparability were determined. For the supraspinatus the cutoff was fatty infiltration >Stage 3 and for the infraspinatus >Stage 2. The cutoff for the Patte classification in determining reparability was a classification of 3. While a positive tangent sign was found to be predictive, it was a weaker predictor than the above factors [128].

Clinical outcomes for patients with large and massive tears have also been assessed in relation to preoperative fatty infiltration. While structural outcomes appear to be more forgiving, one case control study using the UCLA score demonstrated clinical outcomes may be slightly more sensitive. All patients experienced a statistically significant improvement from an average 18.1 points preoperatively to 29.8 points postoperatively. However, those with Goutallier fatty infiltration stages 2 or higher of the infraspinatus and/or subscapularis fared significantly worse even with intact repairs [47].

37.6.4 Preoperative Imaging

Recently, much attention has been devoted to preoperative advanced imaging assessment of tissue quality to determine rotator cuff healing probability.

Evaluation of a new advanced imaging technique, texture analysis, is emerging as a new technique to assess tissue quality. Retraction size averaging 2.6 cm and entropy- a parameter of gray-level co-occurrence matrix to assess tissue types- were identified as possible indicators for retear. Discussing advanced tissue parameters such as entropy with radiologists may become worthwhile practices to determine risk for retear in the future [125].

The Goutallier classification of fatty degeneration is possibly the most familiar classification to orthopedic surgeons. Less familiar advanced MRI techniques are being investigated to assess tissue quality. A recent prospective study analyzed preoperative and postoperative fatty degeneration in 50 patients with full thickness supraspinatus tears undergoing arthroscopic repair. Fat fractions were calculated from preoperative and 1-year postoperative MRI. Fat fractions were significantly higher in supraspinatus tears that went on to retear. An optimal cutoff of fat fraction to predict supraspinatus retear was calculated to be 26.6%. Interestingly, those with intact repairs experienced a reduction in fat fraction at 1 year compared to those with retears. Similar trends were seen for infraspinatus tears although a significant relationship was not established. A cutoff of 31% fat fraction to predict retear of infraspinatus repairs was calculated [131].

A study by Chung et al. in 2015 evaluated several commonly cited factors with healing failure, including fatty infiltration, tear size, and tendinosis grade. Tendinosis grade, as described by Sein et al. [132], was found to be the only significant factor associated with healing failure. A higher grade of tendinosis, Sein Grades 3 and 4, demonstrated a 7.64 elevated risk for healing failure [50].

37.6.5 Muscle Atrophy

Muscle atrophy is commonly seen on preoperative imaging; this information has prognostic significance. A recent study evaluated the supraspinatus occupancy ratio and its relation to reparability of cuff tears. A significant difference in occupation ratio existed between reparable and irreparable tears. Supraspinatus muscle occupation ratio >41 was deemed predictive for the ability to obtain full footprint coverage. Additionally as the occupancy ratio decreased, reparability was shown to significantly decrease [133]. Analysis of similar studies determined cutoff values for supraspinatus occupancy ratios <41–53 as a predictor for retear [54, 129, 133].

A previous study examined the relationship of the easily determined tangent sign and tear reparability. Pre- and posttest probabilities were calculated. A positive tangent sign imparted an 82.3% probability of an irreparable tear, yet only 1.6% of tears with a negative tangent sign were deemed irreparable. Of note partial repairs were classified as not repairable [134]. It has been shown, however, depending on the degree of the retear, partial repairs are capable of producing results that may be close to intact repairs [30].

37.6.6 Does Fatty Infiltration or Atrophy Improve After Successful Repair

Past literature has been split on the natural history of fatty infiltration after rotator cuff repair [135, 136]. Evaluation of more recent studies suggests improvements in both atrophy and fatty infiltration may be attained or progression halted. Of note, recent evidence indicates magnitude of retraction is positively correlated with cross-sectional area and occupation ratio. Thus when analyzing such studies, this fact must be kept in mind [137].

A 2016 study evaluated the progression of fatty infiltration and atrophy in patients with medium to large tears treated operatively and non-operatively. Fatty infiltration did not progress, and atrophy improved in the operative group. In the non-operative group, however, both atrophy and fatty infiltration significantly worsened [138].

Multiple articles demonstrate improvement in both fatty infiltration and atrophy after rotator cuff repair [131, 139, 140]. Degenerative changes, as measured by the fat fraction, can improve modestly with intact repairs [131]. At a 2-year follow-up, one study demonstrated improvement of muscle atrophy, as measured by the occupation ratio, is associated with improvements in Constant scores, abduction strength, and range of motion. In comparison, patients with improved fatty infiltration demonstrated only gains in flexion and abduction range of motion. Of note, atrophy improvements were limited to patients with small to medium tears, while those with fatty infiltration, improvement was more pronounced in patients with large to massive tears [139]. Similar gains in occupancy ratio were found in an additional study. Patients with all levels of retraction experienced atrophy improvements [140].

Successful arthroscopic repair can produce modest improvements in muscle volume. Improvements of 11.3–13.9% were seen in one study using preoperative MRI as a baseline. As with many studies, fatty infiltration was not reversed [141].

Prior studies by Gerber and Thomazeau provided evidence that muscle atrophy changes were linked to retears [142, 143]. A 2016 study measured preoperative, immediate postoperative, and 1-year postoperative muscle atrophy changes. The tangent sign, occupation ratio, and cross-sectional areas of the infraspinatus and supraspinatus improved significantly from baseline to 1 year postoperatively. When comparing tear integrity at 1 year, all parameters improved in both the intact and retear group; however, more significant gains were realized in the intact group [144].

Evidence supporting muscle atrophy improvement is reported in multiple studies, yet improvement in fatty infiltration is not consistently reported. Additionally, the time points considered as baseline may impact the measurement of changes in both measures. Comparison of fatty infiltration at 1 year based on preoperative compared to immediate postoperative changes produced different results. In several studies improvements were noted at final follow-up compared to preoperative measures, but not when compared to immediate postoperative measures. Only a handful of patients with intact repairs exhibited fatty infiltration improvements, while the vast majority progressed. The authors reiterated patients should be offered early surgical intervention before "a point of no return" after which degenerative changes will progress regardless [145].

Analyzing data produced in the last 5 years does not definitively resolve the issue regarding improvements in degenerative changes after successful arthroscopic repair. It appears muscle atrophy can be improved after successful repair; however, the course of fatty infiltration appears less defined.

37.6.7 Patient Factors

Several additional patient factors have been listed as risk factors for poor rotator cuff tissue potential for healing. Declining bone mineral density (BMD) is inversely correlated with healing rates according to one study. Those with normal BMD had 9% failure rates compared to 30.2% and 41.7% for those with BMD in the osteopenic and osteoporotic ranges. These values were determined to give 4.38 and 7.25 times failure rates for those with osteopenia and osteoporosis, respectively, compared to patients with normal BMD [14]. Systemic conditions such as body mass index ≥25, dyslipidemia [129], and diabetes mellitus [14, 129, 146] have also been demonstrated to impair rotator cuff repair healing. Cho et al. demonstrated the role of glycemic control in healing capacity of repairs. Patients with poor glycemic control determined by hemoglobin A1c (HbA1c) measurements ≥7% sustained failure rates of 43.2% compared to 25.9% in well-controlled diabetics. This difference was statistically significant [146].

37.6.8 Summary

Rotator cuff size and age remain the most commonly cited factors for retear after repair. Specifically a preoperative tear anteroposterior dimension greater than 2 cm appears consistently in the literature in the population of patients who go on to retear. This size may be the critical threshold beyond which tissue degeneration and tear propagation accelerate. Biomechanical and anatomic studies support the claim. Fatty degeneration beyond Goutallier stage 2 is consistently reported as an additional risk factor; however, new data suggests lesser degrees may still compromise long-term outcomes. Tendon retraction also impacts repair success. It seems retraction medial to the glenoid face may be the most reproducible indicator of increased repair failure. New imaging techniques, e.g., the fat fraction, may allow more precise quantification and preoperative risk assessment which may alter treatment timelines and surgical techniques. Several other patient-specific factors, e.g., diabetes mellitus with poor glycemic control (HbA1c ≥7%), hyperlipidemia, and declining bone mineral density, are also thought to contribute to the "healability" of degenerative rotator cuff tears. Close monitoring of tear size and tissue quality and intervention prior to tear size exceeding 2 cm in the anteroposterior dimension and Goutallier stage 2 fatty infiltration or fat fraction <25–30% are logical indications for earlier surgical intervention. Thorough attempts at medical optimization, e.g., glycemic control, lipid reduction, and improved bone health, should be maximized prior to surgical intervention.

37.7 Postoperative Management

Postoperative rehabilitation is a critical aspect of any surgical procedure. In the recent decade, rotator cuff rehabilitation has received significant attention in the literature. Specifically, the attributes and detriments of early or accelerated compared to delayed or conservative protocols have been compared extensively. Most studies demonstrate modest gains in early, 3–6 months, range of motion for early range of motion (ROM) protocols without increased retear rates. However, it must be noted most studies do not demonstrate an advantage at 1 year compared to conservative protocols. It also must be highlighted that the majority of studies exclude large and massive tears; thus their applicability to the larger degenerative cuff tear population must be questioned [44, 147–149]. What is agreed upon is closed chain passive ROM exercise is the best tool available to decrease the rates of postoperative arthrofibrosis; the timing of initiation and its impact on healing, however, remains debated [150]. For the purposes of the below discussion, early ROM protocols begin motion between postoperative days 1–7, while delayed motion prescribes immobilization for at least 4–6 weeks [151].

Multiple meta-analyses investigating rehabilitation protocols for rotator cuff repair have been performed since 2014. The review and analysis by Shen et al. found no difference in healing rates between early ROM and immobilized groups fol-

lowing rotator cuff repair. External rotation was improved in the early ROM group at 6 months, but this advantage disappeared at 1 year. Constant scores also slightly favored the early ROM reaching statistical significance but not surpassing the accepted MCID of 10.4 points [68, 152]. As with the meta-analysis by Shen, no difference in clinical outcomes nor retear rates were identified in additional, high-quality, meta-analyses by Chan et al. and Riboh et al. Statistically significant gain in forward flexion in the early ROM group was identified in both analyses, but this was unlikely to be clinically significant [153, 154]. Early ROM gains—up to 6 months—were demonstrated by Chang et al.; however, increased retear rates were demonstrated in the early ROM group after exclusion of studies recruiting only small to medium tears. They conclude early ROM may likely inhibit proper healing after repair of large-sized tears [155]. Similar conclusions were made by Chen et al. with early ROM protocols providing increased ROM up to 6 months but also a decreased healing rate compared to delayed mobilization protocols [156]. While no clear evidence exists regarding optimal timing of ROM initiation, tear size has been demonstrated to influence retear rates with early ROM protocols. Kluczynski et al. demonstrated risk of retear is greater with early ROM protocols for tears >5 cm. Interestingly, retear rates were lower with early ROM protocols for tears ≤3 cm [157]. A review by the same group also demonstrated universal increased risk of structural defect for tears of all sizes when active ROM was initiated prior to 6 weeks postoperatively. Significantly less attention has been devoted to the initiation of active compared to passive ROM in rotator cuff repair rehabilitation.

No clear advantage has been elucidated by the above analyses. Tear size, however, does appear to be a critical factor in determining the most appropriate rehabilitation protocol with larger tears demonstrating higher retear rates with early ROM protocols. A consensus statement by the American Society of Shoulder and Elbow Therapists was published in 2016 to provide some clarity. Goals of postoperative rehabilitation include restoration of full, symmetric passive and active ROM, restoration of balanced glenohumeral and scapulothoracic force couples and pain-free function of the shoulder. Individualized protocols should be established with close communication between surgeon and rehabilitation teams. Passive range of motion is performed during the first 6 weeks. When full ROM is restored, incremental increases in active ROM may begin, no sooner than 6 weeks postoperatively, in coordination with isometric strengthening. After sufficient healing is accomplished, typically 12–16 weeks, progressive resistance training may commence. Work- and sport-specific training may commence at 4–5 months, again with emphasis on individual progress and characteristics of both original tear and resulting repair [147].

37.7.1 Senior Author's Preferred Rehabilitation Protocol

In our practice, the senior author employs close communication with the rehabilitation team to tailor each patient's postoperative rehabilitation. The structure of rehabilitation protocols is based on tear size, tissue quality, and repair construct characteristics. Patients are immobilized in a shoulder abduction brace in neutral rotation when not performing rehabilitation exercises. Preoperative range of motion, exam under anesthesia, and intraoperative findings (degree of synovitis, capsular contracture, and tissue quality) all influence the commencement of ROM exercises. Even then, motion may still be initiated incrementally depending on patient compliance factors and communication with physiotherapy providers. For those with acceptable tissue quality and significant preoperative stiffness, passive closed chain exercises begin immediately (e.g., table slides). For those with poor tissue quality and larger tears, patients are instructed to wait until they see their physiotherapist to begin ROM exercises. Select scapular stabilization exercises are commenced immediately for all patients. Passive- and active-assisted closed chain range of motion protocols in the scapular plane are employed for the first 6 weeks postoperatively.

Patients with large and massive tears and poor tissue quality employ the same strategies, yet this phase (including bracing) is extended to a total of 8 weeks. Given the high activity level and low physiologic age of our patient population, we have a high rate of addressing biceps pathology. If biceps tenodesis is performed, a similar approach is taken. We limit elbow ROM to active-assisted ROM exercises for 6 weeks for patients with good tissue and 8 weeks for poor. If subscapularis tears are identified and repaired, external rotation is prohibited for 3 weeks in those with good tissue quality and 6 weeks if tissue quality is poor. For biceps tenotomized patients immediate elbow ROM and strengthening progression is allowed.

After completion of phase one, brace use is discontinued. Active-assisted ROM exercises are increased, and isometric strengthening exercises of the cuff and deltoid are employed. If biceps tenodesis was performed, we begin concentric biceps strengthening for 2 weeks, followed by initiation of eccentric strengthening.

At 12 weeks postoperatively, we advance the patient to below the shoulder active resistance training of the rotator cuff, deltoid, and scapular stabilizers. Based on patient progression and tear and repair characteristics, we commence sport or work specific rehabilitation at 4–5 months. Return to overhead activities or full golf swings are allowed at 6–9 months. Unrestricted return to sport can be expected by 9–12 months, again determined by individual patient progression.

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Subacromial Spacer

38

Enrique Salas, Guillermo Arce,
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38.1 Introduction

Rotator cuff tears (RCT), either massive (M) or irreparable (I), can pose significant challenges to orthopedic surgeons, as they are frequently linked to high failure rates. There are several surgical options to deal with such cases including reverse shoulder arthroplasty, superior capsular reconstruction, tendon transfer, arthroscopic debridement with biceps tenotomy and subacromial decompression, partial cuff repairs, grafts, patches, as well as tuberoplasty. Each option has advantages and disadvantages, and the ultimate treatment must be customized according to the type of injury as well as the specific patient needs. Recently the use of subacromial spacers provided encouraging results, emerging as a valuable option for the treatment of both MRCT and IRCT.

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38.2 Literature Review

Currently, there is no consensus regarding the most suitable surgical approach for patients with IRCT who failed conservative treatment. Prior to surgery, various diagnostic methods such as fatty infiltration (Goutallier), assessment of acromion humeral head distance, as well as the degree of retraction may help estimate procedural outcome. Nonetheless, the final selection of the most suited surgical technique is typically made intraoperatively. Several surgical techniques have been proposed and revised for MRCT and/or IRCT [1]. The use of subacromial spacers, either alone or as an adjunct during cuff repair, has recently emerged [2–7]. Such technique requires inflation of a balloon spacer with saline solution at the subacromial space for 3 months (spacer usually reabsorbs by 1 year). Theoretically, the balloon reduces subacromial friction during shoulder abduction by lowering the head of the humerus, facilitating humeral gliding against the acromion during motion. Additionally, the spacer centers the head against the glenoid. It is yet unclear why functional improvements persist after balloon disintegration [7]. Some authors hypothesize that long-lasting improvement in function is due to a change in muscle patterning of the force coupled between the internal and external rotators, obtained by re-centering of the humeral head [8]. A 1-year follow-up magnetic resonance imaging (MRI) study described a bursa-like soft tissue

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formation that covers the surroundings of the repaired rotator cuff, which may explain functional improvement despite balloon resorption [9]. Alternatively, another MRI study showed complete disintegration of the space in most patients at 3 years [2].

In patients who are not suitable or simply do not desire to undergo open and extensive surgery, subacromial spacer implantation arises as a potential solution. Fluoroscopy-guided implantation of a subacromial spacer can be performed with local anesthesia, without tenotomy of the long head of the biceps, bursectomy, or any form of repair [3, 10].

Subacromial spacer implantation following cuff repairs has recently been introduced as a viable option, in which the balloon provides further protection acting as a shield [2, 8, 9, 11]. Holschen et al. [8] compared MRCT repair versus MRCT repair with adjunctive subacromial spacer implantation, demonstrating superior shoulder function with the spacer.

There are a few alternatives to revert pseudoparalysis in non-arthritic joints. Arthroscopic releases and repairs with or without patches or augments provide good clinical outcomes. Particularly, fascia lata or extracellular matrix augmentation during repair appears beneficial at 2-year follow-up [12–17]. Alternatively, superior capsule reconstruction has shown promising results. Nonetheless, augmentation and superior capsule reconstruction techniques have yet to be compared to subacromial spacer implantation.

38.3 Technique

38.3.1 Materials

The spacer device (InSpace; OrthoSpace, Caesarea, Israel) comes with an introducer and a pre-shaped balloon made of poly-L-lactide- co-3-caprolactone, which is a biodegradable polymer material widely used in medical devices and the pharmaceutical industry. The spacer deflates within 3 months after placement and degrades fully at 1 year. It comes in three different sizes: small, medium, and large.

38.3.2 Indications

Subacromial spacer implantation is indicated in patients undergoing MRCT or IRCT repair. The spacer contraindicated in patients with known allergy to the device's material or in patients with active or latent infection, as well as in the presence of glenohumeral arthropathy with advanced arthritis. A pseudo-paralytic shoulder precludes active arm lifting beyond the shoulder level, constituting a partial contraindication to spacer placement owing to unpredictable procedural results.

38.3.3 Surgical Technique

The operating room setup is as for any regular arthroscopic rotator cuff surgery. To place the patient in beach chair position is preferable because the traction of the humeral head in lateral decubitus position can make device sizing more difficult. The spacer size is selected by the surgeon according to the extent of the tear and the distance from the lateral border of the greater tuberosity to approximately 1 cm medial to the glenoid apex. In cases where the distance lies between two main sizes, the larger spacer size is used to ensure proper positioning and to minimize the possibility of implant displacement. The biodegradable spacer is introduced through the lateral portal. The system should be placed approximately 1 cm over the glenoid rim and the rotator cuff tendon stump. After achieving accurate device positioning, the protective sheath is withdrawn to reveal the spacer. The extension tubing is connected to the distal side of the Luer lock connector, and the spacer is inflated to its maximal volume. The valve should remain open to allow backflow of saline solution into the syringe until the recommended volume is achieved. Overinflation would impede full range of motion. The spacer is then sealed and secured in situ by firmly grasping the deployer and withdrawing the connecting syringe. Finally, the delivery system is removed.

38.4 Rehabilitation

38.4.1 General Guidelines and Phases

Patients should avoid quick, sudden, or repetitive movements and lifting weights or heavy objects. They are also asked to limit activities demanding force or power.

Phase I (0–2 weeks): Immediately after surgery: sling, only to be removed for short periods of time at home. Passive and active movements of the scapula, cervical spine, elbow, wrist, and hand. Forward flexion and abduction up to 60°.

Phase II (2–6 weeks): Active motion with a physical therapist for 6–10 weeks. A sling may be discontinued; patients are encouraged to stretch at home, as well as active- and passive-assisted movements; strengthening is begun lightly and is progressively increased.

Phase III (6–12 weeks): Regain preoperative range of motion or make steady gains on a weekly basis. In this phase, it is expected to feel temporary discomfort or transient increases in shoulder pain [18].

38.5 Complications

A few uncommon complications have been reported. One of them is device migration, which can be left until it disintegrates or can be removed through arthroscopy. Patients can also experience foreign body reactions or infections, requiring spacer removal.

38.6 Discussion

Adjunctive subacromial spacer implantation constitutes a straightforward procedure that may solve highly complex medical problems like MRCT and IRCT. This biodegradable device can be introduced either arthroscopically or under fluoroscopy. Up until now, there is no agreement or guidelines for the invasive management of MRCT/IRCT. Meanwhile, Calvo et al. recently reported a European experience in more than 11,000 subacromial spacer implantation procedures demonstrating significant reduction in pain and improvement in shoulder function [19]. By using the constant score (up to 5 years), clinical results seem comparable to more aggressive and complex surgical techniques. Importantly, the use of a subacromial spacer, even if it fails, it does not preclude future surgical procedures.

As previously mentioned, the precise mechanism for which the spacer provides long-lasting improvement remains elusive. Another relevant but unanswered issue is whether the placement of a permanent balloon may lead to even superior long-term results.

38.7 Conclusions

Subacromial spacer implantation provides long-lasting pain relief and improvement in arm mobility in patients with IRCT. Such device can serve as an adjunct during rotator cuff repairs. The insertion appears safe, straightforward, and fast. It represents an alternative procedure for the management of MRCT or IRCT especially in those patients who cannot stand or do not desire an extensive surgery. Time and further research are needed to elucidate its role in the management of difficult shoulder cases.

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39 Massive Tears: Techniques for Mobilization of the Large Retracted Rotator Cuff Tears

Maristella F. Saccomanno and Giuseppe Milano

39.1 Introduction

Arthroscopic rotator cuff repair grants successful and predictable outcomes for small- and medium-sized tears; however, it remains challenging and controversial for large and massive tears that are often associated with tendon retraction, fatty infiltration, and tissue degeneration. Massive rotator cuff tears represent up to 40% of all tears [1], and unfortunately, despite new technology and a better understanding of rotator cuff biomechanics, tendon healing drops considerably to 47% for this subset of tears [2].

Exact definition of massive tears is somehow still controversial. DeOrio and Cofield [3] described them as lesions characterized by an anteroposterior or mediolateral diameter greater than 5 cm on preoperative magnetic resonance (MR). Gerber et al. [4] described them as tears involving two or more tendons, though some authors restricted this definition to tears of more than two tendons. In a recent meta-analysis, Henry et al. [5] used a hybrid definition that accounts for both length and number of tendons: "greater than 3 cm in the coronal plane but with complete detachment of both supra- and infraspinatus tendons or 4 cm in the coronal plane and the complete detachment of at least one tendon."

Irreparable rotator cuff tears are well-defined lesions consisting of massive retracted rotator cuff tears that cannot be repaired primarily to their insertion onto the tuberosities despite conventional techniques of mobilization and soft-tissue releases.

With advanced chronicity and tissue deterioration, massive tears can become irreparable. The rate of arthroscopically irreparable rotator cuff tears has been estimated ranging from 6.5% to 30% [6].

The aim of the following chapter is to provide an overview on surgical steps for mobilization of the large retracted rotator cuff tears.

39.2 Surgical Technique

39.2.1 Key Points

A clear field of view is paramount to create an optimal repair.

Essential surgical steps, which are about to be discussed, are:

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- Mobilizing and reducing the lesion.
- Understanding the tear pattern.
- Performing a tension free repair.

39.2.2 Position and Portals

Surgery can be performed under general or regional anesthesia with an interscalene block or blended. Beach chair or lateral decubitus are only based on the surgeon's preference. It is authors' preference to perform rotator cuff repair in beach chair position. Five pounds of balanced suspension is used with the arm in 20–30° of abduction and 50–60° of forward flexion.

The following bony landmarks are drawn by using a permanent skin marker: acromion, scapular spine, distal clavicle, acromioclavicular joint, coracoid tip, and coracoacromial ligament.

Standard arthroscopic portals are used for the repair:

- Posterior portal as viewing portal or working portal for suture management.
- Anterosuperior portal as outflow portal or working portal for powered/radiofrequency instruments and suture management.
- Standard lateral portal as viewing portal or working portal for powered/radiofrequency instruments and suture management.
- Superior lateral portal for suture anchors placement. One or more portals could be needed according to tear sagittal extension for optimizing anchor placement.

39.2.3 Intra-articular Inspection

Shoulder arthroscopy always starts with a diagnostic evaluation from the posterior portal. A 30-degree scope is used for the entire procedure. After palpating the soft spot, a skin incision is made, and a blunt trocar is then inserted into the joint. Once the posterior portal has been established, the scope is introduced into the joint, and the articular space is distended with 30–40 cc of air inflated with a syringe through the arthroscopic sheath. Intra-articular inspection on air of all relevant structures is then performed. In massive cuff tears, intra-articular and subacromial spaces are in continuity if the tear is retracted to the glenoid (Fig. 39.1).

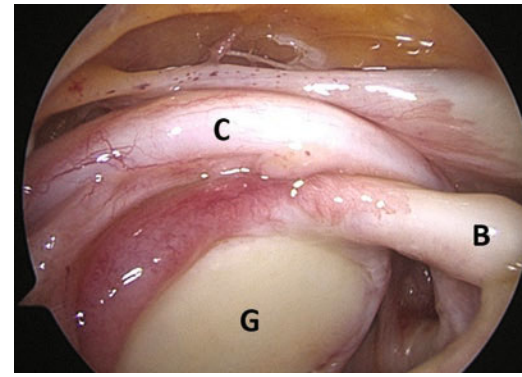

Fig. 39.1 Air arthroscopy of a right shoulder. In massive rotator cuff tears, tendons are retracted to the glenoid, and intra-articular and subacromial spaces are in continuity (*C* cuff, *G* glenoid, *B* biceps)

After air examination, the anterosuperior portal is established. The following steps are always the same for each single portal. An 18-G spinal needle is used to identify the right direction of the arthroscopic access, and then a vertical skin incision is made. Once again, a blunt trocar with a metal cannula is inserted. The metal cannula is then left in place and the blunt trocar is replaced by a switching stick. A dilator is then used, and a plastic cannula is then inserted over the switching stick. Intra-articular structures can be then palpated and evaluated. In case of biceps instability or degeneration, the treatment is established based on patients' age and functional request. A biceps tenotomy is usually performed in patients aged older than 60 years, while a tenodesis in the proximal part of the bicipital groove with one double-loaded suture anchor is usually performed in younger patient. In case of massive or irreparable tears, the proximal part of the long head of the biceps might be used as an augmentation or for superior capsule reconstruction [7].

Subscapularis tendon should be inspected through dynamic maneuvers for visualization of lesser tuberosity footprint in order not to miss partial-thickness articular surface tears. In case of a subscapularis tendon tear, the "comma sign" should

be identified, and one or two suture anchors can be needed for its repair according to the tear size. If needed, subscapularis tendon repair should be performed at this stage because in continuity repair of the this tendon will reduce tension and retraction of the posterosuperior cuff tear [8] (Fig. 39.2).

39.2.4 Subacromial Space: Clear Field of View

Once the intra-articular surgical step is completed, the scope is passed into the subacromial space, through the posterior portal just sliding under the acromion. Then, a standard lateral portal is established as previously described. Posterior and lateral portals will be either used as viewing or working portals.

Bursectomy is a mandatory step in order to guarantee a clear field of view. A powered and/or a radiofrequency instrument can be used. In chronic massive tear, it can be hard to distinguish the bursa from the cuff; therefore, a cleavage must be searched, and a careful release should be performed. Scar adhesions should be carefully released, and cuff tissue should be recognized and preserved. A cleavage between the posterior rotator cuff and posterior scar adhesions/bursa can be found by grasping the anterosuperior cuff and following its superior margin. If the superior rotator cuff is scarred to the undersurface of the acromion, the cuff tissue can be preserved by directing the radiofrequency instrument toward the acromion and gently excavating the cuff from the bone (Fig. 39.3). Radiofrequency is usually preferred rather than a powered instrument because it allows a volumetric reduction of scar tissues while controlling bleeding. Bleeding is also controlled by adding norepinephrine to the saline solution, while reducing the risk of hypotensive and bradycardic events [9].

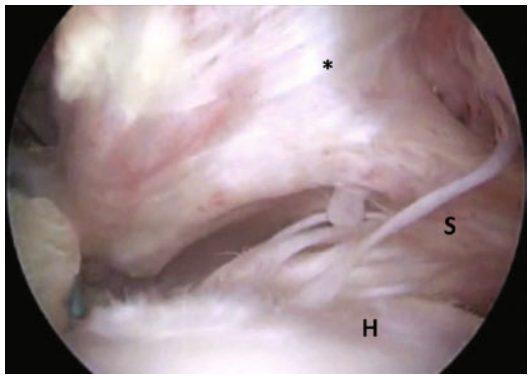

Fig. 39.2 Left shoulder. Subscapularis tendon tear should be repaired at the beginning of the procedure (*H* humeral head, *S* subscapularis, * comma sign)

39.2.5 Assessing Tear Shape and Reducibility

Once the visualization is adequate, the scope is placed in the lateral portal, so an en face view of

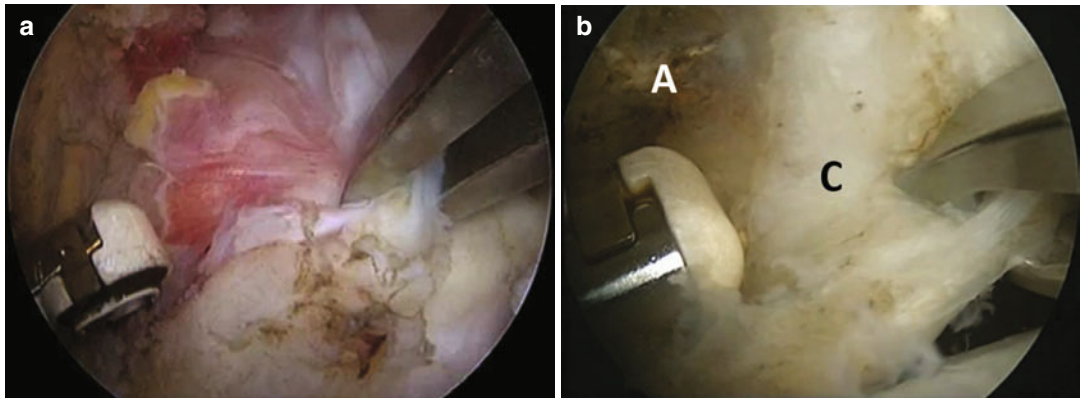

Fig. 39.3 Rotator cuff should be released from scar adhesions (**a**). If the superior rotator cuff is scarred to the undersurface of the acromion, the cuff tissue can be preserved by directing the radiofrequency instrument toward the acromion and gently excavating the cuff from the bone (**b**) (*A* acromion, *C* cuff)

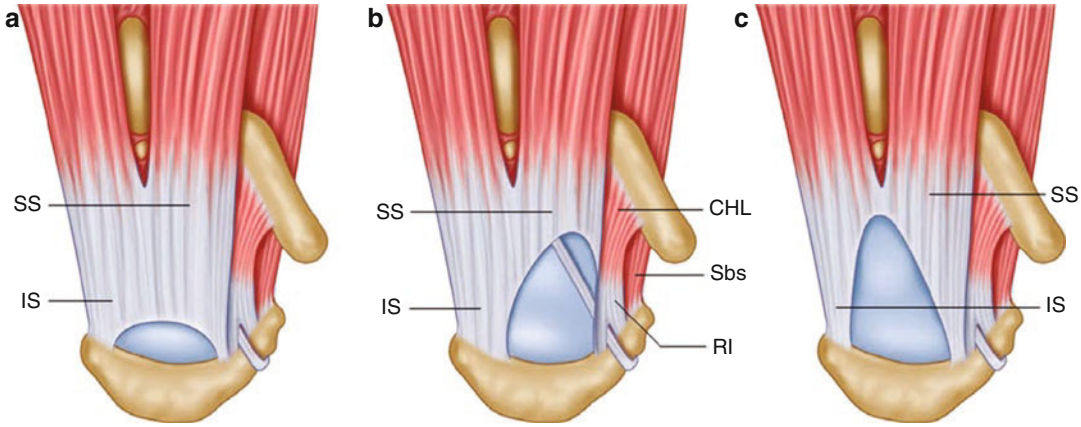

Fig. 39.4 Geometric classification of full-thickness rotator cuff tears. (**a**) Crescent. (**b**) Reverse L shaped. (**c**) U shaped (*SS* supraspinatus, *IS* infraspinatus, *RI* rotator interval, *Sbs* subscapularis, *CHL* coracohumeral ligament)

the lesion can be obtained. If only the posterior portal is used as viewing portal, tear pattern and posterior cuff delamination can be easily missed. It is essential to point out that understanding the tear shape is the key of the surgical procedure in order to avoid excessive tension in the final repair.

Two tissue graspers through the anterosuperior and the posterior portals can be used to assess tendon edge mobility and reducibility.

The shape of reducible tears (Fig. 39.4) can be described as follows:

- Crescent-shaped tears: easy to mobilize, and a direct repair to the bone with minimal tension can be performed.
- U-Shaped, L-shaped, or reverse L-shaped tears: reduction must be obtained by following the direction of force vectors. If a direct repair (cuff to bone) is attempted, it will increase the risk of an early failure due to the excessive tension.

Massive contracted irreparable tears are characterized by tendon retraction over the glenoid with no possibility of standard reduction by pulling the tear tendon edges.

39.2.6 Mobilization Techniques

In-continuity repair of the subscapularis tendon repair as well as scar adhesion/bursa removal are first important steps of mobilization techniques. However, sometimes they are not enough. At this stage, if complete tendon reduction is not achievable without tension, some other strategies could be put in place:

- Capsular release.
- Interval slides.
- Margin convergence.

The capsular release is usually performed by using the radiofrequency device. The scope is always placed in the lateral portal, whereas posterior and anterosuperior portals are used as working portals. A cleavage could be created between the articular side of the posterosuperior cuff and the glenoid edge and neck (Fig. 39.5). Sometimes, release can be extended to the posteroinferior capsule in order to address fixed superior migration of the humeral head. However, this procedure is ineffective when the tear is extended to the entire infraspinatus tendon.

The interval slides could be categorized as anterior, posterior, or double. They are usually performed in case of immobile retracted massive tears. An anterior interval slide consists of a release of the rotator interval, along the coracohumeral ligament. It can be performed by using a radiofrequency instrument or scissors. If a radiofrequency instrument is used, the procedure can be performed from the base of

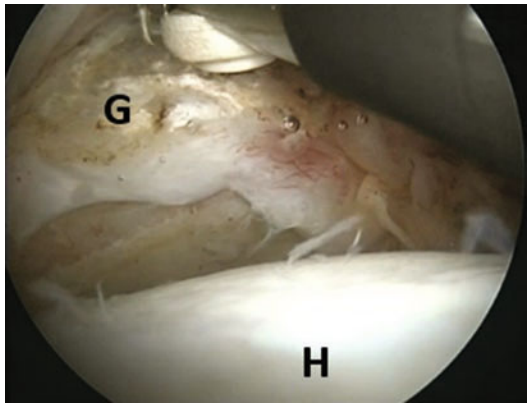

Fig. 39.5 Superior capsular release consists of creating a cleavage between the articular side of the posterosuperior cuff and the glenoid edge and neck (*G* glenoid neck, *H* humeral head)

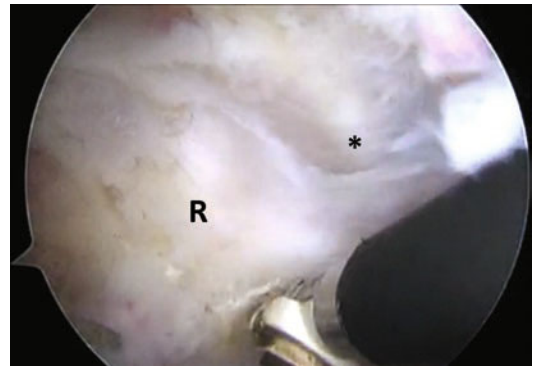

Fig. 39.6 An anterior interval slide consists of a release of the rotator interval, along the coracohumeral ligament, from the base of the coracoid to lateral (*R* rotator interval, * coracoid base)

the coracoid to lateral, preferably avoiding the most lateral part of the coracohumeral ligament (release in continuity) (Fig. 39.6). The posterior interval slide consists of a release between the supraspinatus and the infraspinatus tendon. Usually, the posterior interval can be easily identified by exposing the spine of the scapula, which separate the supraspinatus from the infraspinatus musculotendinous unit. The slide is always started from the lateral edge of the lesion and extending medially by following the spine of the scapula until reaching the muscle fibers. Traction sutures on the supraspinatus and infraspinatus tendons can be applied, to pull and separate the tendons during the procedure. Release should not be extended more than 1.5 cm medial to the glenoid rim in order to avoid the risk of suprascapular nerve injury. A double interval slide, which means a combination of anterior and posterior slides, might also be performed. After tendons mobilization through an interval slide, cuff must be repaired to the bone with suture anchors before performing side-to-side sutures to close the slides.

Margin convergence is used to reduce tension and restore a crescent shape in case of U-shaped, L-shaped, or reverse-L-shaped tears. Based on tear size and retraction, side-to-side repair can be performed with individual sutures or as a continuous repair in a basket-shoes configuration.

If margin convergence is performed by using suture strands from suture anchor placed on the greater tuberosity, the tension on the tear apex will be increased, and the direction of the force vectors will not be respected. For this reason, side-to-side repair with sutures from anchors is recommended only in non-retracted tears.

When individual sutures are used, they should be tied sequentially in order to achieve margin convergence and gradually assess tension reduction. The apex of the tear must be first identified. The first suture is the most medial and it should run through the apex of the tear (Fig. 39.7). Two to three sutures are usually necessary to restore a crescent shape. In case of U-shaped tears, the anterior and posterior leaves will be equally mobilized; therefore, once the sutures are passed from medial to lateral, the portal from which sutures are knotted makes no difference. In case of L-shaped tears (the anterior edge is more mobile), sutures should pass from medial to lateral and from anterior to posterior; the post is the strand of the suture that is passed through the anterior edge, and sutures are knotted from the posterior portal. In case of reverse L-shaped tears (the posterior edge is more mobile), sutures pass from medial to lateral and from posterior to anterior; the post is the strand of the suture that is passed through the posterior edge, and sutures are knotted from the anterosuperior portal. This approach

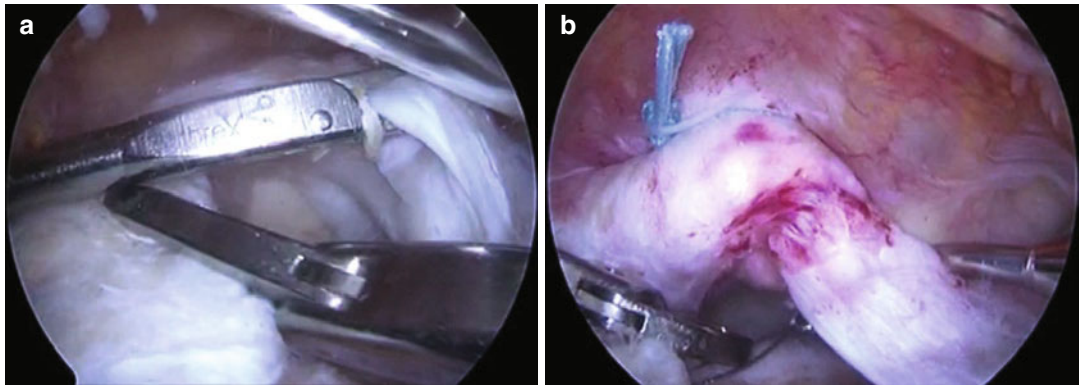

Fig. 39.7 Margin convergence repair. The shape of the tear should be addressed in order to accomplish anatomic tear reduction and repair along the force vectors (**a**). The apex of the tear must be first identified. The first suture is the most medial and it should run through the apex of the tear (**b**)

allows reducing repair tension, thus decreasing chances of mechanical failure of the repair.

39.2.7 Tension-Free Repair

Once the tendon edges have been mobilized and reduced to a crescent shape, a tension-free repair could be attempted.

Scope can be switched to the posterior portal or remain into the lateral portal, as surgeon's preference. A radiofrequency instrument is used to remove soft tissue from the footprint, while a shaver is used to perform the cortical abrasion in order to achieve a bleeding bed. Surgeon's ability is important to manage the shaver. The harder the tissue, the fewer revolutions per minute are necessary, but greater pressure must be applied on the instrument. Since excessive abrasion can increase risk of anchor pullout in osteoporotic bone, microfracture (or nanofracture) of the greater tuberosity is a viable alternative to cortical abrasion. Multiple bone vents are performed with a small-diameter awl about 4–5 mm apart, before or after anchor placement (Fig. 39.8).

Suture anchors are placed from the superolateral portal. Different surgical techniques and suture configuration can be used, based on surgeon's preference. A single-row technique is usually preferred in massive cuff tears in order to avoid excessive tension. An average of 2–3

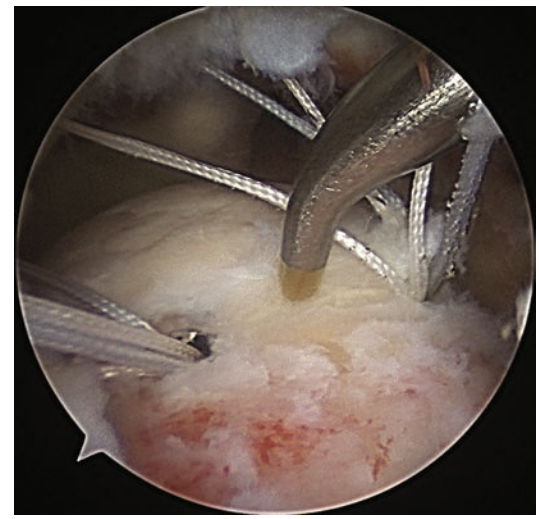

Fig. 39.8 Multiple bone vents are performed with a small-diameter awl about 4–5 mm apart, before or after anchor placement

double-loaded or triple-loaded suture anchors are usually required for a complete repair of the posterosuperior cuff (Fig. 39.9). They should not be too close in order to avoid interference and should be placed along to the articular cartilage margin to further reduce repair tension, from anterior to posterior or vice versa. Suture strands are passed through the tear immediately after each anchor placement but are knotted only after all anchors are placed. Direct antegrade suture passers are usually used for the superior cuff, while direct retrograde suture passers are used

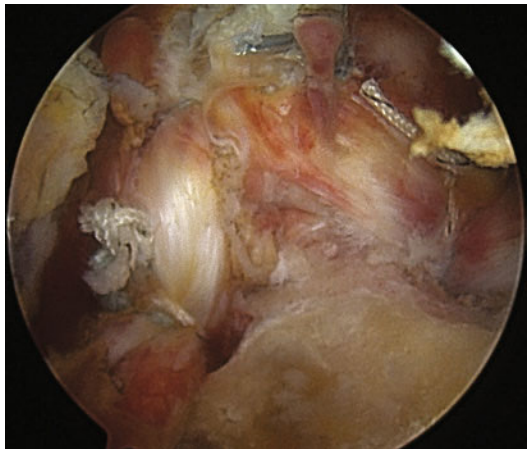

Fig. 39.9 Complete repair of a massive rotator cuff tear. A single-row technique is usually preferred in massive cuff tears in order to avoid excessive tension with 2–3 double-loaded or triple-loaded suture anchors

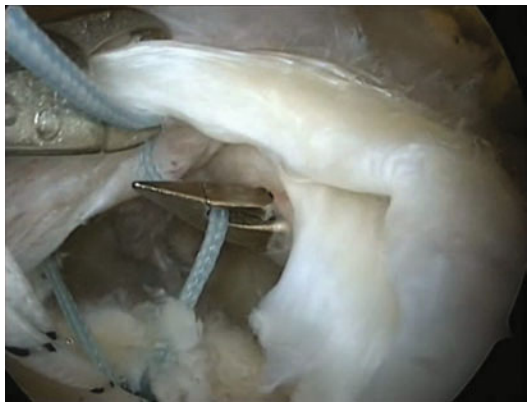

Fig. 39.10 A direct retrograde suture passer is used for the posterior cuff. If the cuff is delaminated, both layers should be included in the repair

for the posterior cuff. If the cuff is delaminated, both layers should be included in the repair (Fig. 39.10). Alternatively, indirect suture passers can be used, especially in delaminated tears to catch both layers. Plastic cannulas can be used for suture management in order to prevent suture entanglement or soft tissues interposition.

Before tying the knots, it is important to assess the direction of the force vectors and following them. Knot type can be selected according to the tendon quality and surgeon skill set. Non-sliding knots are usually preferred in case of poor tendon quality. Otherwise, sliding knots can be safely performed.

Accessory step such as subacromial decompression intended as acromioplasty and release of coracoacromial ligament is never performed by the authors in massive tears because it might weaken the deltoid and increase the risk of anterosuperior glenohumeral instability.

39.3 Postoperative Care

Immobilization in a sling in neutral rotation and 20° of abduction is recommended for 4 weeks.

After the sling is removed, patients undergo a standard rehabilitation program as follows:

- Phase 1 (5–8 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 for 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 scapulothoracic muscles).

Return to heavy manual work and competitive sports activities is allowed 6 months after surgery. We routinely perform an MRI at 6-month follow-up.

39.4 Literature Review

Complete repair without excessive tension is the goal of the arthroscopic treatment of massive rotator cuff tears. An adequate mobilization and identification of the tear shape are the principal surgical steps to achieve a successful repair. The present chapter showed sequential surgical steps that might help in mobilizing retracted massive

tears. However, literature data on those techniques are somehow lacking and controversial.

Bursectomy, subscapularis tendon repair, and adoption of appropriate structure of side-to-side repair based on tear shape are standard and at the same time mandatory steps in any tear size. On the contrary, capsular release and interval slides are only suggested in case of massive contracted tears. Regarding effects of capsular release in massive cuff tears, only one cadaveric study is available [10]. The authors showed that release of either the superior capsule or the coracohumeral ligament diminished the tension of the repaired rotator cuff by an average of 25% with the arm in adduction; release of both structures further reduced the tension by an average of 44% in adduction and 43–60% with the arm in 15° of elevation.

Regarding interval slides, only few studies provided data on homogeneous populations treated with either single or double interval slides for tendon mobility. Anterior interval slide was first described by Tauro [11], whereas double slide was then proposed by Lo and Burkart [12]. A single anterior interval slide has the main goal to gain 1–2 cm of medial-to-lateral mobility of the supraspinatus tendon, whereas a double interval slide could allow 3–5 cm of lateral excursion of both supraspinatus and infraspinatus tendon. Although clinical improvement have been showed in some studies [13, 14], concerns have been raised with double interval slide, mainly related to devascularization of the supraspinatus tendon, muscle tendon unit dysfunction, and suprascapular nerve damage during posterior interval slide [15, 16]. Moreover, the effect on muscle atrophy and fatty infiltration is still unknown.

From a clinical standpoint, studies comparing partial repair versus complete repair of large-to-massive contracted cuff tears obtained with interval slides showed no differences in clinical or structural outcomes between the two techniques [14, 16]. Kim et al. [16] also showed that the interval slide group showed 91% of re-tear rate at 2-year follow-up.

In our opinion, on considering the wide range of options available for treating massive to irreparable rotator cuff tears including partial repair as well as superior capsule reconstruction, the room for extensive capsular releases or interval slides is very limited. Although a definitive conclusion is difficult to draw, those surgical maneuvers must be considered aggressive and salvage procedures with no proved benefit over more cautious mobilization techniques.

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Biologic Augmentation in RC Repair (Patches and Grafts): Part I

40

Kevin D. Plancher, Brian McCormick, Jordan Murphy, and Stephanie C. Petterson

Approximately 18 million Americans report shoulder pain every year, and a large percentage of these patients have rotator cuff pathology [1]. The incidence of rotator cuff repairs has risen to more than 250,000 procedures each year [2]. The average total cost of a rotator cuff repair is $6904, accounting for over $1.7 billion dollars in health care costs per year [2]. Rotator cuff repair produces a net societal cost savings compared to nonoperative treatment [3]. Even with the cost savings of operative intervention, rotator cuff repairs remain a significant financial burden to the United States health economy. This high cost is compounded by the number of adverse events associated with this patient population, including retears of repaired tendons, infection, muscle atrophy with lack of strength improvement, and permanent stiffness of the shoulder [4].

Failure of rotator cuff repair has been reported to occur in 20–94% of patients at 1- to 2-year follow-up with 80% of these failures occurring within 3 months of surgical intervention [5, 6]. While patients may report improved symptomatology regardless of repair integrity, superior clinical outcomes have also been reported in patients with an intact repair [7]. Failures of rotator cuff repairs are multifactorial in nature. Patient demographics (e.g. age, smoking status, tear size/retraction, fatty infiltration), intraoperative variables (e.g. single-row vs. double-row fixation, anchor placement, margin convergence), and postoperative factors (e.g. use of abduction pillow, early vs. late motion, traumatic falls) all play a significant role in clinical failure [8–10]. Many types of rotator cuff tears exist with 35–44% of partial thickness rotator cuff tears progressing to full thickness tears over time due to increased strain at the injury site with an increased risk for developing a large or massive tear [11, 12]. Large and massive tears have historically been more difficult to treat, with massive tears often being deemed irreparable as a result of these reported high failure/retear rates [13]. These high failure rates in the massive or large rotator cuff tear remain a great clinical concern for the orthopedic surgeon.

Retears may occur at one of three locations: bone-tendon failure inside the tunnel, at the interface between the tendon and tunnel, and

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the tendon-suture junction [14]. It has been hypothesized the overall poor tissue quality (e.g., significant fatty infiltration) and fragile nature of these tendons, paired with the difficult task of balancing tension properly across the tendon repair, lead to inadequate tissue regeneration and resultant mechanical failure [15, 16]. With a 14.5% increase in the total number of rotator cuff repairs performed each year, it is imperative that cost efficient and clinically effective treatment modalities are developed to adequately treat this patient population [17, 18]. The development of new techniques to augment rotator cuff repairs has been postulated and shown in several preclinical studies to improve outcomes for many patients [19].

Treatment strategies for rotator cuff tears are guided by rotator cuff tear classification, with surgical intervention often recommended for any lesion involving greater than 50% of the tendon thickness [20]. Partial thickness tears may be subclassified into Grade 1, Grade 2, and Grade 3 based on the depth of the tear [21]. Grade 1 tears involve minor, but definitive disruption of the tendon that does not exceed more than 3 mm in depth. Grade 2 tears extend deeper into the cuff and range from 3 to 6 mm in depth, assuming that the tear does not exceed more than half of the tendon's thickness. Grade 1 and Grade 2 partial thickness tears are often treated nonoperatively. Grade 3 partial thickness tears and those that have failed a course of nonoperative treatment require surgical intervention [22]. Grade 3 tears constitute those tears that are greater than one half of the tendon thickness. Full thickness tears are classified based on how far the tendon edge has retracted from the greater tuberosity of the humerus [23]. One classification system subclassifies them as small (<1 cm), medium (1–3 cm), large (3–5 cm), or massive (>5 cm) [24].

New promising treatment options for the repair of rotator cuff tears are enhancement of rotator cuff repair with the addition of growth factors and stem cells and through the use of a biologically augmented patch [25]. These cells create an ideal environment for tissue regeneration by releasing immunomodulatory and angiogenic cytokines such as TGF-Beta, VEGF, and PGE2 and included in a biologically augmented patches that may provide structural stability and an environment that is conducive for cell and vessel migration [26]. Various types of grafts have been tested, including autografts, allografts, xenografts, and synthetic grafts (Table 40.1). Each type of graft comes with its own advantages and disadvantages. Naturally derived (autograft, allograft, xenograft) materials incorporate an ideal structural/chemical milieu, which is important to host tissue integration; however, there have been concerns regarding the stability of these grafts in vitro [13]. Synthetic grafts do not have this specific issue and provide ideal mechanical stability; however, there have been concerns regarding poor tissue integration and possible host reactions [27, 28]. More recently, the incorporation of amniotic cells as a form of bioinductive matrix has been tested and shown to enhance cell migration and augment tissue healing [29, 30].

One type of augmentation patch with promising clinical results in the repair of partial thickness rotator cuff tears is a bioinductive implant derived from reconstituted bovine Achilles tendon (REGENETEN, Smith and Nephew, Andover, MA, USA). The implant itself is not intended for mechanical augmentation but rather the strength comes from the remodeled tissue. A finite element analysis revealed reduced tendon strain with the creation of 2 mm of new connective tissue over the bursal surface of the supraspinatus tendon, which theoretically might lead to lessen failure rates with a rotator cuff repair [31]. The profile of the bioinductive implant allows for resorption of the implant at a similar rate to host tissue formation, rapid ingrowth of cells and vascularity to promote functional remodeling of the new tissue [32, 33]. Preclinical studies in a sheep model demonstrated complete ingrowth of fibrovascular tissue by 6 weeks in the infraspinatus tendon, formation of collagenous tissue by 12 weeks, and complete resorption of the scaffold by 26 weeks [34]. Increased thickness of the native tendon and integration of the host tissue at the tendon-bone interface were observed.

Table 40.1 Commercially Available Augmentation Patches for Rotator Cuff Repair

Product	Company	Source
Human-derived tendon augmentation grafts		
Clarix® Cord 1K	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

40.1 Guided History and Physical Examination

The most common complaint of a patient with rotator cuff disease is pain at night located on the upper posterolateral aspect of the arm. A full inspection of the shoulder girdle should be completed to identify any atrophy of the rotator cuff musculature followed by palpation of the rotator cuff tendons. Palpation of a full thickness rotator cuff tear can be as accurate as an MRI in the experienced examiner [35]. Side-to-side comparisons again should be made with a palpable defect under the deltoid often appreciated. Classically, patients will have decreased active range of motion compared to passive range of motion due to pain on muscle contraction.

Supraspinatus weakness, weakness in external rotation, and impingement in external or internal rotation are often useful in clinically assessing a patient for a potential rotator cuff tear [36]. A lidocaine injection test can also be performed to assist in the diagnosis of rotator cuff tear with pain relieved after injection and persistent weakness observed.

Other positive special tests with rotator cuff tears include the empty can test, drop arm sign, Whipple test, and in the presence of a massive rotator cuff tear, the hornblower's sign. The empty

can test, or Jobe test, is performed with the arm elevated 90° in the scapular plane with the thumb pointed down (full internal rotation and forearm pronation). The patient resists the downward-directed force applied by the examiner. Pain with arm elevation against resistance is considered a positive test for subacromial impingement and suggestion of a partial rotator cuff tear. The drop arm sign can also be a sign of rotator cuff tear when a patient cannot maintain their arm in a position of 90° of shoulder abduction or is unable to smoothly lower their arm from 90° to 0° abduction. The Whipple test is performed by flexing the arm to 90° and adducting the arm so the hand is in front of the contralateral shoulder. A positive test occurs when pain occurs with resisted elevation. Infraspinatus pathology is noted by pain and/or weakness with resisted external rotation with the arm in adduction. Lastly, the hornblower's sign may be indicative of a massive rotator cuff tear including the infraspinatus and teres minor. The hornblower's sign occurs when the patient's arm is abducted at 90° with the elbow flexed at 90° and the patient is unable to hold external rotation of the arm when placing the hand to the mouth.

Imaging of the shoulder can help to confirm physical exam findings. The MRI (sensitivity and specificity for detecting rotator cuff tears, 98% and 79%, respectively) is a useful modality to aid in the diagnosis of rotator cuff disease to help determine the extent of the tear as well as to evaluate fatty atrophy of the rotator cuff [37]. T2 images provide the best identification of a rotator cuff tear where the footprint separation is often seen in addition to cystic changes of the greater tuberosity. Ultrasound has also become an increasingly popular cost effective, in-office modality to aid in the diagnosis of rotator cuff tears (sensitivity 80.8%, specificity 100%) [38].

40.2 Patient Selection

Candidates for biologic augmentation include patients with suboptimal tissue quality such as patients with diabetes, hemochromatosis, immunosuppression, smokers, and steroid users. Additionally, laborers that place high stress on the rotator cuff and the weekend warrior athlete that has failed conservative treatment including injections and rehabilitation may be suitable candidates to name just a few categories of patients.

40.3 Biologic Augmentation Outcomes

Biologic augmentation in partial thickness rotator cuff tears have been shown to reduce retear rates and improve clinical outcomes compared to rotator cuff repair alone [39]. The efficacy of the reconstituted bovine Achilles tendon bioinductive implant (REGENETEN, Smith and Nephew, Andover, MA, USA) was tested in a clinical trial involving 13 patients (average age of 53.8 years, range 42–67 years) with supraspinatus tendon tears [six intermediate grade (3–6 mm) and seven high grade (>6 mm)], chronic shoulder pain greater than 3 months resistant to medications, and physical therapy [40]. Patients were excluded if they had grade 3 or greater chondromalacia or grade 2 or greater fatty infiltration of the supraspinatus muscle. MRI evaluation was used to determine if the tears progressed, remained the same, or reduced in size over the course of 3, 6, 12, and 24 months postoperatively. Clinical assessments including the Constant-Murley shoulder score and the American Shoulder and Elbow Society (ASES) shoulder score were used to assess pain and functional outcomes at similar intervals. Three months postoperatively, MRI evaluation displayed a significant increase in new tissue induction with a mean increase in tendon thickness of 2.2 ± 0.26 mm [40]. No patients showed evidence of tear propagation or tendon degeneration on imaging at the 24-month follow-up visit. Similarly, constant and ASES scores showed significant improvements during clinical follow-ups supporting the efficacy of this bioinductive implant to repair partial thickness, intermediate-, and high-grade rotator cuff tears.

A recent prospective, multicenter trial of 33 patients with intermediate-/high-grade partial thickness supraspinatus tears also reported positive results at 1 year with subacromial decompression and placement of a bioinductive implant on the bursal side of the tear without rotator cuff

repair [41]. Eleven patients had an articular-sided tear, ten had a bursal-sided tear, four had intrasubstance tears, and eight had both articular- and bursal-sided tears. Clinical follow-up 1 year postoperatively showed improved ASES pain and function and shoulder index scores. MRI evaluation showed a reduction in defect size in 76% of patients and a complete filling in of the defect in 18% of patients by 3 months. At 1 year, 24% of patients demonstrated a complete filling in of the defect, and 70% had a reduction in defect size. Tendon thickness improved from 3.1 ± 0.3 mm preoperatively to 5.4 ± 0.3 and 5.2 ± 0.2 mm at 3 and 12 months, respectively, demonstrating the induction of new tissue on the bursal side of the supraspinatus tendon.

While the augmentation implants were initially designed for the treatment of partial thickness rotator cuff tears, they have now become a treatment alternative in patients with full thickness and massive rotator cuff tears. A study by Cai et al. assessed the effectiveness of a 3D type I collagen implant (Zhejiang Xingyue Biotechnology) in 104 patients with moderate to large rotator cuff tears [42]. All patients underwent rotator cuff repair with a suture-bridge technique, and the investigational group underwent repair plus augmentation with the 3D collagen implant. Patients in the 3D collagen implant group demonstrated improved UCLA and Constant scores 12 months postoperatively. A 40% reduction in retear rate was seen (control group, 34%; treatment group, 13.7%). Similar results have also been reported in patients with two-tendon rotator cuff tears measuring greater than 3 cm treated with arthroscopic single row repair plus an acellular human dermal matrix [43]. While these results are promising, more studies are necessary with longer term follow-up to assess the true efficacy of these alternatives.

40.4 Other Augmentation Graft Alternatives

40.4.1 Human-Derived Allografts

Acellular human dermal matrixes are capable of promoting vascularization and structural stability while attempting to minimize immunologic response to the foreign material. While there are currently a number of dermal tissue allografts on the market, the GraftJacket (Wright Medical Group, TN, USA) has been most frequently studied in clinical trials. Biologic augmentation with the GraftJacket has been found to produce significantly improved functional outcomes and pain scores with healing rates ranging from 74% to 85% [43–47]. Bond et al. noted that 81.3% of repairs were intact on final analysis, with only three of their study participants demonstrating radiographic failure of the allograft [44]. Interestingly, all three of these patients were satisfied at their last clinical follow-up due to the pain relief postoperatively. Gupta et al. conducted a study investigating the utility of human dermal tissue allograft in repairing massive rotator cuff tears of 24 patients demonstrating improved postoperative ASES, SF-12, and pain scores [45]. Nineteen patients returned for follow-up ultrasound at an average of 3 years following surgery, and 14 of these patients (74%) were found to have fully intact repairs while the remaining 24% of patients demonstrating partial retears.

Other acellular human dermal matrix allografts that have been clinically investigated include the Allopatch HD Ultra Thick (MTF Sports Medicine) and Arthroflex (2-mm ArthroFlex Patch; Arthrex, Naples, FL) patches. Studies using these acellular human dermal patches also demonstrate high patient satisfaction, with intact rates of 85.7% and 83.3% for the patients that completed follow-up imaging, respectively [48, 49]. Agrawal et al. assessed intact rates by tear size and found that 90% patients presenting with large tears (3–5 cm) had an intact repair at follow-up compared to only 66.7% of patients with massive tears (>5 cm) suggesting that massive tears continue to pose a problem for the orthopedic surgeon [48].

40.4.2 Xenograft

Xenogenic material can undergo a decellularization process to become an extracellular matrix for scaffolds for tissue engineering. Several types of xenografts have been utilized to augment the repair of RTCs including porcine submucosa [50,

51] and porcine dermis [52]. Porcine small intestine submucosa not only serves as a scaffolding upon which host cells can attach, but it also contains growth factors such as fibroblast growth factor-2 (FGF-2), transforming growth factor-β (TGF-β), and vascular endothelial growth factor (VEGF) [53]. Several authors have hypothesized that these agents could allow porcine submucosa to be a viable option for biologic augmentation of rotator cuff tear repairs. In a study by Iannotti et al., 30 patients with chronic, two-tendon rotator cuff tears were randomized to be surgically repaired by augmentation with porcine small intestine submucosa (Restore Orthobiologic Implant; DePuy, Warsaw, Ind) or no augmentation [50]. Rotator cuff healing was observed in 4 out of 15 shoulders in the augmentation group and 9 out of 15 patients in the control group. When adjusting for the effect of tear size on the rate of healing, repairs without augmentation were 7% more likely to heal than augmented repairs.

Phipatanakul and Peterson conducted a similar study prospectively investigating the utility of the same porcine small intestine submucosa (Restore Orthobiologic Implant; DePuy, Warsaw, Ind) for the augmentation of massive rotator cuff repairs primarily in a revision setting [51]. Mean UCLA scores significantly improved from 13.9 to 25.7, and mean ASES scores improved from 36.3 to 71.8. Ten of the 11 patients were satisfied with the results. Repair integrity was assessed in nine patients (eight with MRI and one with second-look arthroscopy). Despite the promising functional outcome scores, only three out of nine patients had intact rotator cuffs. Furthermore, the authors reported an infection in one patient localized skin reactions in two patients requiring additional surgery. The failure of porcine small intestine submucosa xenografts is thought to be due to the mechanical weakness of the graft outweighing any potential biologic advantages of the xenograft tissue.

Other studies have investigated the utility of porcine dermis patch augmentation. Flury et al. compared 19 patients who underwent repair and porcine dermal patch augmentation to 20 patients who underwent arthroscopic transosseous-equivalent technique rotator cuff repair [52]. At 24-month follow-up, nine patients in the porcine dermis patch augmentation group had a recurrent supraspinatus tendon defect, while this occurred in only four patients of the control group, despite no difference in pain or functional outcomes. This study serves to suggest that porcine xenografts are not associated with better results relative to no biologic augmentation. On the contrary, Badhe et al. conducted a similar study investigating the utility of porcine dermal collagen (Zimmer Patch, formerly known as Permacol; Tissue Science Laboratories plc, Aldershot, Hampshire, UK) in tendon augmentation of rotator cuff tears demonstrating promising results [54]. Preoperative and postoperative functional outcomes, pain scores, and MRI or ultrasound imaging in ten patients with chronic, massive tears of either the supraspinatus or infraspinatus tendons were compared. Patients exhibited improved pain, function, and abduction strength at 1-year follow-up with eight of the ten grafts intact on MRI assessment at average follow-up of 4.5 years (range 3–5 years). The authors concluded that porcine dermal collagen can be used to effectively augment the surgical repair of chronic, massive rotator cuff tears; however, further randomized studies are warranted as there was no control group in this study.

40.4.3 Synthetic Grafts

Several synthetic patches have also been developed for augmentation of rotator cuff repairs with the hope of creating a biologically and mechanically viable scaffold to optimize outcomes and enhance repair. Synthetic patches have been constructed from a variety of materials, including polypropylene, polyurethane, poly(L-lactide), and polyethylene polymers with varying degrees of degradability. Vitali et al. compared augmentation with a polypropylene patch to a non-augmented control group in 120 patients [55]. Functional and clinical results including adduction and elevation range of motion were superior in the augmented cohort. Patients in the augmented cohort had a 15% retear rate compared to 40% in the control group. This study exhibited clear evidence in favor of synthetic patches over non-augmentation repair techniques for tears over 5 cm in size. In a 2014 study, the polypropylene patch was com-

pared to a xenograft (bovine pericardium-induced patch) and control group [56]. VAS and UCLA scores, range of motion, and strength were significantly higher in the polypropylene group at 36 months as compared with the control and xenograft cohort. Retear rates were the lowest in the synthetic cohort at 17% compared with the 41% retear rate seen in the control cohort. Interestingly, the xenograft cohort exhibited the highest retear rates at 51%.

Polyurethane patch augmentation was investigated in ten female patients with tears ranging from 1 to 4 cm who had failed conservative treatment after 6 months [57]. Significant improvements in pain, ASES score, Simple Shoulder test, and Constant Activities of Daily living score were reported 12 months postoperatively compared to preoperative scores. The retear rate was 10% and no adverse events were associated with the patch.

Lenart et al. investigated the use of poly-L-lactide patch augmentation in rotator cuff repairs for patients with massive or recurrent rotator cuff tears and an average fatty atrophy grade of 1.5 (range 0–3) [58]. While the PENN and ASES score showed significantly higher postoperative values, there was a 61.5% retear rate noted on MRI at 1.5-year follow-up. This is in contrast to the 17% retear rate that was noted in a study including 18 patients presenting with large to massive rotator cuff tears that were augmented with the poly-L-lactide patch (X-Repair; Synthasome Inc., San Diego, CA, USA) [59].

We have utilized the bovine bioinductive patch augmentation (REGENETEN, Smith and Nephew, Andover, MA, USA) for the last 3 years in patients with partial thickness and full thickness rotator cuff repairs. At average follow-up of 20 ± 6 months (±standard deviation), we have had no clinical failures (e.g. retear of rotator cuff). Patients exhibit improved shoulder range of motion and strength as well as functional abilities [average Disabilities of the Arm, Shoulder and Hand (DASH) Score 10 (0 = better function)] by 3 months postoperatively. Average patient satisfaction score is 8.5 out of 10.

We present here the case of a 69-year-old diabetic male with a sudden onset of right shoulder pain after feeling a pop in his shoulder when transferring a heavy weight. The patient reported pain and weakness with abduction and external rotation ranges of motion. Visual inspection of the shoulder revealed no erythema, warmth, or rubor and no evidence of atrophy in the shoulder girdle. Physical examination revealed mild loss of range of motion, 140° of forward flexion, 100° of abduction, and 35° of external rotation and internal rotation to T11, equivocal to the other side. Impingement and Neer tests were positive with a painful arc of abduction prior to injection. Lift-off, belly press, Whipple sign, O'Brien's, as well as instability and apprehension tests were negative. Empty can test was weak and painful. Shoulder strength was 5/5 throughout including the infraspinatus and deltoid with the exception of 3+/5 strength of the supraspinatus. The patient was neurovascularly intact. MRI revealed severe supraspinatus tendinosis associated with high-grade partial thickness tearing of the anterior fibers. All treatment options were discussed, and a decision was made to proceed with rotator cuff repair with augmentation with a bovine bioinductive patch augmentation (REGENETEN, Smith and Nephew, Andover, MA, USA) (Figs. 40.1, 40.2, 40.3, and 40.4). At 2.5-year follow-up, the patient is pain-free performing all activities including weight lifting without any difficulty. The patient's range of motion is 170° of forward elevation and abduction, 90° of external rotation, and internal rotation to T11 with

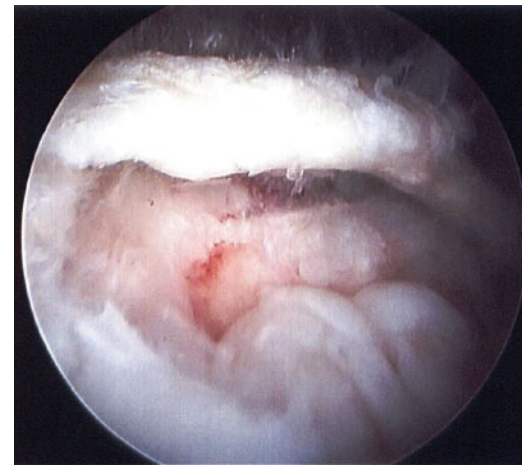

Fig. 40.1 Arthroscopic view of massive rotator cuff tear in the right shoulder of a 69-year-old diabetic male. Copyright Kevin D. Plancher, MD, MPH

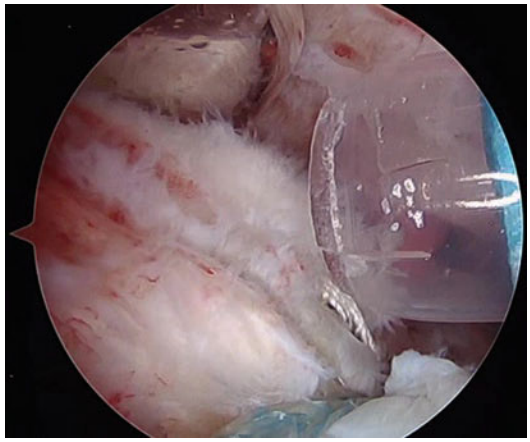

Fig. 40.2 Rotator cuff repair completed with insertion of cannula for the bovine bioinductive patch (REGENETEN, Smith & Nephew, Andover, MA, USA). Copyright Kevin D. Plancher, MD, MPH

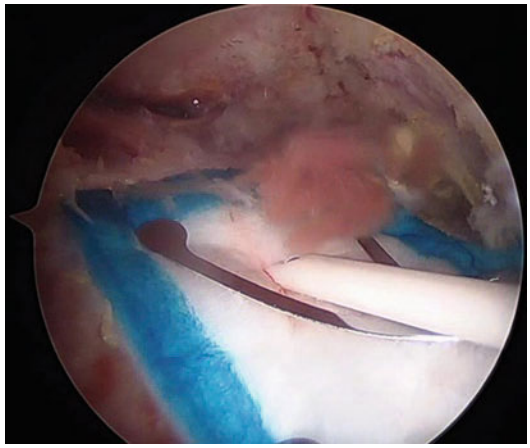

Fig. 40.3 Placement of the bovine bioinductive patch (REGENETEN, Smith & Nephew, Andover, MA, USA) over the rotator cuff repair. Copyright Kevin D. Plancher, MD, MPH

5/5 strength throughout the rotator cuff musculature demonstrating success with rotator cuff repair and biologic augmentation.

40.5 Conclusions

Rotator cuff repairs are commonly performed procedures in spite of the high failure rate. A variety of augmentation patches have been tested

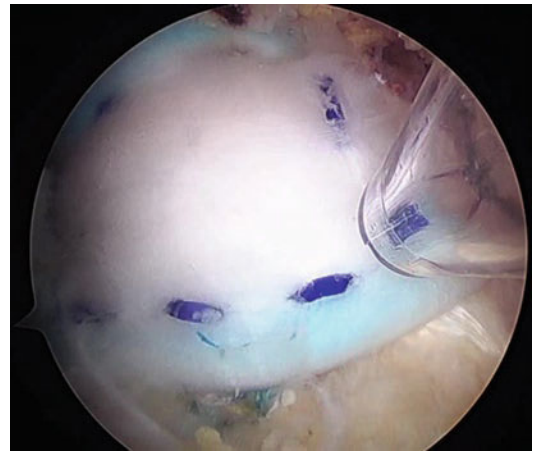

Fig. 40.4 Final placement of the bovine bioinductive patch (REGENETEN, Smith & Nephew, Andover, MA, USA) secured with multiple tendon anchors over the completed rotator cuff repair. Copyright Kevin D. Plancher, MD, MPH

in clinical trials to develop new surgical techniques that will hopefully lower failure rates. One patch made of reconstituted bovine Achilles tendon (REGENETEN, Smith and Nephew, Andover, MA, USA) has shown promise in recent clinical trials, but long-term studies are warranted to further identify which materials will provide ideal mechanical stability and growth environment to aid in the repair of rotator cuff tears.

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41 Biologic Augmentation in RC Repair (Patches and Grafts): Part II

Kristi Hultman, Brandon J. Erickson, Meghan E. Bishop, and Anthony A. Romeo

41.1 Introduction

Rotator cuff tears are a common problem among middle age and older adults that can result in significant morbidity. Shoulder pain accounts for over 4.5 million doctor visits per year in the United States, with rotator cuff pathology as the leading cause [1]. Current studies suggest the prevalence of rotator cuff abnormalities in symptomatic shoulders is 40% in adults 40–50 years old, between 61% and 68% in adults 50–80 years old, and 50% in adults over 80 years old [2]. As our population continues to age, the number of patients requiring treatment will increase.

Current standard of care for a symptomatic rotator cuff tear is either an open or arthroscopic repair of the torn tendons with sutures and anchors in a variety of configurations, although there is a role for conservative treatment alone in certain patients. Certain rotator cuff tears, such as acute on chronic tears, partial-thickness tears, etc., can be treated with conservative measures including therapy and steroid injections. Unfortunately approximately half of those patients will have tear progression that can result in worsening pain and disability, often necessitating operative intervention at a later point in time. Rotator cuff tear progression is associated with smoking, male sex, hand dominance, trauma, age, fatty infiltration, medium- to large-sized tears, and full-thickness tears. These tears have been shown to progress at an average rate of 2 mm/year in width and 3.8 mm/year in length [3, 4]. Surgical repair of the rotator cuff is recommended for younger patients, laborers who have acute or traumatic tears and larger tears, or patients that have failed conservative treatment [4]. Despite advances in surgical techniques and technology, current literature shows retearing of the rotator cuff in approximately 25% of patients within the first 2–5 years following surgical treatment, with an even higher percentage of retears seen in larger rotator cuff tears [5–7].

41.2 Tendon Healing

Considering the relatively high rate of failure for rotator cuff repairs, it is important to examine the biology behind the tendon-to-bone healing process to better understand how it can be improved. Predisposing factors known to contribute to poor healing capacity and that carry a greater risk for retearing include tear size, tear chronicity, patient age, smoking status, tendon and muscle quality, and fatty infiltration or muscle atrophy [4, 8].

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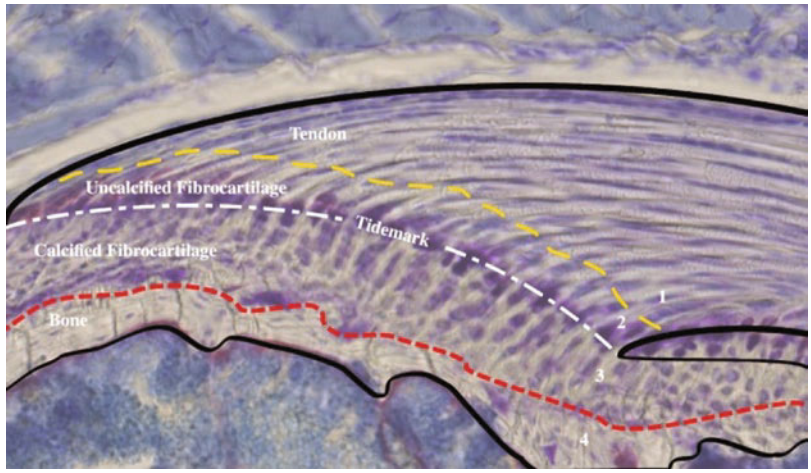

Fig. 41.1 Four zones of the tendon-to-bone interface. Zone 1 is the tendinous region composed primarily of linearly arranged Type I collagen. Zone 2 is non-mineralized fibrocartilage composed of Type I, II, and III collage. The tidemark separates the non-mineralized and mineralized fibrocartilage zones. Zone 3 is composed of primarily calcified Type II collagen and is separated from Zone 4 by an irregular border. Zone 4 is composed of bone and contains osteocytes, osteoblasts, and osteoclasts

For a rotator cuff repair to heal, a complex process must take place at the tendon-to-bone interface, known as the enthesis. The enthesis is where the tendon inserts into the bone and consists of four structurally distinct zones (Fig. 41.1) [9]. Zone 1 is the tendinous region composed primarily of linearly arranged Type I collagen with mechanical properties similar to mid-substance tendon. Zone 2 is an avascular region of non-mineralized fibrocartilage composed of Types I, II, and III collagen. This region functions as a force damper, dissipating stress generated by the bending of the collagen fibers during movement of the arm. A tidemark between Zones 2 and 3 demarcates the boundary between soft and hard tissue. Zone 3 is the mineralized fibrocartilage region comprised of calcified Type II collagen, along with lesser amounts of Type I and X. This zone is the true junction between tendon and bone and has an irregular boundary with the bone, which acts to interlock the layers and provides mechanical integrity of the enthesis. Finally, Zone 4 consists of bone, made up of Type I collagen and carbonated apatite mineral with osteocytes, osteoclasts, and osteoblasts living within the matrix [8, 9]. Unlike these four very structured and organized zones found in native tendon-to-bone attachments, tendon repair sites heal with the formation of fibrovascular scar tissue which does not demonstrate the same underlying structure and is weaker and more prone to failure [10–12]. Embryological development studies have shown that both biological and mechanical factors are required for proper development of the enthesis and thus are targets for improving the healing of the tendon repairs [11].

The development of the fibrocartilage scar tissue passes through three stages: inflammation (immediately after injury), fibroblastic (2–7 days after injury), and remodeling (1–2 months after injury) (Fig. 41.2) [9, 12, 13]. The inflammation stage begins with platelets depositing fibrin and fibronectin at the injury site, followed by an accumulation of macrophages and neutrophils responding to cytokine signaling from insulin-like growth factor 1 (IGF-1), platelet-derived growth factor (PDGF), and transforming growth factor beta (TGF-β) [12]. The accumulated macrophages then secrete TGF-β1 which causes a proliferation of fibroblasts and marks the transition into the repair phase. The scar tissue formed during the repair stage is composed primarily of Type III collagen, which then undergoes matrix metalloproteinase (MMP)-mediated remodeling as a result of extracellular-mediated turnover, remodeling a portion of the Type III to Type I

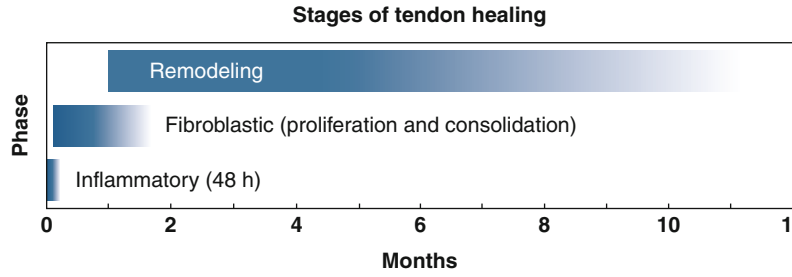

Fig. 41.2 Timeline for the tendon healing process as it passes through three stages: inflammation (beginning immediately after injury), fibroblastic (beginning 2–7 days after injury), and remodeling (beginning 1–2 months after injury)

collagen [12]. Despite the above healing process, a large proportion of the tendon remains Type III, and the mineralized fibrocartilage zone does not reform during healing which results in a biomechanically weaker junction of tendon to the bone. This complex healing process, combined with biological factors of the rotator cuff that limit healing (limited vascularity to the anterolateral rotator cuff, intrinsic degenerative changes to the tendon and muscle in patients with chronic, atraumatic tears), contributes to the relatively high failure rate of healing following rotator cuff repairs [14].

Biologic augmentation seeks to improve on the healing process by providing growth factors or cells to the repair site to encourage a more native-like structure to the tendon-to-bone interface after repair. The three main methods of biologic augmentation include platelet-rich growth factors, platelet-rich plasma (PRP), and stem cells. These techniques can be used on their own or in addition to other techniques such as patches and xenografts to help create a stronger rotator cuff repair. Growth factors follow predictable expression patterns during early tendon healing and are critical for the healing process. The functions of these growth factors include promoting the inflammatory response (vascular endothelial growth factor [VEGF], PDGF, basic fibroblast growth factor [bFGF]); increasing cellular proliferation, differentiation, and matrix synthesis (TGF-β); remodeling the extracellular matrix (MMP); and promoting incorporation of the tendon into the bone (bone morphogenetic protein [BMP]) [14]. Early studies used primarily single bolus dosing of growth factors, often intraoperatively, which often results in a very short half-life and thus limits the body's response [15, 16]. Animal studies have shown that growth factor concentrations in the rotator cuff rise and fall over the span of 2 weeks coinciding with the inflammation and early repair phases of tendon healing; thus there is a shift toward using multiple bolus doses or sustained delivery methods to mimic the natural growth factor expression levels [15–17].

41.3 Insulin-Like Growth Factor

IGF-1 is an endocrine hormone similar to insulin that stimulates the proliferation and migration of fibroblasts and other cells to assist with tendon repair. A study by Dines et al. used rat tendon fibroblasts cultured and transfected with a gene for IGF-1 to demonstrate increased toughness and maximum load to failure in repairs with increased IGF-1 in vivo [18].

41.4 Vascular Endothelial Growth Factor

VEGF is a family of signaling proteins that use tyrosine kinase receptor-mediated signaling cascades to promote angiogenesis and vasculogenesis. A study by Zumstein et al. used a leukocyte- and platelet-rich fibrin concentrate, given in four doses locally to the tendon-bone interface of the rotator cuff repair, to deliver a steady stream of VEGF to the repair site over the course of 28 days. Improved vascularization was

found in VEGF-treated patients early on using doppler analysis, but no significant improvement or clinic benefits were identified after 3 months [19]. Using a rat Achilles tendon model, VEGF was injected into the repair site, and increased Achilles tendon tensile strength was found in the VEGF group during the early postoperative period [20]. However, in a sheep ACL model, grafts soaked in a VEGF solution prior to implantation demonstrated less stiffness and greater laxity to the ACL graft compared with the control group. On histology, the VEGF-treated grafts did demonstrate increased vascularity and angiogenesis compared with the controls [21]. It is unclear whether the ACL and Achilles findings would translate to rotator cuff healing, and it is important to note the differences in the method and timing of VEGF delivery to the injury site which may be important to how the healing tendon responds.

41.5 Platelet-Derived Growth Factor

PDGF is a pro-inflammatory cytokine that peaks in the first 7–14 days and functions as a chemotactic agent for recruiting inflammatory cells and promoting the production of Type I collagen synthesis [15]. Hee et al. [22] demonstrated increased biomechanical strength and anatomic morphology of rotator cuff repairs in the ovine model using a human recombinant PDGF-BB-infused Type I bovine collagen graft matrix. Additionally, the degree of the healing response was dependent on the dose, timing, and PDGF delivery vehicle that was used. PDGF is a promising growth factor for augmentation of rotator cuff repairs, though further studies are needed to confirm the results in human patients.

41.6 Basic Fibroblast Growth Factor

Basic fibroblast growth factor (bFGF) is a growth factor produced by fibroblasts and leukocytes that strongly stimulate angiogenesis and the proliferation of fibroblasts [15, 23]. It also promotes the production of Type III collagen and inhibits the production of Type I pro-collagen [16]. Production of bFGF is highly elevated for the entire healing process. Using an intrasynovial flexor tendon model in canines, Thomopoulos et al. [24] demonstrated that the use of bFGF resulted in increased vascularity, cellularity, and adhesion of the tendon. However, bFGF also caused increased peritendinous scar formation and did not improve mechanical or functional properties of the tendon.

41.7 Transforming Growth Factor Beta

TGF-β is a cytokine superfamily made up of three isoforms (TGF-β1, TGF-β2, TGF-β3) that are believed to have a significant role in tendon and ligament formation through a diverse array of physiologic functions including cellular growth, proliferation, differentiation, and matrix synthesis [14]. TGF-β1 and TGF-β2 are highly expressed during postnatal wound healing and are associated with extensive scar formation, while TGF-β3 is not expressed in the adult healing environment. In contrast, TGF-β3 is highly expressed in prenatal wound healing and is characterized by scarless tendon healing, making it a promising agent to promote regenerative healing of rotator cuff tears [25]. In a study by Kim et al. [26] examining the role of TGF-β1 and TGF-β3 at the tendon-bone insertion site of repaired rat supraspinatus tendons, an osmotic pump was used to deliver the proteins to the repair site. In rats treated with TGF-β1, there was increased Type III collagen production, consistent with a scar-mediated healing response. These animals also trended toward reduced mechanical properties compared with controls. Rats treated with TGF-β3 showed no histological or biomechanical improvement compared with controls. In a subsequent study where TGF-β3 was delivered directly to the tendon insertion site using a heparin-/fibrin-based delivery system, TGF-β3 animals demonstrated accelerated healing with increased inflammation, cellularity, vascularity,

and cell proliferation at early time points [25]. Additionally, these animals showed significant improvements in the structural properties at 28 days, and the mechanical properties at 56 days follow tendon repair with TGF-β3 augmentation. These findings suggest that TGF-β3 can improve the tendon-to-bone healing in vivo following rotator cuff repair in a rat model and also demonstrate the importance of the delivery method used. Movacevic et al. [27] examined the effect of TGF-β3 mixed in an injectable calcium-phosphate (Ca-P) matrix delivered to the tendon-bone interface of repaired rat supraspinatus tendons. Rats treated with the Ca-P matrix alone demonstrated new bone formation with increased fibrocartilage and improved cartilage organization in the early postoperative period. In rats treated with the TGF-β3-augmented Ca-P, there was a significant improvement in strength at the repair site at 4 weeks postoperatively with a more favorable collage Type I/III ratio, indicating more mature healing of the tendon. These studies demonstrate the potential therapeutic role of TGF-β3 to improve tendon healing following surgical repair.

41.8 Matrix Metalloproteinase

MMPs and their inhibitors (tissue inhibitors of metalloproteinases [TIMPs]) maintain the integrity of the tissue extracellular matrix and may play a critical role in the pathophysiology of rotator cuff tears [28]. MMPs, in particular MMP-1, MMP-8, and MMP-13, are zinc-dependent endopeptidases responsible for the degradation of the extracellular matrix through the cleavage of extracellular proteins, including fibrillar collagens [29]. They are present in every human inflammatory disease and contribute to the inflammatory response through modulation of cytokines and chemokines, regulation of the movement of leukocytes, and regulation of physical barriers [30]. MMPs and their antagonists, TIMPs, exist in a dynamic balance to maintain the extracellular matrix; disruption of this homeostasis can lead to degradation and breakdown of tendons [31, 32].

The levels of MMPs and TIMPs in rotator cuffs tears have been examined in several studies. Lakemeier et al. [33] found significantly higher levels of MMP-1 and MMP-9 expression, as well as lower levels of MMP-3 in torn rotator cuff tissue compared with healthy controls. They also saw a significant association between MMP-9 expression and the extent of tendon retraction. In a second study by the group, it was found that MMP-1 and MMP-9 expressions were significantly higher for articular-sided partial-thickness tears compared with bursal-sided tears [34]. They also saw elevated levels of MMP-1 and MMP-9 with decreased levels of MMP-3 in degenerative long head of the biceps tendons associated with rotator cuff tears. No difference was seen for full-thickness tears or when comparing the extent of the cuff tear using Bateman's classification.

Gotoh et al. [35] examined the mRNA expression of multiple MMP and TIMP levels in patients with and without postoperative retears following rotator cuff repair. Patients with recurrent tearing of the rotator cuff showed upregulation of both MMP-3 and TIMP-1 gene expressions with no significant changes seen in MMP-1 or MMP-9. This suggests that MMP-3 and TIMP-1 are potential targets for post-repair therapy to prevent recurrent tearing of the rotator cuff.

41.9 Medications to Regulate MMPs

In addition to the antimicrobial properties of the tetracycline family, they also have the ability to inhibit MMPs and thus reduce degradation and remodeling following a rotator cuff repair [36]. In a rat model study examining the use of oral doxycycline following rotator cuff repair, it was shown by Bedi et al. [36] that perioperative use of doxycycline results in increased amounts of fibrocartilage with improved collagen organization. Animals treated with doxycycline showed significant reduction in MMP-13 expression at postoperative day (POD) 8, but not at 4 weeks. At 2 weeks, biomechanical testing of the rotator

cuff of rats treated with doxycycline preoperatively and on POD 5 demonstrated a greater load to failure compared with controls. Nguyen et al. [37] looked at the effect of doxycycline in Achilles tendon tears in a rat model receiving daily doses via gastric lavage. Rats which had surgical repair of the Achilles tendon showed increased quality of the repair compared with controls, with significant improved of collagen fiber dispersion. The repaired tendons treated with doxycycline also demonstrated an increased dynamic modulus at 6 weeks, with an increased equilibrium modulus and decreased creep seen in doxycycline-treated tendons regardless of repair group. Expression of MMP-3 was significantly decreased in doxycycline-treated rats at 9 weeks. This suggests that treatment with doxycycline preoperatively or early postoperatively may improve tendon repairs and improve biological properties of the tendons.

Medications such as fluoroquinolones and nonsteroidal anti-inflammatory drugs (NSAIDs) can negatively impact the healing ability of rotator cuff due to their influence on MMP levels. Fluoroquinolones are known to carry a risk of tendinopathy and tendon ruptures with their use. Fox et al. [38] used a rat model to examine the effect on fleroxacin on rotator cuff healing. Rats receiving the antibiotic pre- and postoperatively were found to have a 30-fold increase in MMP-3, a sevenfold increase in MMP-13, and a fourfold increase in TIMP-1 expression compared with the other groups. All treatment groups showed significantly less fibrocartilage with poorly organized collagen at the healing enthesis compared with controls, and the tendons were more friable and atrophic. The group receiving fleroxacin both pre- and postoperatively had significantly reduced tendon cross-sectional area and load to failure compared with the other groups. During load to failure testing of the supraspinatus tendon, treated animals experienced intrasubstance failure, while only 10% of the controls failed within the tendon substance. The effect of diclofenac, an NSAID, was examined in rats following supraspinatus tendon repair by Cabuk et al. [39] Animals receiving daily doses of diclofenac showed significant decrease in MMP-3 at the end of week 1 with a reduced maximum load to failure, decreased levels of MMP-13, and decreased stiffness toward week 6 compared with controls. Cohen et al. [40] treated rats with the NSAIDs indomethacin or celecoxib following rotator cuff repair and found significantly decreased maximum load to failure in both groups compared with controls. While the control groups demonstrated increased collagen organization and maturation at the repair site over time, the NSAID-treated rats did not. The rotator cuff completely failed to heal in four of the celecoxib and one of the indomethacin-treated rats. The above results suggest that NSAIDs may disturb the tendon healing process and avoidance in the early postoperative phase could improve the healing after tendon repair.

41.10 Platelet-Rich Plasma

The use of platelet-rich plasma (PRP) as a biological agent to improve tendon healing has been gaining popularity recently. PRP is an autologous derivative of whole blood produced by centrifuging the patient's blood to obtain a plasma solution with supraphysiologic levels of platelets and growth factors, such as IGF-1, VEGF, PDGF, FGF-2, and TGF-β [41]. It can be used either as a way to augment a surgical repair or as an alternative to surgery. Current theories suggest local use of PRP around the injured tendon will result in an increase in the recruitment and proliferation of tenocytes, stem cells, and endothelial cells which will enhance the healing potential of the tissue [41]. Due to the variability in the methods used for processing and administering PRP, there is inhomogeneity in the composition and availability of biologic factors being delivered to the tendon repair site. The lack of uniformity in the preparations makes comparison between studies difficult and limits what conclusions can be made about the efficacy.

41.11 Types of Platelet-Rich Plasma

There are four main types of PRP based on which layers of the solution are included after centrifugation of the blood sample and the presence of fibrin after activation. Pure PRP (P-PRP) includes only the plasma layer of the centrifuged sample; it does not contain leukocytes, fibrin matrices, or thrombin [17]. When the buffy coat layer containing leukocytes is included, in addition to the plasma layer, the solution is called leukocyte-rich (L-PRP) [42]. The effects of the inclusion of leukocytes is controversial, with some studies suggesting the leukocytes pro-inflammatory response is beneficial for tendon healing and pain relief, while other studies indicate that the resulting inflammation may be detrimental to healing [17, 42]. Pure platelet-rich fibrin (P-PRF) and leukocyte and platelet-rich fibrin (L-PRF) have a high-density fibrin architecture made by activating thrombin within the plasma to create a fibrin clot which sequesters the platelets and allows them to be sutured or glued into place [43]. The use of a matrix or scaffold with PRP maintains the PRP at the desired location and allows for a slower, more controlled release of growth factors and cytokines [43].

41.12 In Vitro and Animal PRP Studies

In vitro and animal PRP studies demonstrate promise for its use in improving the healing of rotator cuff tears. Several studies have demonstrated that tenocytes isolated from degenerative rotator cuff tears cultured with a PRP gel had increase cell proliferation, enhanced gene expression, and synthesis of tendon matrix compared with control cells. They also noted that activation of the PRP with calcium or calcium and thrombin increased the production of Type I and III collagen but did not alter their ratio [44–46]. Cross et al. [47] cultured tendon tissue from degenerative supraspinatus tears in PRP solutions containing leukocyte-rich and leukocyte-poor concentrations to determine the effect of leukocyte concentration on the tendon tissue. In tendons with moderate disease, low leukocyte levels promote normal collagen matrix generation and lower expression of cytokines associated with inflammation and matrix degeneration. In severely degenerative tendons, both high and low leukocyte preparations showed increased inflammation, and neither group demonstrated enhanced collagen synthesis. Their results suggest the degree of tendon damage may influence which type of PRP may be the most beneficial for healing.

Studies examining the effect of PRP on rotator cuff repairs in rat models found that rotator cuff repairs augmented with PRP had greater load to failure and enhanced stiffness vs. controls [48, 49]. PRP-augmented repairs also showed increased fibroblastic response and vascular proliferation, as well as more organized collagen fibers at the repair site [49, 50]. A study by Takase et al. [51] demonstrated the proliferation of myoblast cells and inhibition of adipogenic differentiation when PRP was injected into torn rat rotator cuffs, suppressing fatty degeneration of the torn cuff muscles.

41.13 In Vivo PRP Studies

In vivo studies on PRP-augmented rotator cuff repairs in the human population have shown mixed results. Some studies suggest that there may be a decrease in the retear rate in rotator cuff repairs augmented with PRP under certain conditions, such as small- to medium-sized tears, use of a solid PRP matrix, application of the PRP at the tendon-bone interface, and use of a double-row repair [52–54]. In a meta-analysis by Warth of rotator cuff repairs with a tear size greater than 3 cm repaired with a double-row construct, PRP-treated repairs had a significantly greater reduction in retear rates compared with controls (25.9% vs. 57.1%) [53]. Tendon repairs treated with a PRP fibrin matrix showed a greater, but not significant, reduction in retearing compared with those treated by PRP injection (14.8% vs. 46.8%). They were unable to find any significant

improvement clinically in patients with the exception of postoperative Simple Shoulder Test (SST) scores. A meta-analysis by Cai et al. [54] also concluded there was no significant clinical improvement with the use of PRP and that the effect of the PRP was improved using a fibrin matrix over a liquid preparation. However, in contrast to the Warth analysis, the Cai analysis did find decreased tearing in small- to medium-sized tears compared with large to massive tears, similar to the findings from the Saltzman systematic review [52, 54]. Randelli et al. [55] examined pain level and outcome stores following arthroscopic repair in a prospective, double-blinded study and found decreased pain scores over the first 30 days after surgery. They also found significantly improved SST, Constant, and University of California (UCLA) scores and external rotation strength at 3 months postoperatively. However, at 6 months and later, there was no significant difference between the treatment and control groups. A meta-analysis by Hurley et al. [56] found PRP use in arthroscopic rotator cuff repairs resulted in significantly decreased rates of incomplete healing in small-medium (22.4% vs. 38.3%, respectively; $P < 0.05$) and medium-large tears (12.3% vs. 30.5%, respectively; $P < 0.05$), as well as all tears (17.2% vs. 30.5%, respectively; $P < 0.05$) compared with controls. They also found significantly better Constant score (85.6 vs. 83.1, respectively; $P < 0.05$) and visual analog scale (VAS) for pain (2.9 vs. 4.3, respectively; $P < 0.05$) at 1 month postoperative and at final follow-up (VAS 1.2 vs. 1.4, respectively; $P < 0.05$) compared with controls. Jo et al. [57] looked at biologic augmentation of large to massive rotator cuff tears repaired arthroscopically with PRP gels. They found a significantly lower rate of retear in PRP shoulders vs. controls (20.0% vs. 55.6%; $P < 0.05$) along with a significantly larger cross-sectional area (CSA) of the supraspinatus (-15.54 mm^2 vs. -85.62 mm^2). Despite the decrease in retear rate and the increased CSA, there was no significant difference in the clinical outcome. The inconsistencies between the PRP preparations used and delivery methods make comparison between studies difficult. Additionally, many of the studies have small participant numbers, and the lower power of these studies may make it hard to detect smaller improvements in histology or function. Overall, the use of PRP in certain instances can result in improved tendon healing, decreased tearing, and some changes to functional scoring, but there does not seem to be significant clinical improvements despite these benefits beyond the first 3–6 months.

41.14 Stem Cell Therapy

The use of mesenchymal stem cells (MSCs) to augment tendon healing in rotator cuff repair has been an area of significant interest due to their potential anti-inflammatory and angiogenic properties, as well as their ability to differentiate into specific cell types beneficial to the healing of the rotator cuff [58, 59]. In addition to being able to produce growth factors, such as VEGF, TGF-β, and IGF-1, MSCs are capable of differentiating into chondrocytes, osteoblasts, and tenocytes [59].

Compared with preparations like PRP, which contain growth factors and proteins but limit mitogenic cells, samples with MSCs show increased cell proliferation, chemotaxis ability, and the ability to produce growth factor combinations that demonstrate the greatest potency [60]. MSCs have the ability to personalize the growth factors and proteins used and react with the body to optimize the healing environment. In addition to assisting with cell proliferation and healing of the tendon, MSCs can exhibit anti-inflammatory- and immunomodulatory-type behaviors. In response to inflammatory molecules such as IL-1, TNF-α, and INF-γ, MSCs secrete proteins like PGE2, IL-10, NO, and TGF-β1 that react with immune cells to decrease the inflammatory response [59]. MSCs can help promote the transition of T_H1 into T_H2 helper T cells and help shift macrophages from M1 type to the more anti-inflammatory, pro-remodeling, tissue healing M2 type which can improve regeneration in cartilage, muscle, and other soft

tissues [59]. The ability of the MSCs to modulate the healing environment by interacting with the body's own immune system makes it a promising target for biologically augmented rotator cuff repairs.

While MSCs are most commonly harvested via aspiration of bone marrow from the iliac crest, they can also be found in high concentrations in the dermis and adipose tissue. One of the earliest methods for bone marrow cell delivery was by Snyder et al. [61], who first described the robust reddish bone marrow clot formed from punctures through the cortical bone at the site of the repair "crimson duvet" of MSCs, platelets, growth factors, and vascular channels that would contribute to healing. Kida et al. [62] examined rotator cuff repair in rats augmented with bone marrow cells released by drilling the greater tuberosity of the humeral head. They found drilling into the bone resulted in a greater number of MSCs present at the side over 8 weeks with significantly higher ultimate load to failure compared with the control group at 4 and 8 weeks. However, in a study by Gulotta et al. [63] using a rat model with harvested MSCs delivered to the cuff repair site using a fibrin carrier, no biomechanical benefits were found despite evidence of metabolically active MSCs present at the repair site. A more recent study by Peach et al. [64] created a biomimetic rotator cuff tendon matrix composed of polycaprolactone coated in polyphosphazene poly[(ethyl alanato)$_1$(*p*-methyl phenoxy)$_1$] phosphazene (PNEA mPh) to locally deliver MSCs to the site of tendon repair. They found enhanced regeneration at 6 and 12 weeks compared with controls, with improved tissue morphology and increased mechanical properties. These studies suggest that while MSCs can be beneficial to the healing of tendons, the method of delivery and the design of the scaffolding used to hold them in place have an effect of the function of the cells and need optimization for this therapy to reach its full potential.

Recent studies in humans have shown promise regarding improved rotator cuff healing. In a study by Hernigou et al. [65], 45 patients were treated with bone marrow-derived MSCs harvested from their iliac crest placed adjacent to a single-row rotator cuff repair. The group receiving the MSCs had 100% intact repairs at 6 months vs. 67% of controls and 87% intact repairs at 10 years compared with 44% of control. Ellera Gomes et al. [66] studied the effect of bone marrow aspirate-derived MSCs injected along the repair site following mini-open rotator cuff repairs. At 12 months, magnetic resonance imaging showed tendon integrity in all 14 patients. In the year following, only one patient had a relapse of symptoms with recurring pain and weakness. Kim et al. [67] examined the use of fibrin glue for delivery of MSCs to the rotator cuff repair site and found no significant differences clinically between the improvements in motion and strength of the treated group compared with the control group. However, the MSC-treated group did show a significantly reduced tear retear rate of 14.3% vs. 28.5% in controls at the final follow-up period around 28 months. Current evidence shows that stem cells have regeneration potential and are capable of producing tissue that is similar to the native state; thus they have the potential to improve rotator cuff tendon healing. However, more work needs to be done on optimizing the methods used for delivery and securing the cells to the desired area to improve the quality and strength of the repairs and produce more native tendon-to-bone structure post-repair.

41.15 Conclusion

Rotator cuff tendon healing is a complex process that is not fully understood. The use of biologic augmentation with medications, growth factors, PRP, and stem cells has been shown to improve tendon strength and structure to some extent in vitro; however these benefits have not been reproduced in vivo. Further investigation is needed to optimize techniques to use MSCs and other biological factors to improve tendon healing in rotator cuff repair. The use of biologic augmentation does show promise and may be beneficial for tendon healing in the future.

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Arthroscopic-Assisted Lower Trapezius Tendon Transfer

42

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42.1 Introduction

The treatment of massive irreparable posterosuperior rotator cuff tears is especially difficult in relatively young population; in the absence of advanced glenohumeral arthritis, surgeons must be reluctant to offer the reverse shoulder replacement solution because of durability issues. Rotator cuff tears are considered irreparable when two or more tendons are involved and the retraction is up to the glenoid level and/or has fatty infiltration of more than 50% (Goutallier grade 3 or 4) [1, 2]; proximal migration of the humeral head is also considered a criteria for irreparability [3, 4].

A wide range of surgical techniques have been proposed for irreparable rotator cuff tears, including cuff debridement, partial repair, biceps tenotomy, or tenodesis [5]. Some authors advocate treating massive rotator cuff tears with tendon repair and graft augmentation [6, 7]; however, this procedure would be mainly indicated if the quality of the muscle is acceptable with less than 50% of fatty degeneration (grades <2 of the Goutallier classification). Tendon transfers may offer the adequate solution in this difficult scenario; for symptomatic massive irreparable tears in elderly patients with or without signs of rotator cuff arthropathy and/or pseudoparalysis, we opt for reverse total shoulder arthroplasty given the predictable good outcomes in regard to pain and functionality [8].

The earliest and most studied transfer is the latissimus dorsi (LDT), originally described by Gerber in 1988 [9]. Medium- and long-term follow-up studies have demonstrated that patients experience good pain relief and improvements in their shoulder motion [9–13]. Less predictable results are seen in the presence of fatty infiltration grade 3 or higher, osteoarthritis, subscapularis insufficiency, or preoperative forward elevation <90° [14–17]. Particularly, in cases with subscapularis or deltoid insufficiency, transfer of the latissimus dorsi may cause inferior humeral head subluxation due to the vertically

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oriented force vector of the transferred muscle [16]. Alternatively, when the subscapularis and deltoid muscle are intact, the latissimus dorsi works as external rotator and humeral head depressor compensating the missing infraspinatus function [18].

Because of the variability in outcomes after the latissimus dorsi transfer in patients with irreparable rotator cuff tears [19], isolated transfer of the lower trapezius (LTT) with Achilles tendon allograft has become an alternative. LTT was first described by Elhassan and Bertelli [18, 20] in order to restore external rotation in patients with traumatic brachial plexus injuries. 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 [10, 18, 21–23].

In 2016 Elhassan et al. [22] published for the first time an article showing results for open LTT with Achilles tendon allograft in massive irreparable rotator cuff tears; with an average follow-up of 47 months, 32 of 33 patients experienced significant improvement in their shoulder pain and motion; except for internal rotation, most patients improved significantly their abduction and external rotation, especially those with preoperative flexion of more than 60°.

Because of the favorable demonstrated outcomes, the similar excursion to the insufficient infraspinatus and teres minor tendons, the simplicity of the procedure, and the easier postoperative rehabilitation training, LTT is our preferred technique to treat posterosuperior cuff tears where supraspinatus and teres minor tendons can't be restored to their original footprint. In addition, subscapularis tear is not a contraindication, in contrast to the LDT. We favor the arthroscopic technique described by Elhassan and Alentorn-Geli et al. [1] because of the less invasive approach, the avoidance of acromial osteotomy and partial deltoid desinsertion, and the potential advantages with arthroscopic surgery as diminished postoperative pain or infection risk.

When partial repair for infraspinatus and subscapularis tendons is achievable but not the supraspinatus, we tend to perform superior capsular reconstruction (SCR) using dermal patch allograft or fascia lata; recent results for SCR clinical research are encouraging [24–26]; nevertheless partial repair of the remnant tendons is a must, in our opinion, in order to achieve good functional result; when posterior-superior cuff is irreparable, isolated SCR will not restore as efficiently the capability of the shoulder for combined elevation and external rotation; thus we do recommend the use of tendon transfer with or without combined SCR for these patients.

42.2 Applied Anatomy and Biomechanics

The trapezius is the most superficial periscapular muscle, and its primary role is to participate in scapular stabilization and scapulothoracic motion. It originates from the occiput and the ligamentum nuchae to the spinous processes extended caudally to the T10 vertebra (range, T9–T12). There are three component divisions, superior, middle, and lower, with three insertion sites, the acromion and superior lateral spine, the superior scapular spine, and the inferomedial scapular spine, respectively. The spinal accessory nerve (cranial nerve XI) provides motor innervation, and the superficial branch of the transverse cervical artery provides the blood supply [27]. The neurovascular pedicle goes along the underside of the muscle to innervate the middle and lower trapezius. Recent cadaveric studies have defined the surgical anatomy of the lower trapezius and the anatomy of the pedicle, and the location of the nerve is between 2.3 and 5.8 cm (average 3.25 cm) medial to the distal extent of the tendon at the most superior portion of the lower trapezius [28].

Omid et al. [28] also defined an important anatomic landmark, a triangular bony region at the junction of the scapular spine and the medial border of the scapula. This area is tendon

insertion-free allowing an easy identification of the lower trapezius footprint. Proper identification of the lower trapezius is essential to avoid denervation during the splitting of the lower trapezius for the transfer. Having identified this smooth triangular area, then you can slide a finger under the edge of the lower trapezius for the dissection. It is possible to transfer the lower portion of the trapezius directly without the use of tendon grafts; however, there is a high risk of spinal accessory nerve traction injury as demonstrated in a cadaveric study by Gracitelli et al. [29].

Biomechanically, when planning a tendon transfer to restore specific or global shoulder function, it is important to remember some basic concepts. A transferred muscle/tendon unit should be similar to the nonfunctioning unit that is designed to replace. The ideal transfer must have a similar excursion and adequate strength and be designed only to replace one function [23].

Hartzler et al. [23] performed a biomechanical cadaveric study to analyze the effectiveness of different types of tendon transfer around the shoulder to restore external rotation; the authors evaluated the external rotator moment arms of latissimus dorsi, teres major, and lower trapezius transferred in different humeral head positions. They found that the lower trapezius transfer resulted in superior external rotation moment arm with the shoulder adducted than latissimus dorsi transfer, but in the abducted shoulder, latissimus dorsi transfer was superior, although they did not consider the forces of other shoulder girdle muscles. Omid et al. [5] compared in a biomechanical study the effects of the lower trapezius transfer and latissimus dorsi transfer in a model with a massive posterosuperior cuff tear. Their results support the lower trapezius transfer and found this transfer biomechanically superior than latissimus dorsi to restore external rotation and also demonstrated improved glenohumeral kinematics and joint reactive forces in the rotator cuff-deficient shoulder. According to his findings, trapezius transfer restored anteroposterior force couple balance, and latissimus transfer worsened it [5, 30, 31].

42.3 Indications

The main indication for lower trapezius transfer 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 (Table 42.1).

42.4 Preoperative Assessment

42.4.1 Clinical Examination

Most patients with massive rotator cuff tears have pain in the deltoid region irradiated to the lateral area of the shoulder; function loss, reduced strength, and crepitation are frequent findings also in these patients; night pain is characteristic and interferes with their ability to sleep; pain also typically worsen with overhead activities or when trying to lift objects. Physical examination should include an evaluation for muscle atrophy 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, or neurovascular compressive syndromes.

Specific maneuvers are key to obtain a precise differentiation on the affected tendons and their degree of incompetence. The insufficient infraspinatus will manifest as an important external rotation strength loss in adduction and lag or

Table 42.1 Indications for lower trapezius transfer

Indications
Irreparable supraspinatus and infraspinatus tear
– Secondary loss of external rotation
– Fatty infiltration (not necessary)
– Shoulder pain without stiffness
Young and active patient
Omarthrosis less or equal than Hamada 3 [32]

dropping sign in case of massive posterosuperior cuff tear; a positive hornblower's sign implies combined infraspinatus and teres minor insufficiency [33]. 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 [34].

42.4.2 Imaging: X-Rays

Radiographs should be obtained in any patient evaluated for cuff disease. Radiographic changes will vary depending on the stage and the presence of associated pathology. Plain radiographs (AP, axial, and lateral scapula Y view) allow to evaluate acromial changes (shape, acetabulization, os acromiale), proximally migrated or decentered humeral head, tuberosity sclerotic changes, and cysts or signs of cuff tear arthropathy.

42.4.3 Imaging: MRI/CT

Advanced imaging studies are recommended in these patients with 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.

Discontinuity of the complete tendon thickness is best identified as a bright gap in T2-weighted images in between the dark torn tendon edge and the osseous footprint. Supraspinatus tears are best identified in coronal cuts. Tears of the subscapularis, infraspinatus, and teres minor are best identified in axial views. Parasagittal cuts are useful to understand the true extent of the tear from anterior to posterior but also to quantify fatty atrophy (Fig. 42.1). The Goutallier grading system was first recognized using computed tomography [2]; nowadays it is most easily assessed on MRI non-fat-saturated oblique-sagittal T1 sequences which have superior fat-to-muscle contrast [35].

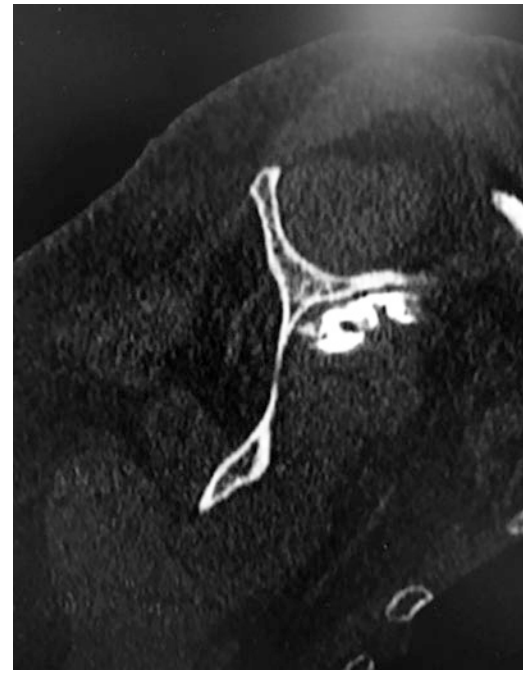

Fig. 42.1 Sagittal view of arthro-CT scan showing infraspinatus atrophy

Computed tomography (CT) scan can be used to assess the rotator cuff for both tears and atrophy; intra-articular injection of iodine contrast (CT arthrogram) provides better images for evaluation of the rotator cuff.

42.5 Surgical Technique

42.5.1 Positioning and Preparation

Arthroscopically assisted lower trapezius transfer was first described in 2016 by Elhassan et al. [1]. Anesthesia is carried out following a standardized protocol based on a single-shot interscalenic blockade under ultrasound control (L-bupivacaine 0.5% 30–40 ml plus epinephrine) combined with general anesthesia (propofol 2–2.5 mg/kg i.v. and alfentanil 20–150 μg/kg i.v. initially, plus 15 μg/kg bolus, and maintenance with sevoflurane).

Antibiotic prophylaxis (2 g cefazolin or 1 g vancomycin as 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 [36]. Beach chair position is the option of choice for the arthroscopic-assisted technique; a Betaclassic 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 having the entire ipsilateral half of the back uncovered until midline (Fig. 42.2). 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 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 stand 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 patient's heels, hands, and forearms.

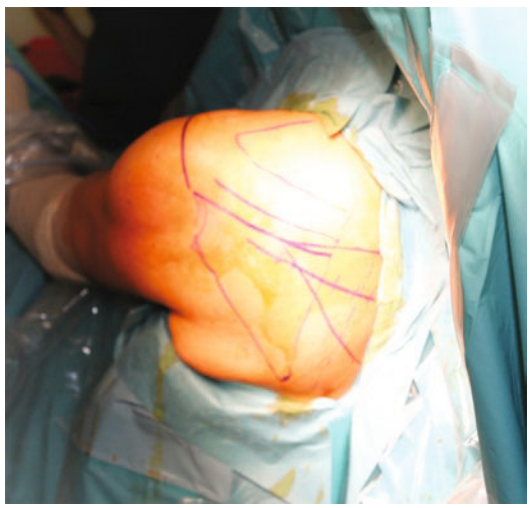

Fig. 42.2 Patient's position in beach position and surgical field with landmarks for lower trapezius tendon harvesting approach

The operative extremity is prescrubbed with chlorhexidine solution and draped conveniently. At the conclusion, the surgical team should change gloves and conduct a final preincision time-out.

During the arthroscopic time, controlled hypotension and muscular relaxation is desirable as it may allow better visualization, decrease blood loss, and reduce operative time which secondarily can affect the quality of the repair and patient safety [37]. Because of the risk for neurological ischemic events, caution should be exercised with hypotensive anesthesia in the beach chair position; hypertensive elderly patients with poor control, BMI > 34, diabetes mellitus, and obstructive sleep apnea and patients with previous history of stroke or cardiac events are considered high-risk population [38]. 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 (FMS®; DePuy, Mitek, Raynham, Massachusetts, USA). We usually set up the pump to start at 80/90 mmHg.

42.5.2 Surgical Technique

We first mark the border of the scapula and the lower trapezius insertion site on the spine of the scapula. It is recommended also to mark the osseous eminences of the shoulder and the arthroscopic portals.

For graft harvesting, we have two options: doing a vertical skin incision, 5 cm in length, approximately 1 cm medial to the medial border of the scapula starting from the upper medial border, or a 5 cm transverse incision just inferior to the scapular spine from 2 cm medial to 3 cm lateral to the medial border of the spine of the scapula. After the skin incision and subcutaneous dissection, we will find a triangular fat area corresponding with the lateral border of the trapezius; dissecting this area medially and laterally will expose the tendon from the deep fascial tissue. The optimal method to identify the lower

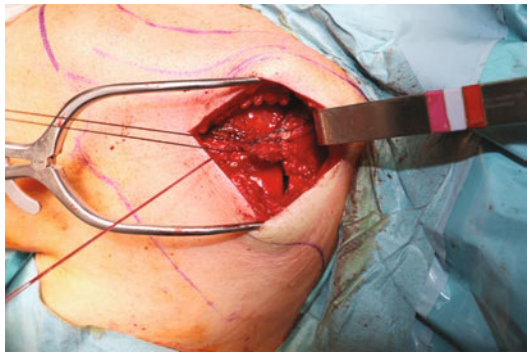

Fig. 42.3 Lower trapezius harvesting after dissection and preparation with Krakow suture with Orthocord. The pulling line of the lower trapezius muscle is similar to the infraspinatus muscle

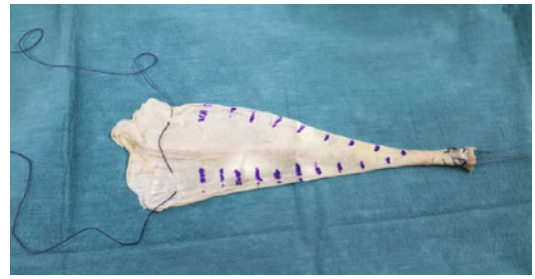

Fig. 42.4 Allograft preparation with No. 2 Orthocord sutures (DePuy Synthes, Warsaw, IN) in a Krakow configuration at the thick and narrow end of the Achilles tendon allograft. Note that the dorsal marks are drawn to prevent allograft flipping inside the joint

trapezius tendon is to "hook" it with the surgeon's index finger laterally beneath the trapezius, freeing the tendon from deep adhesions; this is a triangular bony region at the junction of the medial border of the scapula and the scapular spine. Once the lower trapezius footprint is identified and isolated, we are capable to detach the trapezius off from its insertion in the scapular spine bony region. The shape of the footprint is triangular and the length of the tendinous portion about 49 mm [28]. Then we continue the dissection medially along the upper border of the tendon along the interval between the middle and lower trapezius with the goal of getting adequate release and mobilization of the tendon (Fig. 42.3). The spinal accessory nerve lies within the fascial layer, underneath of the trapezius; thus deep 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 in order to detect overtensioning; removing the edge of the spine of the scapula can be helpful to avoid impingement between the graft and the accessory nerve at the level of the medial border of the spine.

Two number high strength Orthocord® sutures (DePuy Synthes, Warsaw, IN) in a Krakow configuration at each side of the tendon and is left inside the incision to prevent damage of the graft.

The next step is the allograft preparation. It can be performed simultaneously while the lower trapezius is harvested. An Achilles tendon allograft without the osseous calcaneus portion is the graft of choice. Again two No. 2 high-strength Orthocord® sutures (DePuy Synthes, Warsaw, IN) in a Krakow configuration are used to prepare the thick and narrow end of the allograft; it is recommended using different colors for better identification of the sutures during the arthroscopic time as well as marking the dorsal and frontal aspect of the graft. One suture is placed at the thin expanded side of the allograft to avoid lateral migration during the passing and fixation of the graft but 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. 42.4).

Then the arthroscopic part is performed. The main portals needed for this procedure are a posterior portal for visualization and an anterolateral portal and lateral portal for instrumentation. We can use additional portals if necessary. The scope is placed 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. The footprint debridement of the supraspinatus must cause bleeding subchondral bone to enhance graft healing. We also need to create a passing track for the allograft underneath the infraspinatus fascia. The anterolateral portal is placed just 1 cm distal to the edge of the anterior corner of the acromion. From this portal, we introduce in the subacromial space a long

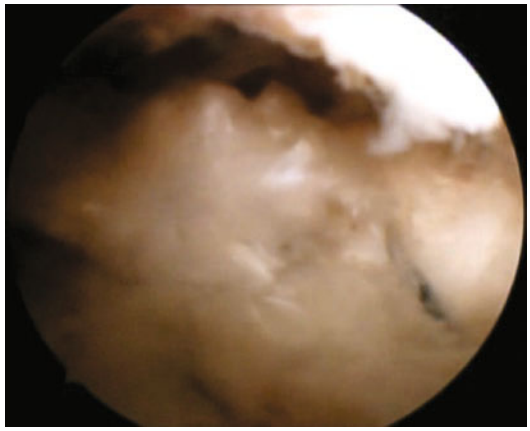

Fig. 42.5 Intra-articular fixation of the allograft

grasping clamp; then under the opened infraspinatus fascia, the clamp is directed toward the harvesting wound. A moist packing gauze can be used to enlarge the passing area for the allograft. Once achieved the medial wound with our clamp, we gather the sutures placed in the thick end of the allograft to pull them out through the anterolateral portal. Before the definitive fixation of the graft over the greater tuberosity, we must check that there is an optimal glissade of the graft pulling from it backward and forward using our prearranged sutures in both ends (Fig. 42.5).

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. It is important to remind your assistant to hold some tension in the opposite side of the allograft during suture passing and knotting to avoid fixation in a twisted 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.

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 extension 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. 42.6).

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 sterile dressing, and the patient's arm is placed in an external rotation brace.

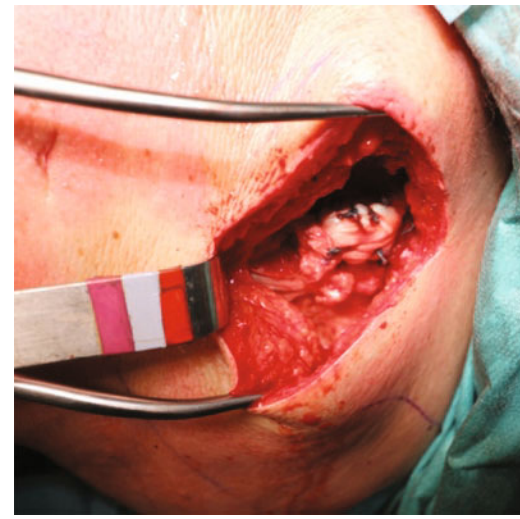

Fig. 42.6 Final appearance of attachment of the allograft to the lower trapezius tendon. The arm must be placed in maximal external rotation with some extension and without abduction

42.6 Postoperative Management and Follow-Up

The postoperative rehabilitation period begins with 8 weeks of external rotation brace; we only allow removal during this period for bath and flexion-extension exercises of the elbow. After 6 weeks, the patient starts proper physical therapy including progression from passive to active assisted motion and finally unassisted active motion around 12 weeks. External rotation strengthening exercises with elastic bands begin 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 previous X-ray [1].

Based in the midterm results showed from Elhassan et al., on average the vast majority of patients who undergo lower trapezius transfer with Achilles tendon allograft for massive irreparable posterior-superior rotator cuff tears experience significant improvement of pain, external rotation, shoulder flexion, and abduction, although better motion is observed in patients with preoperative flexion over 60° [22].

42.7 Results

The only published serie reporting outcomes for LTT for this indication was published in 2016 from Elhassam et al.; the study included 33 patients who underwent open transfer of the lower trapezius to reconstruct patients with persistent symptomatic posterior-superior rotator cuff massive tears with a minimum of 2 years follow-up. Eleven patients had no prior surgeries, but the remaining 22 patients had undergone an average of 2 prior surgeries [22].

At an average follow-up of 47 months (range, 24–73 months), 32 of the 33 patients had significant improvement in pain levels ($P < 0.01$) and shoulder range of motion, with an average forward flexion (FF) of 120° (range, 80–150°) (average preoperative FF 70°), abduction (ABD) 90° (range, 60–140°) (average preoperative ABD 40°), and external rotation (ER) 50° (range, 20–70°; $P < 0.01$) (average preoperative ER 20°). Postoperative internal rotation (IR) was maintained comparing the preoperative examination.

Regarding the results in clinical scores, the mean SSV improved from 54% preoperatively to 78% postoperatively ($P < 0.01$); the 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.

Of note, when eight patients who had flexion/abduction of less than 60° preoperatively were compared with 25 patients who had more motion, the latter group had more significant improvement of motion. Shoulder external rotation motion and strength improved in all patients regardless of the extent of the preoperative loss of motion, with grade 4 or higher muscle strength achieved in all patients.

The 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, 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 [22].

42.8 Complications

From the experience in patients with brachial plexus injury and paralytic shoulder, when LT was performed as single-tendon transfer,

complication from the surgery was 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 afferentation from the brachial plexus injury (23 patients) [36]. Most of the complications they encountered in this group of patients with single-tendon transfer were related to the postoperative custom-made brace such as skin irritation and soreness related to pressure from the brace which can lead to intolerance and poor compliance.

Elhassan et al. reported complications on the aforementioned study of 33 patients with open LTT and found also seroma formation in four patients, who were managed by observation with no sequelae. 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. There was one infection in this serie requiring debridement and later shoulder fusion [22].

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 [1].

42.9 Summary

Arthroscopic transfer of the lower trapezius using Achilles tendon allograft to reconstruct massive irreparable posterior-superior rotator cuff tear leads to good outcomes in most patients, specially 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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Open Latissimus Dorsi Transfer

43

Andreas B. Imhoff, Lukas N. Muench,
and Andreas Voss

43.1 Indication

Patients with irreparable chronic massive posterosuperior rotator cuff tears with functional deficits as well as muscular force deficits. Main indication is the loss of active external rotation and flexion.

43.1.1 Main Criteria for Irreparable Chronic Massive Cuff Tears

- Acromiohumeral distance less than 6 mm in a radiological AP view.
- Muscle atrophy of the affected muscles ≥grade 3 according to Thomazeau.
- Fatty infiltration of the affected muscles ≥3 according to Goutallier.
- Retraction of rotator cuff tendon grade 3 according to Patte.

Physically active patient with good to excellent psychomotor learning skills and good compliance.

43.1.2 Specific Contraindications

– Lesions of the axillary nerve or functional deficit of the deltoid muscles.
– Lesion with insufficiency of the subscapularis muscle consequently not being able to reconstruct the force couple.
– Shoulder stiffness with limitation of passive shoulder joint mobility.
– Advanced osteoarthrosis.
– Lack of compliance of the patient, which is the most import aspect of this operative procedure.

43.1.3 Relative Contraindication

– Lesion with insufficiency of the m. teres minor, which has shown worse results compared to an intact muscle.

43.2 Operative Principles

This procedure aims to transfer and refix the m. latissimus dorsi on the humeral head on the m. supra- and infraspinatus footprint to rebuild the

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force couple. The aim is to lower the humeral head in order to gain a significant functional improvement and reduce pain.

43.3 Preoperative Assessment

43.3.1 Diagnosis

43.3.1.1 Clinical Examination

Prior to the physical examination, a detailed anamnesis is essential to find out about the patients' symptoms, duration of the complaints, and previously performed therapies or surgeries. Furthermore, it is important to find out the patients' expectations to their shoulder function.

Several tests have been described to examine shoulder function; therefore, those tests should be used who the examiner is familiar with. Additionally, passive and active shoulder motion should be documented.

43.3.1.2 Neurological and Vascular Status

To meet the criteria for a latissimus dorsi transfer, the examination of peripheral neurology, especially axillary nerve and the radial nerve, as well as the thoracodorsal nerve, is important.

43.3.1.3 Imaging: X-Rays

A series of three shoulder X-rays should be performed (true AP, Y-view, axial) to assess the bony conditions, degree of arthrosis, and centering of the humeral head. The acromiohumeral distance can be measured on the true AP view.

43.3.1.4 Imaging: MRI/CT

An MRI is necessary to show the rotator cuff tear morphology and size, the assessment of tendon retraction, muscle atrophy, and fatty infiltration. It is important to ask for an MRI with far medial parasagittal images to fully show the rotator cuff muscles. Additionally, accompanying pathologies can be excluded. If shoulder X-rays do not give all the information needed to assess the bony conditions (bone loss, glenoid version, etc.), a CT scan can be helpful.

43.3.1.5 Preoperative Patient Information and Consent

Surgery-specific risks:

- No reliable prognosis of postoperative shoulder function and pain reduction, as mostly depending on compliance and the psychomotor learning skills
- Paresis of the axillary nerve or radial nerve
- Loss of active and passive motion right up to shoulder stiffness
- Primary or secondary insufficiency of muscle transfer surgery
- Elaborate postoperative treatment:
- There should be given a special attention to the postoperative treatment with detailed information about the shoulder brace in abduction external rotation for 6 weeks
- Physiotherapy for at least 3 months and a rehabilitation period from 6 to 9 months to learn the new shoulder motion patterns

43.4 Operative Technique

43.4.1 Positioning and Preparation

A lateral decubitus position with the use of an arm holder is necessary to release the m. latissimus dorsi and refix it on the humeral footprint. Prior to surgery, an examination during anesthesia is recommended (Fig. 43.1).

43.4.2 Technique

Before the tendon transfer, a diagnostic arthroscopy is performed. Subsequently, the dorsal incision is performed, which runs in an arc from the inferior corner of the scapula along the lateral scapular rim to the apex of the axilla. The m. latissimus dorsi and m. teres major are identified and fully digitally separated, circularly dissected, and mobilized until the entry of

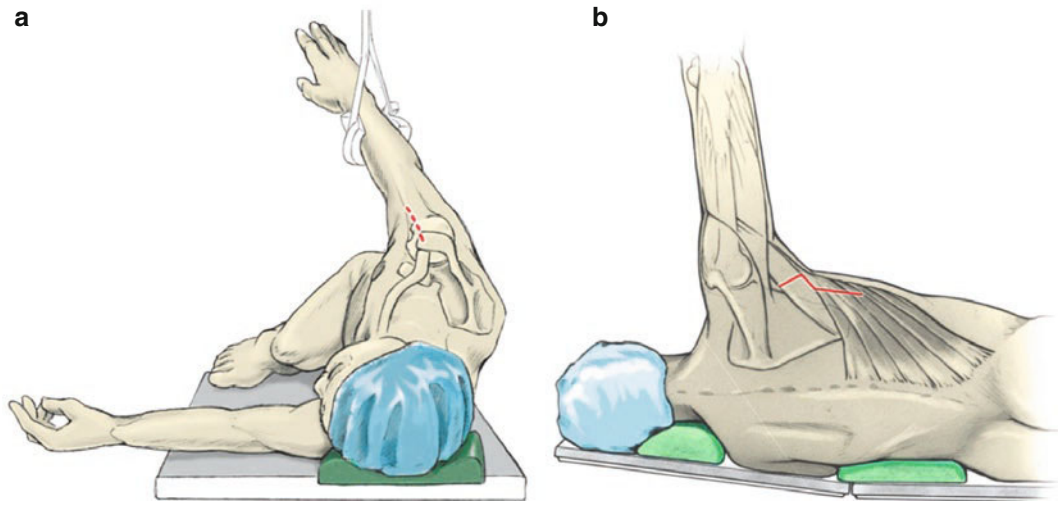

Fig. 43.1 Illustration of lateral decubitus position. (**a**) Red lines indicate anterolateral incision for tendon refixation. (**b**) Red lines indicate dorsal incision for tendon mobilization and detachment [1]

the vascular-nerve bundle. The arm is flexed at 45° and brought into maximum internal rotation.

In this position, the tendon of the m. latissimus dorsi can be detached over a length of approx. 12 cm from its insertion area on the humeral shaft and the thorax. Care must be taken to the radial nerve at this point of the surgery. The m. latissimus dorsi tendon is now looped with a nonabsorbable tear-proof suture material in a Krakow stitching technique (Fig. 43.2). This is followed by anterolateral delta access.

To improve the overview, a bursectomy can be helpful, and the footprint on the greater tuberosity is debrided (Fig. 43.3). Additionally, a tenotomy or tenodesis of the long head of the biceps tendon is a standard procedure.

To transfer the tendon, a proximal preparation between the dorsal deltoid muscle and the long head of the triceps is necessary. Care must be taken to protect the axillary nerve.

Once the tendon has been passed through, it must be carefully checked for any distortion (Fig. 43.4). Then the m. latissimus dorsi tendon can be attached to the posterosuperior part of the greater tuberosity using suture anchors in a Mason-Allen suture technique. For this purpose, the arm is brought in 45° of flexion and maximum internal rotation. To avoid any impingement, the tendon is fixed with knotless suture anchors in the anterior region of the greater tuberosity. If possible a reconstruction of the rotator cuff should be performed additively. Basically, there are three ways of tendon transfer fixation (Fig. 43.5):

(a) If none of the supraspinatus or infraspinatus tendon is left to be reattached, the m. latissimus dorsi tendon is just brought to the anterior border of the greater tuberosity, leaving the torn tendons in place.
(b) If the infraspinatus tendon can be mobilized and partial reconstructed, the m. latissimus dorsi tendon is brought over the infraspinatus tendon and fixed at the anterior border of the greater tuberosity.
(c) If, additionally, the supraspinatus tendon can be mobilized but still not enough to be brought to the footprint, it can be attached to the most medial side of the m. latissimus dorsi tendon. Therefore, the gap left by the prior rotator cuff tear can be completely or partially closed.

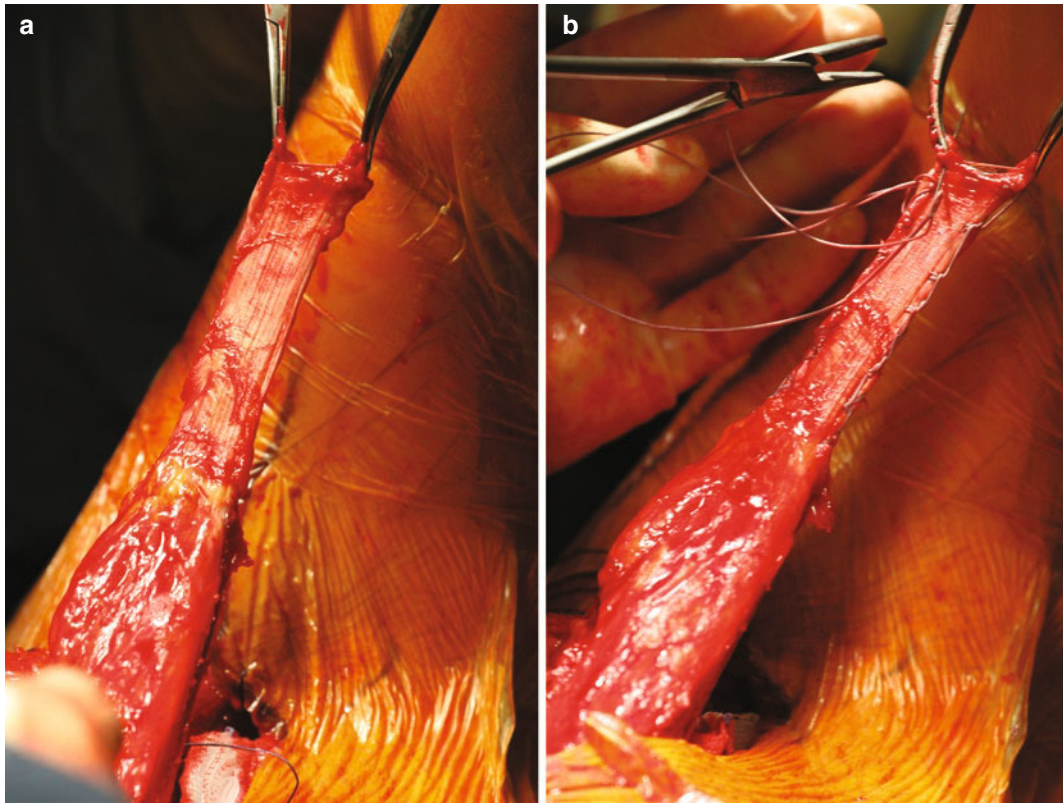

Fig. 43.2 Left: latissimus dorsi tendon after mobilization and detachment. Right: The m. latissimus dorsi tendon is looped with a nonabsorbable tear-proof suture material in a Krakow stitching technique

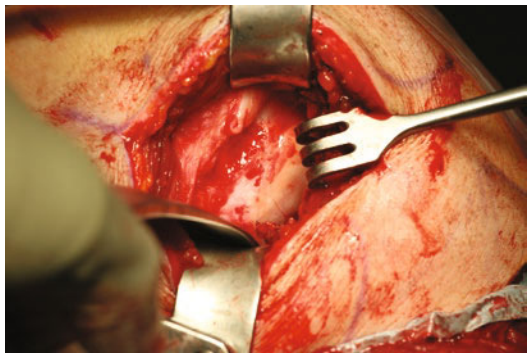

Fig. 43.3 Preparation of humeral footprint

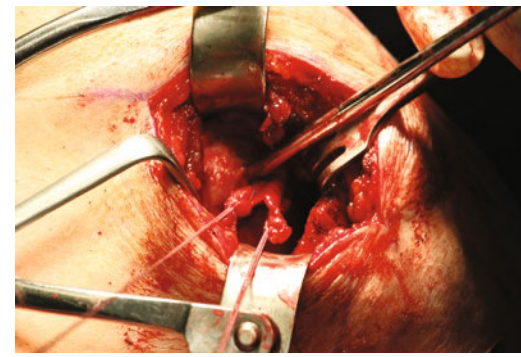

Fig. 43.4 After the latissimus dorsi tendon has been passed through, it must be carefully checked for any distortion

43.5 Postoperative Management

Still within the operation room and during anesthesia, a shoulder brace should be mounted. Therefore, 45° of abduction, flexion, and external rotation is recommended. If a brace is not available, a shoulder cast can be used. Additionally, control of peripheral circulation, motor activity, and sensitivity is essential. To ensure a correct procedure, an X-ray control should be done.

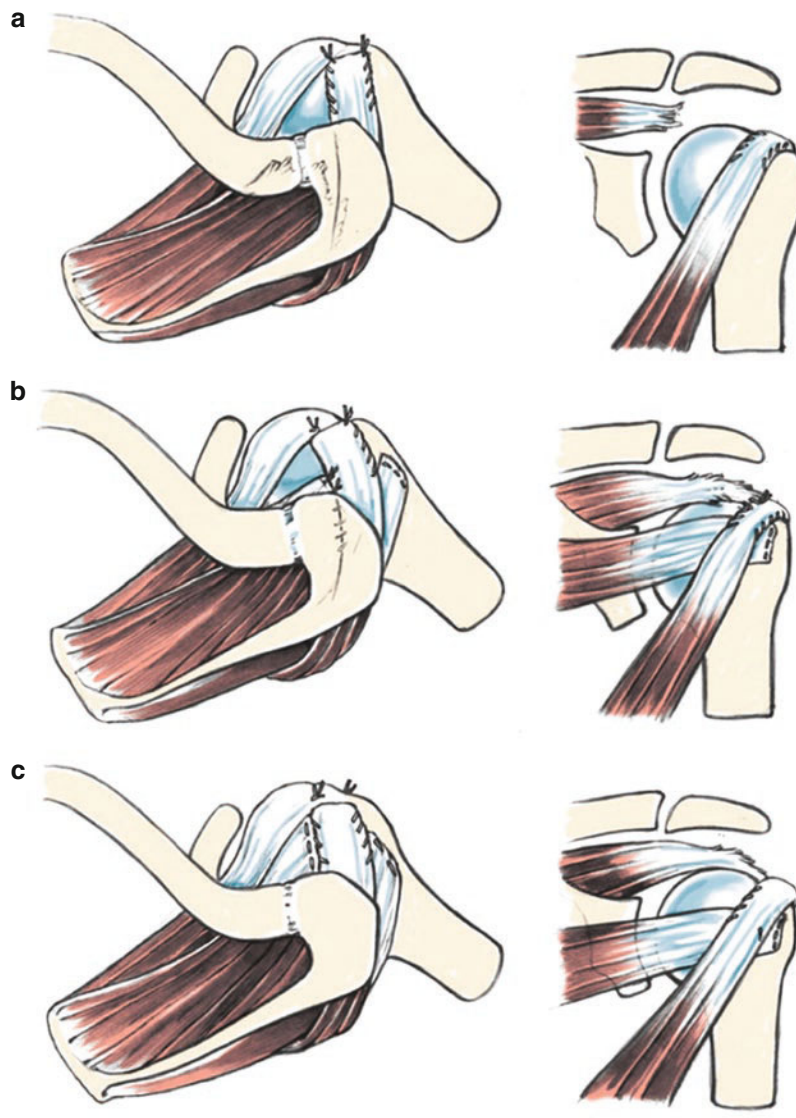

Fig. 43.5 Illustration of three different ways of tendon transfer fixation. (**a**) The m. latissimus dorsi tendon is just brought to the anterior border of the greater tuberosity, leaving the torn tendons in place. (**b**) The m. latissimus dorsi tendon is brought over the infraspinatus tendon and fixed at the anterior border of the greater tuberosity. (**c**) If the supraspinatus tendon can be mobilized, it can be attached to the most medial side of the m. latissimus dorsi tendon [1]

43.6 Follow-Up Treatment

Shoulder abduction brace or cast should be kept for at least 6 weeks.

Week	Motion	Int. rotation/ext. rotation	Abduction/ adduction	
1–3 postoperative weeks	Passive	0–0–Free	90–45–0	Additional exercises for the elbow
4–5 postoperative weeks	Active assisted	0–0–Free (still passive)	90–45–0	
6–7 postoperative weeks	Active assisted	30–0–Free	90–0–0	
8–9 postoperative weeks	Active assisted	Free	Free	
10 postoperative weeks	Active	Free	Free	

43.7 Tips, Tricks, and Pitfalls

Care should be taken when performing the delta-split. The access should not be further than 5 cm distal to the anterolateral acromion to not injure the axillary nerve. For a tension-free fixation, the m. latissimus dorsi must be sufficiently dissected and mobilized.

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44 Management of Irreparable Rotator Cuff Tear: Arthroscopy-Assisted Latissimus Dorsi Tendon Transfer

Jiwu Chen

44.1 Overview

Rotator cuff tear is a common shoulder disorder with pain and loss of range of motion. The prevalence of rotator cuff tear is estimated to be at least 10% among people older than 60 years [1]. Rotator cuff repair is effective for relieving pain and restoring shoulder function, yet in some cases, the torn tendon cannot even be fixed to the humeral head, or the repaired tendon will experience high retear rate, posing a need for alternative surgeries [2, 3]. Many factors have been evaluated to analyze the correlation with this irreparability, including tear pattern, tissue quality, and anatomical abnormalities.

According to Neri et al. and Warner et al., up to 30% of total rotator cuff tears can be classified as irreparable because of massive tear size [4, 5]. A tear can be categorized as massive when at least two tendons are torn [6] or the tear size was more than 5 cm [7]. For massive rotator cuff tear, the pooled retear rate reached 79%, as systematically reviewed by Henry et al. [8].

Concomitant with the tendon tear is tissue degeneration. Chung et al. found that preoperative tendon quality, as indicated as the severity of tendinosis, is positively related to failure to heal [9]. Muscle atrophy and fatty infiltration of rotator cuff is another factor strongly related to retear. Kim et al. summarized data of 758 rotator cuff repairs and identified a significant relationship between supraspinatus fatty infiltration, muscle atrophy, and arthroscopic reparability [10]. Jeong et al. further confirmed that muscle atrophy and infiltration preoperatively measured by magnetic resonance imaging were able to predict retear, thus helping surgeons determine proper treatments [11]. The deformity of normal anatomy causes subsequent pathological change of the glenohumeral joint. The contraction of the deltoid muscle elevates the humeral head, thus narrowing the acromiohumeral distance [12], which is also a risk factor for retear and failure to repair [10, 13].

The challenges drive alternative treatments to be developed. Considering the natural history of rotator cuff tear, conservative management might not be enough to resolve this condition [14]. Surgical interventions, including tendon transfer [15, 16], rotator cuff patch [17], superior capsule reconstruction [18], partial repair [19], subacromial spacer [20], and reverse shoulder arthroplasty [21], are therefore developed and reported to be able to restore shoulder function.

As a choice of tendon transfer, latissimus dorsi tendon (LDT) transfer as a salvage procedure for the treatment of massive rotator cuff tear was proven to be a primary success [22]. Over the past decades, this procedure has become prevalent

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and popular and can be conducted with arthroscopic assistance.

44.2 Massive Rotator Cuff Tear and LDT Transfer

44.2.1 Massive Rotator Cuff Tear

Massive rotator cuff tear is defined as a tear with tear size larger than 5 cm [7], or with two tendons torn completely [6]. Based on the position of tear, massive rotator cuff tear is further divided into anterosuperior and posterosuperior tear, which involves subscapularis and supraspinatus and supraspinatus and infraspinatus with or without teres minor, respectively [23]. Based on whether there is loss of active flexion (<90°) or active external rotation (<0°), patients with massive rotator cuff tear can have concomitant pseudoparalysis. Different measures are used to classify tissue degeneration, including muscle fatty infiltration by Goutallier grade [24], muscle atrophy by Warner grade [25], tendon retraction by Patte grade [26], and acromiohumeral distance by Hamada classification [27].

Primarily, rotator cuff works synergistically with the deltoid muscle to maintain a balanced force couple of the glenohumeral joint. The force couple on two planes, i.e., the coronal and transverse plane, centralizes humeral head to the glenoid, guaranteeing glenohumeral motion. When a massive rotator cuff tear occurs, the normal biomechanics of glenohumeral joint is destroyed; therefore, the main aim of surgical interventions is to reconstruct the force couple [28].

44.2.2 LDT Transfer

First introduced in 1988, Gerber et al. used LDT transfer for posterosuperior massive rotator cuff tear and yielded satisfactory outcome [22]. Numerous clinical and cadaver researches have studied the influence of LDT transfer on the joint, and procedures are continuously modified. This procedure is proven to be able to help patients regain external rotation and flexion, while whether it can depress humeral head is still controversial [29].

44.3 Arthroscopy-Assisted LDT Transfer

The goal of latissimus dorsi transfer is to balance the force couple that maintains centralization of the humeral head on the glenoid during shoulder range of motion [30].

44.3.1 Indications

1. Complete tear of supraspinatus and infraspinatus confirmed by arthroscopy.
2. Level II–III tendon retraction according to Patte classification [26].
3. Level III–IV muscle fatty infiltration of supraspinatus and infraspinatus according to Goutallier classification [24].
4. No disorders of latissimus dorsi.
5. Failure of conservative treatments for more than 6 months.

44.3.2 Preoperative Evaluation

44.3.2.1 History

The individual factors including age, gender, affected side, inducement, duration, previous treatments, demands of shoulder activity, and type of sports should be documented. Relevant comorbidities (e.g., rotator arthropathy) should be excluded, which may be a relative contraindication for latissimus dorsi transfer.

44.3.2.2 Physical Examination

Preoperative active shoulder range of motion, pain, strength, scapular kinesis, Hawkins-Kennedy impingement test, Neer sign, empty can test, full can test, drop arm test, Patte test, lift-off test, belly-press test, internal and external rotation lag sign, etc.

44.3.2.3 Imaging

The shoulders were evaluated preoperatively with anteroposterior and scapular-Y X-ray images for the assessment of glenohumeral joint (e.g., subacromial spur).

MRI (magnetic resonance image) or MRA (magnetic resonance arthrogram) is obtained to assess the size and pattern of rotator cuff tear and screen for any associated lesions (e.g., pathology of biceps tendon).

44.3.3 Operative Technique

44.3.3.1 Anesthesia, Positioning, and Preparation

1. *Anesthesia*: General anesthesia or regional anesthesia with sedation can be selected depending on the preference of the surgeon.
2. *Position*: Beach chair position or lateral decubitus position can be used according to the surgeon's preference.

   The introduced techniques in this chapter are performed with the patient placed in lateral decubitus position and are similar to that in beach chair position.

   The patient is placed in the lateral decubitus position, leaned back about 30° with the shoulder in approximately 30° of abduction and 15° of forward flexion. The arm is initially suspended with 15 pounds of distal traction.
3. *Examination under anesthesia (EUA)*: Before the surgery, physical examination should be performed again to evaluate the passive range of motion to confirm the preoperative diagnosis and modify the surgical strategy if necessary.

44.3.3.2 Arthroscopically Assisted LDT Transfer

1. *Portals*: including three arthroscopic portals, e.g., posterior portal, anterolateral superior portal, and anterior portal and a curved incision at the top of the posterior axillary fossa of approximately 5 cm.
2. *Surgical sequence*:

- Establish a standard posterior portal.
- Diagnostic arthroscopy through posterior portal.
- Establish an anterior portal close to the upper border of the subscapularis tendon.
- Establish an anterolateral superior portal at the anterolateral corner of the acromion.
- Subacromial depression and acromioplasty when necessary.
- Handle biceps tendon pathology when necessary.
- Prepare the bony surface of great tuberosity for LDT fixation.
- Release the suspension, and fix the index shoulder at full abduction with external rotation.
- Make the curved incision and expose the muscle belly of latissimus dorsi.
- Sharply detach the insertion of the tendon, and weave the two sides of tendon with sutures with different colors.
- Release the tendon and muscle to increase the flexibility of graft when the free end can be stretched to the lateral side of acromion.
- Pay attention not to injure the adjacent nerves and vessels.
- Introduce the free end into subacromial space between deltoid and triceps under arthroscopy.
- Fix the free end on to the superior aspect of the great tuberosity.
- Examine the reliability of fixation.
- Close the incisions layer by layer.

44.4 Conclusion

Considering the high retear rate of massive rotator cuff repair and the irreparability of massive rotator cuff tear, alternative treatments other than rotator cuff repair are needed to restore shoulder function.

LDT transfer has satisfactory outcomes for massive rotator cuff repair with, or without, pseudoparalysis and can be conducted with arthroscopic assistance.

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Superior Capsule Reconstruction: The Italian Perspective

45

Giuseppe Milano and Maristella F. Saccomanno

45.1 Introduction

Rotator cuff tears are a common cause of upper extremity pain and disability. The rate of primary rotator cuff repair has continued to rise in recent years with successful clinical results [1, 2]. However, treatment of massive and irreparable tears still remains a challenge. Moreover, clinical manifestations of these tears are quite variable ranging from no symptoms with good mobility to intense pain and pseudoparalytic shoulder.

In the last decades, several treatments have been proposed ranging from joint-preserving options to total joint replacement. The treatment strategy is usually customized to the patient, based upon numerous factors that include functional demands, age, quality of remaining rotator cuff tissue, muscle quality, and presence of glenohumeral osteoarthritis. Therefore, older patients with low functional demand in the setting of a severe cuff tear arthropathy are undoubtedly directed to a reverse shoulder arthroplasty. On the contrary, the optimal treatment for patients with irreparable cuff tears in the absence of osteoarthritis is less obvious and remains controversial.

Owing to the difficulty in managing these tears, shoulder surgeons have developed multiple strategies to improve outcomes and ideally change the natural history. Burkhart et al. [3] introduced the concept of a partial, also known as functional, cuff repair. It basically consists of reestablishing the balance of transverse force couple and recentering the humeral head by repairing the subscapularis tendon anteriorly and the infraspinatus tendon posteriorly [3]. Good clinical outcomes have been reported in terms of pain relief and shoulder function improvement, but the rate of failure is still high, exceeding 40% [4].

More recently, the use of a biodegradable subacromial spacer has been introduced with the main goal of replicating the lowering effect of humeral head, physiologically exerted by rotator cuff tendons. This effect should produce an increase in the deltoid lever arm, thus improving active elevation while reducing the subacromial friction. Early studies reported successful reestablishment of acromiohumeral distance and improvement in shoulder function [5–9]. However, it has been shown that the spacer begins to degrade approximately 2–3 months postimplantation and fully disintegrates within 12 months [10]. Further, it is unclear how long it remains inflated. This treatment has been

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proposed as part of the treatment algorithm in young patients with an irreparable rotator cuff in order to delay the need for more invasive surgery or as a potential definitive option in medically unfit patients [11].

Non-anatomic repairs, such as tendon transfers, have also been used to manage these injuries and most commonly require the transfer of latissimus dorsi or pectoralis major tendons to restore posterosuperior or anterior rotator cuff function, respectively. These procedures are technically demanding and involve the risk of neurovascular injuries. They are considered as savage procedures able to relieve pain relief and improve active motion, although restoration of normal shoulder function is not likely to be achieved [12–14].

In 2012, Mihata et al. [15] first described the superior capsule reconstruction (SCR) technique in a cadaveric study. One year later, preliminary clinical results were published [16]. The authors showed that, in the setting of irreparable rotator cuff tears, the arthroscopic SCR can restore superior glenohumeral stability and shoulder function. From now on, several slight variations of the original technique have been proposed with good clinical outcomes [17–26].

The following chapter will provide an overview on indications, surgical technique, and results of arthroscopic SCR, with a specific focus on a modified technique by using the proximal portion of the autologous long head of the biceps tendon (LHBT).

45.2 Biomechanical Rationale

Most of the surgical treatments for irreparable rotator cuff tears relieve shoulder pain, albeit complete recovery of shoulder function is rarely achieved. The main goal of SCR is to restore superior stability of the shoulder joint starting from the premise that the shoulder capsule is the main static stabilizer of the glenohumeral joint [27]. Recreation of the superior capsule was supposed to keep the humeral head centered in the glenoid allowing the restoration of a full ROM.

There have been many clinical reports on patch graft surgery for irreparable rotator cuff tears. However, patch graft augmentation or bridging procedures, in which the graft is attached medially to the stump of the torn rotator cuff tendons, showed high re-tear rate [28–31].

In its original version, the SCR was described by using a fascia lata autograft that was attached medially to the superior glenoid and laterally to the greater tuberosity [15]. From a biomechanical standpoint, the authors showed that glenohumeral superior translation after SCR in which the graft was attached medially on the superior glenoid was significantly less than that after a tendon patch graft in which the graft was attached medially to the torn rotator cuff tendon (Fig. 45.1).

There are two other issues that might affect the mechanical efficiency of SCR: ideal graft thickness and optimal arm position for graft fixation. Based on the assumption that, anatomically, the thickness of the superior shoulder capsule ranges from 4.4 to 9.1 mm at the attachment of the greater tuberosity [32], it has been shown that 8-mm-thick graft provides greater

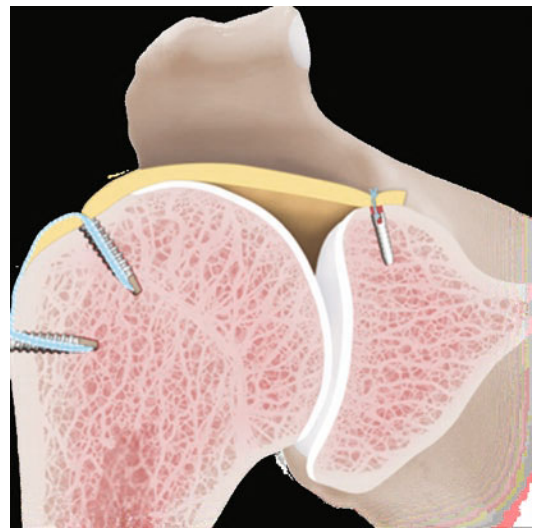

Fig. 45.1 In its original version, the SCR was described by using a fascia lata autograft that was attached medially to the superior glenoid and laterally to the greater tuberosity. Recreation of the superior capsule was supposed to keep the humeral head centered in the glenoid allowing the restoration of a full range of motion

stability than 4-mm-thick graft [33]. Moreover, since the distance between the superior glenoid and the greater tuberosity decreases with shoulder abduction, a graft attached at a high degree of shoulder abduction may therefore be at increased risk of tearing after reconstruction because of increasing tension during adduction. According to a recent biomechanical study, the best compromise is to fix the graft at 15° to 45° of shoulder abduction (equal to 10–30° of glenohumeral abduction) [33]. Subsequently, it was also highlighted that adding posterior side-to-side sutures between the graft and infraspinatus tendon as well as the underlying residual capsule completely restored superior stability. Therefore, according to the "circle concept," improvement after SCR can be also favored by achieving capsular continuity in the transverse direction [34].

Indeed, further modifications of the technique did not change its rationale. They mainly concerned the graft choice, the addition of microfractures to the greater tuberosity and variable number of anchors for both medial and lateral fixation, suture configurations, as well as the use of tapes to fix the graft laterally [17–22, 26]. No biomechanical studies up to now questioned the importance of lateral graft fixation by using one or two rows of anchors and sutures or tapes. On the contrary, Mihata et al. [35] recently compared biomechanical characteristics of using human dermal allograft, largely used in the United States [17, 18, 22, 26], and fascia lata. Main advantages of human dermal allograft consist of avoidance of donor site morbidity (associated with harvesting of the fascia lata autograft) and uniformity of the graft. However, the results showed that fascia lata completely restores superior glenohumeral stability and subacromial contact characteristics. The human dermal allograft was found to elongate by approximately 15% during testing, whereas the size of the fascia lata did not significantly change after testing. Interestingly, it was also noted that SCR using human dermal allograft with both anterior and posterior side-to-side suturing increased total glenohumeral range of motion (ROM) relative to the intact condition. Conversely, anterior side-to-side suturing decreases the total ROM when SCR was performed by using fascia lata; therefore only posterior side-to-side sutures are recommended [35].

Despite the growing interest in the use of dermal patches, it must be also considered that their price remains a potential issue in terms of socioeconomic aspects. Therefore, while respecting the basic principles of the SCR, alternative graft sources have been proposed, like the LHBT autograft [23–25].

The proximal part of the LHBT has been previously used in irreparable tears as biological augmentation to bridge the gap and to promote healing of the repaired tendon. LHBT tenotomy or tenodesis is a standard procedure during rotator cuff repair surgery; therefore, some authors suggested using the proximal portion of the LHBT as interpositional graft without detaching it from its origin from the superior glenoid pole. This pediculated graft might provide additional blood supply to the repaired rotator cuff tendons, whereas the distal part of the tendon can undergo tenotomy or tenodesis, as usual [36–38].

Arthroscopic SCR by using the proximal portion of the LHBT combines the advantages of the previously described bridging technique and the biomechanical rationale of the standard SCR. Moreover, costs are surely reduced because neither additional graft nor anchors for medial fixation are required. Finally, donor site morbidity is completely avoided.

45.3 Indications

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.

Indications for an arthroscopic SCR are:

- 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 [39, 40].
- Upper migration of the humeral head.
- Intact or at least repairable subscapularis tendon.
- Intact teres minor.
- No severe cuff tear arthropathy (stage I–III/IVa according to Hamada classification) [41].

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

Recent papers showed that SCR is also a viable option in the setting of revision of failed rotator cuff repair [21] as well as in pseudoparalytic shoulders [42, 43]. Moreover, combination of SCR and partial cuff repair [19] as well as over-the-top incorporation of the native rotator cuff [44] have also been reported. Suturing the cuff over the SCR probably widens the indication of SCR also to repairable cuff tears.

As a matter of fact, it has been hypothesized that the defect in the superior capsule could be the "essential lesion" in a superior rotator cuff tear rather than the defect in the rotator cuff itself [45]. Basically, in case of small- and medium-sized cuff tears which do not exhibit delamination of capsular and tendinous layers, a simple repair of the tear margin repairs both the capsule and the tendon. In case of large and massive cuff tears, delamination of capsular and tendinous layers is more likely to happen; therefore, attention must be paid to repair both layers in order to prevent progression to proximal humeral migration. But when tear exhibits rigid medial retraction or the capsular layer cannot be included in the repair and proximal humeral migration has occurred, it could make sense to perform both a SCR and a cuff repair over the SCR in order to recenter the humeral head and favor cuff healing by reducing the repair tension.

Based on recent biomechanical studies, the defect in the superior capsule probably cannot be considered "the essential lesion" [46], but anatomic restoration of the superior capsule and tendon insertion in delaminated rotator cuff tears demonstrated superior footprint restoration with increasing abduction strength. Moreover, construct displacement under cyclic loading showed comparable results to the native tendon [47].

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 [48]. 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 tendons have not been defined yet.

45.4 Surgical Technique

Standard SCR must be surely considered as a technically demanding procedure requiring a long learning curve and high surgical skills and experience. Concerns are mostly related to the management of anchors and sutures, preparation of the glenoid side, and accuracy in measurements of the defect and the graft. All these steps require a quite long operative time even for expert shoulder surgeons.

SCR by using the proximal portion of the LHBT, besides reducing costs, also simplifies the procedure, because it requires shorter operative time and shorter learning curve compared to the original technique.

Senior author's preferred technique is now described. The procedure can be performed under general anesthesia or interscalene block or a combination of both. Beach-chair position is the senior author's preference for cuff repair, but the procedure can be performed either way in lateral decubitus according to surgeon's preference.

Standard portals are utilized:

- Posterior portal, used as a viewing portal or as working portal for suture management when the scope is in the lateral portal.
- Anterosuperior 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.

Two plastic cannulas with different calibers are always used: one 8.0 mm operative cannula and one 5.5 mm outflow cannula.

During diagnostic arthroscopy tear characteristics, the presence and status of LHBT and eventual subscapularis tendon tears are assessed, thus defining indication for SCR. If a reparable subscapularis tendon tear is present, it must be repaired before starting the SCR procedure. A 30-degree scope is used even in case of subscapularis tendon repair.

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. Mobility and integrity of the LHBT is checked with a tendon grasper (Fig. 45.2). Two double-loaded anchors are used to fix the LHBT over the greater tuberosity. The first anchor is inserted just behind the bicipital groove. Sequentially, using a suture passer from the anterosuperior portal, both sutures are passed through the LHBT with a "lasso-loop" configuration [49] in the anterior half of the tendon (Fig. 45.3). Similarly, the posterior half of the LHBT is fixed with a second suture anchor placed posteriorly on the greater tuberosity, about 1 cm apart from the anterior one (Fig. 45.4). The LHBT is then tenotomized distally to the sutures, 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 (Fig. 45.5). All sutures are then tied by using non-sliding knots with five alternating half hitches (Revo knot) [50]. 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 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. 45.6). Functional repair

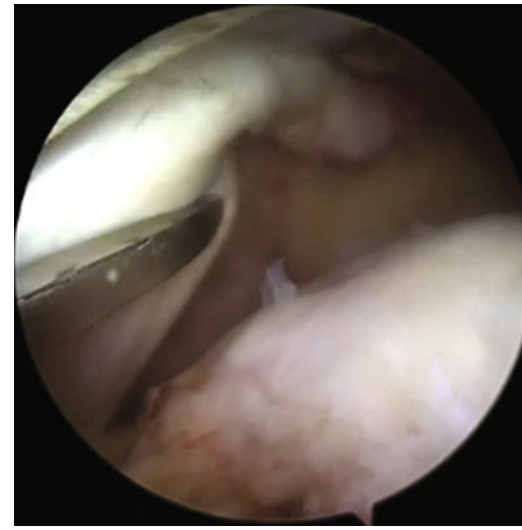

Fig. 45.2 Mobility and integrity of the LHBT is checked with a tendon grasper

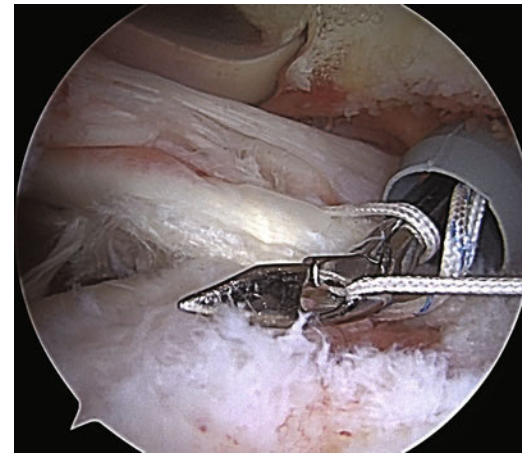

Fig. 45.3 Sutures from the anterior anchor are passed through the LHBT with a "lasso-loop" configuration

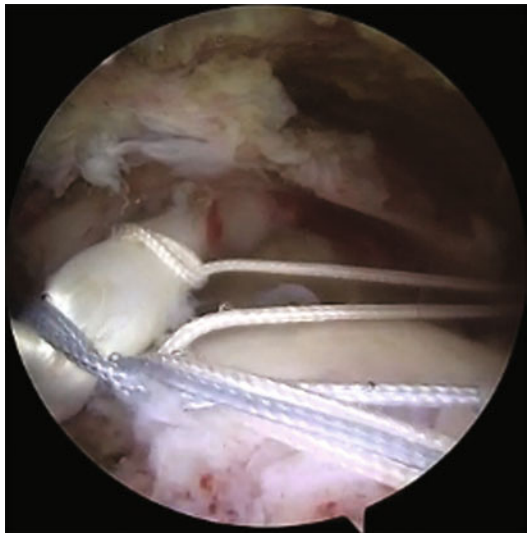

Fig. 45.4 The posterior half of the LHBT is fixed with a second suture anchor placed posteriorly on the greater tuberosity, about 1 cm apart from the anterior one

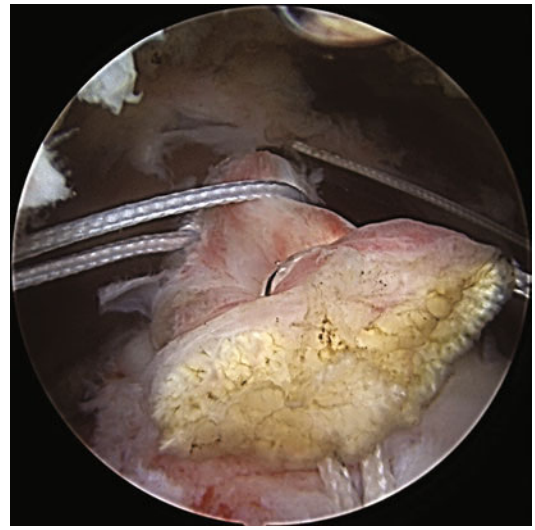

Fig. 45.5 The LHBT is tenotomized distally to the sutures, and the proximal stump of the tendon is re-routed posteriorly and transferred onto the supraspinatus tendon footprint

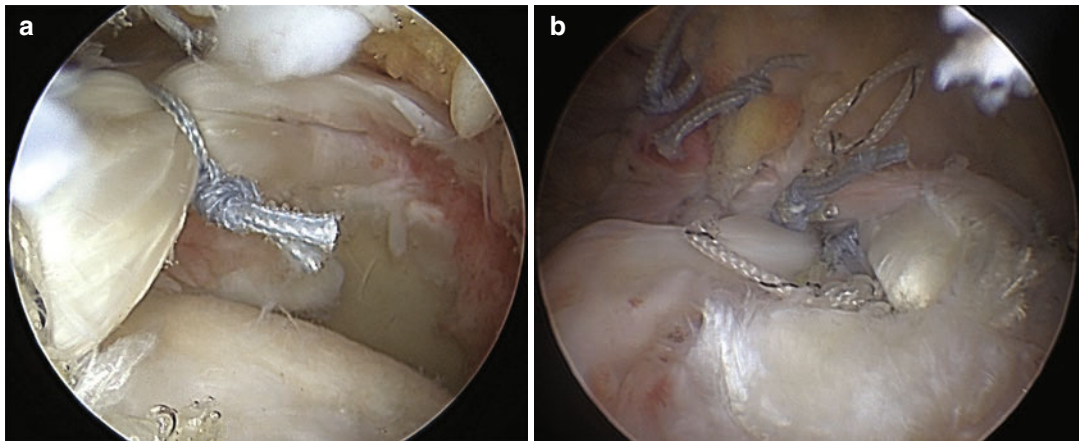

Fig. 45.6 (**a**, **b**) Side-to-side repair with the posterior and the anterior cuff edged should be attempted to restore capsular continuity in the transverse plane

by margin convergence of the residual rotator cuff can be performed over the biceps (Fig. 45.7). 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. Small bone vents of the greater tuberosity are always performed.

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:

- 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

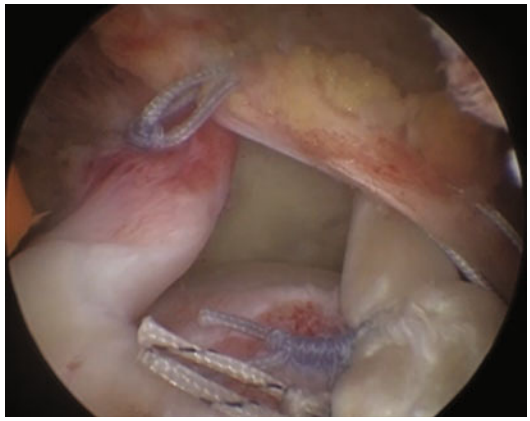

Fig. 45.7 Functional repair by margin convergence of the residual rotator cuff can be performed over the biceps

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 scapulothoracic muscles).

Return to heavy manual work or sports activities is allowed 9 months after surgery. We routinely perform an MRI at 12-month follow-up.

Similar techniques have been recently described. Main differences concern type of anchors and suture configuration [24, 25] as well as use of tapes and transosseous fixation [23].

45.5 Literature Data

Arthroscopic SCR is a relatively new surgical technique. Therefore, only preliminary results of cohort studies are available up to now.

Regarding standard SCR performed by using either fascia lata or human dermal allograft, promising results have been shown [16, 42, 43, 51, 52]. Short-term follow-up studies showed clinical success rate exceeding 70%. Radiographic analysis also confirmed a consistent and lasting increase in acromiohumeral distance, indicating maintenance of superior stability [52]. Tear rate of the graft has been reported as high as 29%, although small clinical improvements were also detected despite the recurred superior capsule defect [53]. Two recent studies [42, 43] showed that even in the case of pseudoparalysis, up to 90% of patients regained shoulder function. Nevertheless, Kanji et al. [54] described a difficult case of irreparable massive rotator cuff tear with axillary nerve palsy after a shoulder dislocation. Although SCR is not indicated for patients with deltoid muscle dysfunction, in this case the procedure provided a favorable postoperative outcome. The axillary nerve palsy was almost completely resolved 3 months after the operation, and the patient achieved a ROM comparable to that of the unaffected side 1 year after the operation. Mihata et al. [55] also reported successful results in manual workers and athletic population. The authors showed at a mean follow-up of 48 months that all patients practicing sports returned their sports activities at a preinjury level. Similarly, 32 out of 34 manual workers fully returned to their working activities.

Preliminary results of SCR by using the proximal portion of the LHBT are also encouraging [23]. A recent systematic review [56] investigated the role of biceps autograft augmentation for rotator cuff repair. Eight case series were included in the review. Despite the paucity of studies included with different surgical techniques, clinical results showed significant improvement in function, pain relief, and ROM. Overall, MRI evaluation showed 82% of structural integrity within 2 years.

Nevertheless, suitability of SCR with LHBT is mainly affected by the pathoanatomy of the biceps tendon. Although degenerative hypertrophy and flattening of the tendon, frequently observed in a large-to-massive rotator cuff tear, facilitates the use of the proximal stump of the biceps for SCR, severe fibrillation and partial or complete rupture of the tendon are contraindications for its use, and alternative techniques for SCR must be considered when those pathological features are found during surgery.

Future clinical studies are surely needed before drawing definitive conclusions on superiority of one SCR technique over another. Up to now, it is only possible to say that SCR is a safe

and reliable technique, although requiring good surgical skills and experience. Encouraging clinical and radiological results are a solid foundation for incoming studies. SCR by using the proximal portion of the LHBT has several potential benefits over the standard technique mainly related to its vitality, its availability, and its double value as autograft for SCR and as interpositional graft and, nevertheless, for its ease of use.

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Superior Capsule Reconstruction: The US Perspective

46

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46.1 Background

Massive rotator cuff tears are associated with significant weakness, pain, functional disability, and progressive shoulder arthritis [1–3]. By definition, massive tears involve at least two tendons and are most commonly subacute or chronic in nature. Compared to moderate-sized rotator cuff tears, repair of massive tears has a higher failure rate, likely due to a combination of tear chronicity, extent of retraction, fatty muscle atrophy, limited tendon elasticity, and poor tissue quality [4]. Treatment options include debridement with or without biceps tenotomy or tenodesis, partial rotator cuff repair, augmented repair with a bioinductive implant, bridging patch graft, tendon transfers, and reverse total shoulder arthroplasty.

In young and middle-aged, active patients, debridement alone, partial rotator cuff repair, and use of a bridging patch graft for massive rotator cuff tears have demonstrated suboptimal outcomes and complications, with clinical improvements that tend to deteriorate over time [5]. Reverse total shoulder arthroplasty is a viable treatment option for irreparable massive rotator cuff tears in the elderly population. It has been shown to dramatically improve pain and restore upper extremity function in patients older than 70 years of age with pseudoparalysis and Hamada Grade 3 arthropathy or higher [6]. In younger or more active patients, arthroplasty is less optimal due to concerns regarding implant longevity, required activity limitations, permanent joint destruction, high complication rates, and inferior clinical outcomes compared to elderly low-demand patients [7, 8].

Superior capsule reconstruction (SCR) has emerged as an alternative surgical technique to lessen pain and disability associated with massive irreparable rotator cuff tears while preserving the native shoulder and minimizing risk in active middle-aged patients. The annual volume of SCR with dermal allograft has risen dramatically over the recent years [9]. Originally described by Dr. Teruhisa Mihata in 2007, SCR is hypothesized to restore the superior stability of the glenohumeral joint lost by the incompetent rotator cuff complex and superior capsule. Patient factors that are used as relative indications for SCR include age under 65 and higher functional demand. While published results are lacking, the senior author has successfully employed SCR in the setting of failed prior rotator cuff repair with poor remaining tendon quality, even if the tear

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would technically be repairable. In these settings, we prefer to perform SCR while incorporating the remaining rotator cuff tissue into the repair over the top of the SCR.

46.2 Anatomy and Biomechanics

The glenohumeral joint is a shallow articulation that relies heavily on static and dynamic structures for stability. Static stabilizers include the glenoid labrum, glenohumeral ligaments, and joint capsule. The intact capsuloligamentous complex contributes to glenohumeral stability by fully sealing the joint space and maintaining negative intraarticular pressure. Disruption of the glenohumeral capsule results in loss of the stabilizing "vacuum" phenomenon and subsequent increased joint laxity. The superior capsule spans from the undersurface of the supraspinatus and infraspinatus musculotendinous units to the greater tuberosity and plays a crucial role in both static and dynamic glenohumeral stability [10]. A defect of the superior capsule, as seen in massive rotator cuff tears, results in increased glenohumeral translation in all directions, most notably in the superior direction [11].

The rotator cuff complex, deltoid, and long head of biceps are dynamic stabilizers of the glenohumeral joint. Stability is achieved through a combination of joint concavity compression, coordinated muscle contraction with balancing of coupled forces, and glenohumeral ligament dynamization through direct attachment to the rotator cuff [12]. The rotator cuff complex provides a medially directed force, centering and compressing the humeral head against the glenoid and maintaining the humeral head in a depressed position. During shoulder motion, the synergistic action of the rotator cuff and deltoid muscles maintain balanced force couples in both the coronal and axial planes. Coordinated contraction of the supraspinatus balances the superiorly directed force generated by the deltoid. The posterior rotator cuff, infraspinatus, and teres minor are balanced in the transverse plane by the subscapularis anteriorly. The muscles, tendons, and ligaments work in concert to afford the shoulder the most range of motion of any joint while at the same time maintaining stability and function.

A massive tear of the rotator cuff with concomitant disruption of the superior capsule results in marked loss of superior glenohumeral joint stability. Biomechanical cadaveric studies have shown that cutting the supraspinatus and superior capsule significantly decreases the glenohumeral compression force and increases glenohumeral superior translation and subacromial peak contact pressure [13, 14]. Superior instability, in combination with unbalanced force couples and loss of joint compression, leads to inefficient shoulder kinematics, manifesting clinically as pain and dysfunction. Progressive superior migration of the humeral head causes abnormal loading of the superior glenohumeral joint, impingement of the humeral head against the acromion, and ultimately development of arthropathy. Reconstruction of the superior capsule in patients with massive, irreparable rotator cuff tears is postulated to restore superior glenohumeral stability and prevent superior humeral head migration, thereby improving joint kinematics and overall shoulder function. By restoring superior glenohumeral stability and maintaining the humeral head in a depressed position, SCR is thought to halt progressive impingement of the head against the acromion and limit the subsequent development of rotator cuff tear arthropathy.

Mihata et al. performed several cadaveric studies evaluating the biomechanical effects of SCR following creation of an irreparable rotator cuff tear [13, 14]. Reconstruction of the superior capsule was found to correct the superior translation of the humeral head and normalize subacromial contact forces, but did not affect the glenohumeral compression force [13]. In a separate analysis, the authors emphasized the biomechanical importance of establishing capsular continuity between the graft and the residual posterior rotator cuff tissue. Reconstruction without posterior side-to-side sutures did not correct superior glenohumeral translation, though subacromial peak contact pressure decreased. Posterior side-to-side sutures normalized both the superior humeral head translation and sub-

acromial contact pressure. The addition of anterior side-to-side sutures between the graft and the subscapularis did not have a significant biomechanical effect [14].

46.3 Patient Evaluation

46.3.1 History

When evaluating a patient with a rotator cuff tear, a systematic assessment of the patient's history and symptoms is vital to select the most optimal treatment. The onset of symptoms, any preceding trauma, and duration of symptoms are important to clarify the acuity of the rotator cuff tear. The majority of massive rotator cuff tears are subacute or chronic, characterized by gradual tear progression and worsening of symptoms and dysfunction over time. Pertinent history includes prior injury to the shoulder and previous failed shoulder surgeries, with particular attention to etiology of the failure and exclusion of any indolent infection. A thorough evaluation of the patient's complaints and level of disability is required to elucidate the specific etiology of shoulder dysfunction and subsequently determine if SCR can appropriately address the patient's symptoms.

Pain is the most common presenting symptom of a rotator cuff tear. Patients often endorse a pain over the superolateral aspect of the shoulder girdle that may radiate to the anterolateral upper arm. Shoulder motion, particularly overhead activities, tends to exacerbate the pain. Night pain is common and frequently wakes patients from sleep. While active motion is frequently limited, passive range of shoulder motion should be relatively preserved. Diffuse shoulder pain in the setting of limited passive external rotation and abduction is not consistent with an isolated rotator cuff tear, but rather concurrent adhesive capsulitis, which often responds well to nonoperative treatment. Acromioclavicular (AC) joint pain can also mimic rotator cuff pathology, as it is predominantly located over the superolateral shoulder girdle as well and worsens with shoulder motion. Tenderness over the AC joint, pain at the AC joint with adduction of the arm across the chest, and pain relief following a local anesthetic injection to the AC joint are all more consistent with AC joint pathology.

The predominant functional limitation caused by a massive rotator cuff tear is subjective weakness of forward elevation and external rotation. Weakness can range from a barely perceptible loss of shoulder strength to pseudoparalysis, commonly defined as inability to abduct the arm past 90°. It is important to establish whether pain or shoulder dysfunction is the primary complaint, as SCR more reliably improves pain but is less predictable with respect to improvements in shoulder function, and patients should be counseled appropriately [15].

46.3.2 Physical Examination

A thorough physical examination of the bilateral shoulders should be performed. The shoulder girdle should be inspected for muscle atrophy, scapular dyskinesis, and presence of any gross deformity indicative of superior humeral head subluxation (Fig. 46.1). Active and passive shoulder range of motion (ROM) and strength should be assessed and compared to the contralateral shoulder. It is essential to evaluate the subscapularis strength to determine if there is a tear that may require concomitant repair at the time of

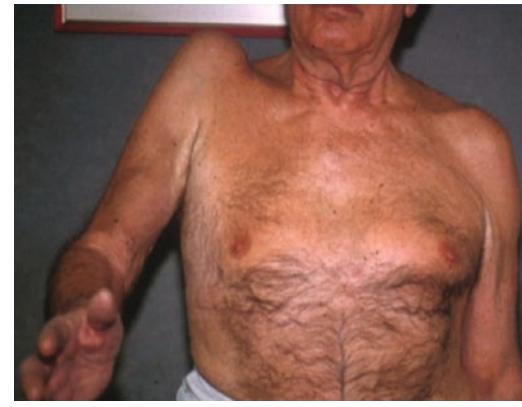

Fig. 46.1 Image demonstrating significant proximal migration of the humeral head of the patient's right shoulder in a patient with a massive, irreparable rotator cuff tear

SCR. Passive ROM should be relatively preserved. A loss of passive ROM should alert the clinician to a secondary process. Limitation of active range of motion may be due to a combination of weakness, superior humeral head migration, and pain. Inability to actively forward elevate the arm above 90° or externally rotate the arm from neutral in the setting of preserved passive range of motion and no neurologic impairment is defined as pseudoparalysis and is concerning for an irreparable massive rotator cuff tear.

Several clinical findings have been identified as predictors of an irreparable rotator cuff tear [16]. Visible anterosuperior humeral head subluxation with pseudoparalysis of forward elevation and dynamic anterosuperior subluxation with resisted shoulder abduction is associated with an irreparable tear of the anterosuperior rotator cuff. Irreparable posterosuperior rotator cuff tears are characterized by painless pseudoparalysis of forward elevation and inability to actively stabilize the arm after passive elevation to 90°, termed the "dropping sign." The presence of the "hornblower's sign," defined as the inability to maintain the arm in 90° abduction and 90° external rotation, and the dropping sign is consistent with substantial fatty degeneration of the supraspinatus and infraspinatus, respectively [17].

46.3.3 Imaging Studies

Plain radiographs of the shoulder should include true anteroposterior (AP), outlet, and axillary views. Radiographs are useful to detect static superior subluxation of the humeral head and presence of glenohumeral arthritis (Fig. 46.2). On the AP radiograph with the arm in neutral rotation, superior migration of the humeral head is quantified by measurement of the acromiohumeral interval. The acromiohumeral interval (AHI) is measured as a vertical line between the most proximal aspect of the humeral head and the inferior aspect of the acromion, with a normal range of 8–12 mm [18]. An AHI <7 mm is indicative of a rotator cuff tear with static superior subluxation of the humeral head. AHI <7 mm has been associated with a significantly high repair failure rate and is considered a predictor of rotator cuff tear irreparability [2]. Radiographs should also be evaluated for the presence of any glenohumeral arthritis and can be categorized using the Hamada classification depicted in Table 46.1 [19]. Patients with preserved AHI >7 mm (Hamada Grade 1) or AHI <7 mm with minimal to no degenerative changes (Hamada Grade 2) are amenable to superior capsule reconstruction. Once moderate to severe degeneration occurs at the undersurface of the acromion and the glenohumeral joint, SCR is no longer a viable surgical option, and these patients are better treated with reverse shoulder arthroplasty.

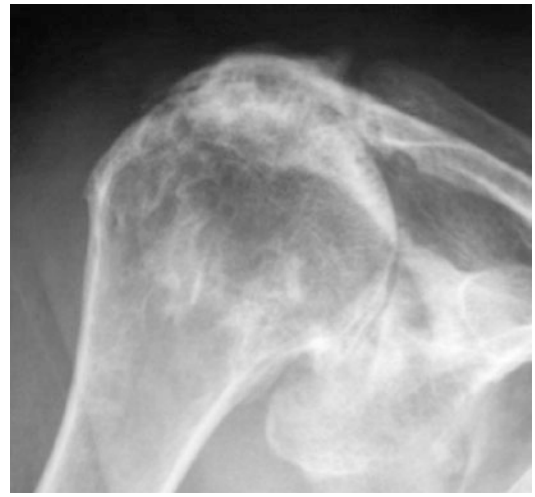

Fig. 46.2 Anteroposterior X-ray demonstrating proximal humeral migration in a patient with rotator cuff tear arthropathy. Notice the humeral head is articulating with the undersurface of the acromion

Magnetic resonance imaging (MRI) of the shoulder is helpful for characterizing the rotator cuff tear size, extent of tendon retraction, amount of fatty infiltration of the cuff musculature, as well as assessment of the glenoid and humeral head cartilage. The original Goutallier classification system for fatty degeneration of the rotator cuff muscles used computed tomography (CT) images; however, with the advent of MRI, the Goutallier classification has been modified to stage fatty infiltration utilizing MRI images, displayed in Table 46.2 [20]. Tendon retraction

Table 46.1 Hamada classification of rotator cuff arthropathy [19]

Grade	Radiographic findings
Grade 1	AHI[a] ≥ 6 mm
Grade 2	AHI < 6 mm
Grade 3	AHI < 6 mm + acetabularization
Grade 4a	Glenohumeral joint narrowing
Grade 4b	Glenohumeral joint narrowing + acetabularization
Grade 5	Humeral head collapse

[a]Acromiohumeral interval (AHI)

Table 46.2 Goutallier classification of rotator cuff fatty infiltration, MRI modification [22]

Stage	MRI findings
Stage 0	Normal muscle, no fat
Stage 1	Some fatty streaks; fat <10%
Stage 2	More muscle than fat; fat: 10–50%
Stage 3	Muscle equal to fat; fat 50%
Stage 4	Less muscle than fat; fat >50%

>3 cm and Goutallier fatty infiltration ≥Stage 3 in the supraspinatus or ≥Stage 2 in the infraspinatus are predictors of tear irreparability and have been associated with a high rate of failure and inferior clinical outcomes following rotator cuff repair [21].

46.4 Indications and Contraindications

The indications for SCR are a massive irreparable supraspinatus and/or infraspinatus tear with unmanageable shoulder pain or dysfunction that has failed conservative treatment, minimal to no shoulder arthropathy (Hamada Grade 1 or 2), intact or repairable subscapularis tendon, and a fully functioning deltoid muscle in a patient who is not an ideal candidate for arthroplasty due to age or activity level. SCR is also a viable surgical option for patients with a failed prior rotator cuff repair with significant tissue loss or poor quality tissue remaining. Patients with Goutallier Stage 4 fatty infiltration and atrophy of the torn rotator cuff musculature have inferior clinical outcomes following rotator cuff repair and may also benefit from superior capsule reconstruction with or without a concomitant repair of any rotator cuff tissue that is viable [21].

SCR is contraindicated in patients with moderate to severe rotator cuff arthropathy (Hamada Grade 3 or higher) or substantial bony defects, an irreparable subscapularis tear, dysfunction of the deltoid, latissimus dorsi or pectoralis muscles, and significant shoulder stiffness. Patients with these findings, particularly those who are older than 70 years of age and/or low-demand, are more appropriately managed with shoulder arthroplasty. Additionally, patients with extensive medical comorbidities and those unable to comply with postoperative restrictions and rehabilitation are not ideal candidates for SCR. SCR in patients with poor bone quality is relatively contraindicated, as these individuals have an elevated risk of anchor pullout and subsequent failure of reconstruction.

46.5 Surgical Technique

Surgical treatment of massive rotator cuff tears, whether with mobilization and repair or with SCR, requires longer surgical time and greater technical skill than a standard arthroscopic rotator cuff repair. A team approach is essential, including assistants and technicians experienced in the procedure. Anesthesiology is also critical for regional anesthesia and intraoperative blood pressure control to reduce bleeding and ensure visualization. In 2007, Dr. Teruhisa Mihata introduced the concept of SCR using fascia lata autograft for irreparable massive rotator cuff tears with superior glenohumeral instability [23]. The use of the long head of the biceps tendon as a local autograft for SCR has also been described although long-term convincing results are lacking [24]. In an effort to avoid the donor site morbidity associated with the harvest of fascia lata autograft, the use of an acellular dermal allograft tissue was proposed and has quickly become the predominant graft choice for SCR in North America. Many surgical techniques for SCR with dermal allograft have been published in the recent years and are generally similar with regard to the necessary steps, differing only by preferences for

graft passage, type of anchor or suture, and method of fixation [25–29]. Dr. Stephen Burkhart and colleagues have extensively described and modified the most commonly used surgical technique, which is detailed below [30].

46.5.1 Diagnostic Arthroscopy

SCR is performed under general anesthesia, often with a regional interscalene nerve block. The patient may be placed in the beach chair position or in the lateral decubitus position, with the arm held in approximately 20° forward flexion and 20° abduction in balanced suspension with 10 pounds of weight. Portal placement is similar to those used for an arthroscopic rotator cuff repair and includes posterior, anterior, lateral, accessory anterolateral, and Neviaser portal. The posterior viewing portal is established, followed by the anterior portal using an outside-in technique just lateral to the coracoid process.

A diagnostic arthroscopy is performed with systematic evaluation of the articular cartilage, glenoid labrum, long head of biceps, axillary pouch, and the rotator cuff tendons.

46.5.2 Long Head of the Biceps Tendon and Subscapularis

Attention is turned to the biceps. Our preference is to perform biceps tenotomy in massive rotator cuff repairs. For the majority of patients, we will perform biceps tenodesis at the conclusion of the case, with biceps tenotomy reserved for select patients. Our preferred biceps tenodesis technique involves a mini-open subpectoral tenodesis. An arthroscopic biceps tenodesis can be performed alternatively based on surgeon preference.

Next, the subscapularis is inspected carefully for evidence of tear. If torn, the subscapularis is then repaired to the lesser tuberosity with a variety of arthroscopic techniques depending on tear pattern and surgeon preference. This is critical to successful SCR given the role of the subscapularis in depressing the humeral head to prevent proximal humeral migration, as well as to restore disrupted rotator cuff force couples.

Moving to the subacromial space, the rotator cuff tear is visualized, and primary repair is attempted in every case. The lateral portal is created approximately 3 cm distal to the lateral edge of the acromion. Careful circumferential debridement of the cuff, extensive bursectomy, and anterior/posterior interval slides are performed to mobilize the rotator cuff to its fullest extent and obtain a partial repair. If the cuff tissue remains irreparable following maximum mobilization, SCR is performed using a commercially available acellular dermal allograft. The humeral head is translated inferiorly to ensure reduction will be possible following reconstruction of the superior capsule.

46.5.3 Glenohumeral Joint Preparation

Thorough debridement of the subacromial space, taking care to preserve the coracoacromial (CA) ligament, is completed. The decision to uniformly release the long head of the biceps tendon is by surgeon preference. If tenosynovitis, fraying, or tearing is present, the tendon should be tenotomized and possibly tenodesed later in the case, depending on patient age and activity level. Some surgeons prefer to routinely tenotomize the long head of the biceps tendon in all cases, as the extensive superior glenoid debridement required for medial anchor placement is thought to destabilize the biceps attachment.

The soft tissue along the superior aspect of the glenoid is debrided using a combination of the radiofrequency wand, motorized shaver, and ring curettes, until a bleeding bed of the bone is achieved. Attention is then turned to the rotator cuff footprint at the greater tuberosity. Residual soft tissue is debrided with the radiofrequency wand, motorized shaver, and ring curettes down to bleeding bone (Fig. 46.3).

46.5.4 Suture Anchor Placement

Accessory portals are created for suture anchor placement in the superior glenoid and medial tuberosity. Portal options include the modified anterosuperior portal just anterior to the acro-

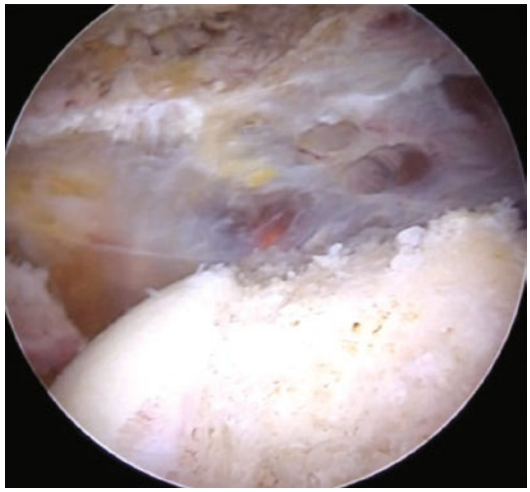

Fig. 46.3 Arthroscopic image following debridement of the residual soft tissue; the humeral footprint is adequately exposed, and bleeding bone is achieved before placement of the anchors

mion, accessory anterolateral portal at the anterolateral edge of the acromion, accessory posterior portal just portal to the acromion, and Neviaser portal just medial to the articular convergence of the clavicle, AC joint, and scapular spine.

Two anchors are placed into the superior glenoid, aiming lateral to medial, 3–5 mm medial to the articular surface to maximize contact area between the graft and the bone bed while minimizing risk of articular surface penetration and suprascapular nerve injury. The anterior glenoid anchor can be placed through the modified anterosuperior portal or the Neviaser portal, depending on surgeon preference and optimal trajectory. The anterior anchor is placed at the base of the coracoid, just anteromedial to the origin of the long head of the biceps tendon, roughly at the 2 o'clock position. The posterior glenoid anchor can be placed through the accessory posterior portal or the Neviaser portal. The posterior anchor is placed roughly at the 10 o'clock position.

Two anchors are placed into the medial tuberosity, at the junction between the bone bed and the articular cartilage. The anterior anchor is placed just posterior to the bicipital groove, and the posterior anchor is placed at the posterior aspect of the cuff defect. Anchor placement is performed through percutaneous punctures just adjacent to the lateral acromion to optimize trajectory (Fig. 46.4).

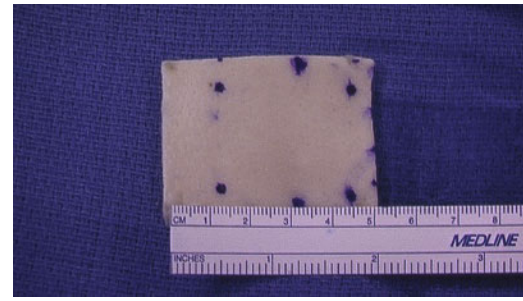

Fig. 46.4 Arthroscopic image demonstrating placement of the glenoid and humeral head anchors

46.5.5 Graft Preparation

Using an arthroscopic measuring device, the medial-lateral and anterior-posterior distances between the four suture anchors are measured and recorded. The graft is cut to the appropriate dimensions on the back table. The graft is oversized, adding 5 mm to the anterior, posterior, and medial edges to ensure some graft overhang for suturing to the adjacent intact cuff tissue and decrease the chance of suture cutout. Along the lateral edge, 10 mm of extra graft is added to establish 10 mm of contact between the greater tuberosity and the graft (Fig. 46.5). A large flexible cannula is precut and placed in the lateral portal for suture retrieval without development of a soft tissue bridge. All suture limbs from the glenoid anchors and medial tuberosity anchors are retrieved out the lateral portal, taking care to keep the sutures from each anchor in separate quadrants for organized passage through the graft and subsequent graft passage without tangling the sutures.

46.5.6 Graft Passage and Medial Fixation

Several methods of graft passage have been published, most of which describe the use of a pulley and/or zip-line system to shuttle the graft into the joint and medially onto the superior glenoid. Suture management and maintenance of correct graft orientation are critical for successful passage. All techniques require passage of the suture limbs from the glenoid anchors and medial tuberosity anchors through the graft outside the joint,

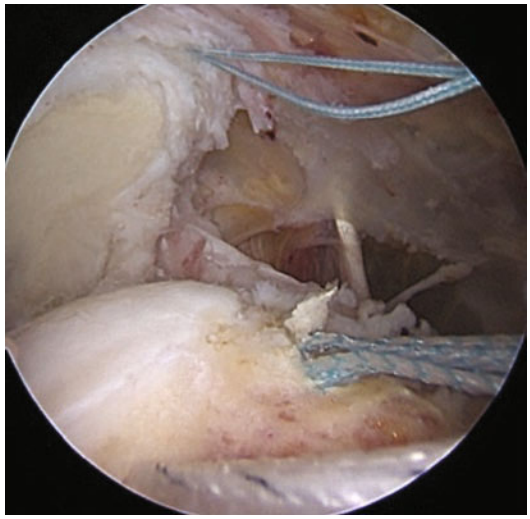

Fig. 46.5 The SCR graft is prepared on the back table. Distances between the anchors have been measured to make a quadrilateral. Dots are placed at the intended anchor sites with an additional 5 mm of graft left medially, anteriorly, and posteriorly. Laterally, 10 mm of graft is left to cover the greater tuberosity. The graft is marked to ensure the orientation is maintained during graft passage and fixation

followed by shuttling the graft into the joint and final tying of the glenoid suture limbs to secure the graft to the superior glenoid. Burkhart et al. initially described a double-pulley technique for graft passage and fixation [30]. Each of the four suture limbs from the two single-loaded glenoid anchors is passed individually through the graft along the medial edge. A bulky mulberry interference knot is then tied in each of the two central limbs, one from the anterior anchor and one from the posterior anchor.

The four suture limbs from the two medial tuberosity anchors are passed through the graft laterally. Two holes are premade in the graft 10 mm medial to the lateral edge using an anchor inserter for ease of suture tape passage. The suture from the posterior tuberosity anchor is passed through the posterior hole and similarly for the anterior suture. Once all the sutures are passed, the precut flexible cannula is removed from the portal, and the graft is inserted into the joint space. The two free suture ends from the anterior and posterior glenoid anchors are pulled, effectively pushing the two mulberry knots against the graft, pushing it medially toward the two anchors until it touches the glenoid. Once the graft contacts the glenoid, a retriever is passed down each of the tuberosity suture limbs to remove redundancy from the sutures beneath the graft. The two suture limbs with the mulberry knots are then retrieved, the knots are removed, and the two central limbs, one from each anchor, are tied together over a metal post. The knot is then pulled back into the joint by again pulling on the free suture limbs. The anterior and posterior free suture limbs are then tied together to complete the glenoid fixation. Another variation of this technique is to tie the central two limbs together at the start, rather than two individual mulberry knots, and shuttle it into the joint in the same manner, by pulling on the anterior and posterior free suture limbs.

In cases of massive rotator cuff tears with large residual defects >35 mm in the anterior-posterior dimension, three double-loaded suture anchors can be placed in the superior glenoid for better fixation of the wider graft. Due to the larger graft size, graft passage is met with significant resistance, which could dislodge the glenoid anchors from the bone if graft passage is done using the pulley system alone. Therefore, Burkhart and colleagues modified the graft passage to include a zip-line technique, which simultaneously pushes the graft into the joint space, thereby lessening the force transmitted to the glenoid anchors. Similar to the original technique, the glenoid sutures are passed through four holes along the medial edge of the graft. All four suture limbs from the posterior anchor pass through one hole in the posteromedial edge. All four suture limbs from the anterior anchor pass through one hole in the anteromedial edge of the graft. Two different color suture limbs from the central anchor pass through two individual central holes along the medial edge. Two mulberry knots are again tied in the two central suture limbs, and the two corresponding free limbs are pulled out of the Neviaser portal. The medial tuberosity sutures are passed through the lateral graft, in the same fashion as previously detailed. The two free suture limbs are pulling from the Neviaser portal to guide the graft into the joint, while a retriever is sequentially passed down the

posterior glenoid suture limbs and anterior glenoid suture limbs, pushing the graft along the two "zip lines." Once the graft is seated medially against the glenoid, the two suture limbs with the mulberry knots are then retrieved, the knots are removed, and each limb is tied to its corresponding free limb in a simple knot fashion. The suture limbs from the anterior and posterior anchors are then tied together and shuttled into the joint using the same double-pulley technique. All glenoid suture limbs can be tied, or a full suture in each anchor can be saved for later side-to-side fixation with the anterior interval and posterior residual rotator cuff. Regardless of what technique is used for graft passage, meticulous suture management, patience, and attention to detail are paramount to prevent issues with the graft.

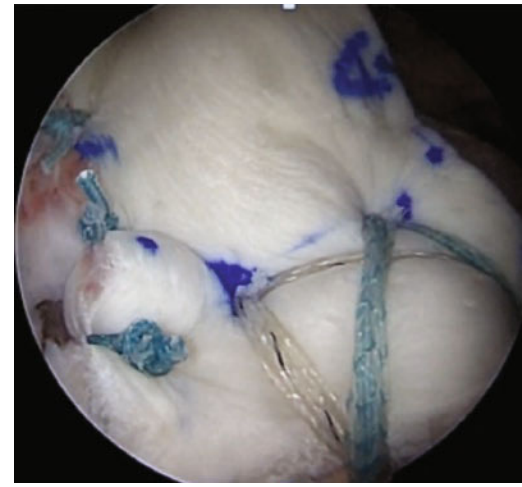

Fig. 46.6 Arthroscopic image demonstrating the final superior capsular construct with the graft fixed medially on the glenoid, laterally on the humeral head, and posteriorly to the remnant posterior rotator cuff tissue

46.5.7 Lateral Fixation

Once the medial graft is secured to the glenoid, attention is turned to fixation of the lateral graft. A suture pusher is passed down each suture limb of the medial tuberosity anchors to remove all slack and push the graft against the tuberosity. With the arm held in approximately 20° forward flexion, 20° abduction, and neutral rotation, the suture limbs are crisscrossed and fixed laterally into the humeral metaphysis with two lateral row anchors.

46.5.8 Side-to-Side Fixation

Side-to-side fixation between the graft and the intact posterior rotator cuff is essential to improve force coupling of the shoulder (Fig. 46.6). The anterior margin of the graft can be secured to anterior interval tissue, if present. If there is no residual interval tissue, the anterior margin of the graft should be left free and not sutured to the subscapularis, as that will excessively constrain the graft and limit shoulder motion. The importance of capsular continuity between the graft and the residual posterior rotator cuff tissue was highlighted in a biomechanical study by Mihata et al. SCR without posterior side-to-side sutures did not correct superior humeral head migration, while specimens with posterior sutures did restore normal humeral head height. Addition of anterior sutures to the rotator interval tissue did not exhibit a significant biomechanical effect [14].

46.6 Rehabilitation

Appropriate rehabilitation is vital to the success of SCR. Postoperative protocols differ between surgeons, but most require an initial period of shoulder immobilization to allow for graft healing, then passive range of motion exercises to minimize stiffness followed by active-assisted and active range of motion exercises, and finally initiation of strengthening activities once ROM has been regained [31]. Patients are usually immobilized in a sling with an abduction pillow to support the glenohumeral joint for 6 weeks postoperatively. During this phase, patients should be encouraged to actively range their neck, elbow, wrist, and digits to maintain accessory joint mobility. At 6 weeks, the sling is discontinued, and patients begin passive shoulder ROM under the supervision of a physical therapist. At 8 weeks postoperatively, active-assisted range of motion exercises are initiated followed by active ROM exercises. ROM goals during

weeks 6–12 are 140° of forward elevation, 40° of external rotation, and 60–80° of abduction [25]. Muscle strength begins at 12 weeks postoperatively, beginning with closed-chain exercises and light resistance bands and advancing to overhead strengthening and proprioceptive and plyometric exercises at week 16. Strengthening is advanced as tolerated but should be performed no more than three times per week to avoid tendonitis. Deltoid and scapular stabilizers are emphasized in addition to rotator cuff strengthening. Sport-specific rehabilitation including eccentric resisted motions, plyometrics, and proprioception is delayed until 4–5 months after surgery. Patients will continue to improve for upward of a year after surgery.

46.7 Outcomes

SCR remains a relatively new surgical procedure. Consequently, clinical data and postoperative outcomes are sparse and limited to short- and midterm follow-up. Mihata et al. reported the clinical and radiographic outcomes of SCR with fascia lata autograft [23, 32, 33]. At an average follow-up of 5 years, patients reported significant improvement in pain, function, active shoulder range of motion in forward elevation and external rotation, and muscle strength. At final follow-up, 95% of patients with pseudoparalysis preoperatively had complete resolution of pseudoparalysis [32]. All patients were able to return to sports and physical work, with only 2% of patients requiring reduced workloads [33]. Radiographic evaluation showed normalization of the acromiohumeral interval and no progression of osteoarthritis. MRI demonstrated 98% graft healing rate without retear. Patients with graft tears on MRI had inferior clinical outcomes scores, persistent pseudoparalysis, and positive external rotation lag and hornblower's signs at final follow-up [32]. It must be noted that the thickness of the fascia lata graft used by Mihata in his studies is greater than that of the commercially available dermal allograft used for SCR in the United States. As such, the results of Mihata may not be exactly translatable to the dermal allograft.

Comparably, studies focused on SCR with dermal allograft have also shown significant improvement in pain, function, muscle strength, active forward flexion and external rotation, and radiographic improvement in the acromiohumeral interval [34–36]. Denard et al. reported a successful outcome in approximately 70% of patients after superior capsule reconstruction with allograft. Eleven of their 59 patients (18.6%) required a revision surgery. Furthermore, postoperative MRI evaluation demonstrated graft healing in only 45% of patients, significantly less than that reported by Mihata and colleagues [34]. In a retrospective review of 86 patients who underwent SCR with dermal allograft, Pennington et al. found a 90% patient satisfaction rate. Patients demonstrated improvement in pain level, functional outcome scores, strength, and range of motion at 1 year postoperatively [36].

Mihata et al. reported a further larger series of 102 SCRs in 100 patients for massive rotator cuff tear with fascia lata autograft [37]. Similar to the initial series, patients experienced improved forward flexion from 92° to 149°, external rotation from 26° to 41.6°, and ASES score from 31.6° to 93.3°. MRI at 3 months postoperative showed intact SCR in 93.1% of patients, with 2.9% infraspinatus retear rate and 3.9% graft retear rate. Furthermore, 32 of 34 (94%) of patients returned to prior occupation and 26 of 26 (100%) returned to sport. Future studies to confirm long-term outcomes of these excellent short-term results are needed, as are comparative studies of SCR and alternative techniques for managing irreparable rotator cuff tears.

Failure of the SCR with persistent pain and loss of shoulder function is a challenging problem. Failure of the SCR is more common on the humeral side although can occur either on the humeral or glenoid side of the SCR graft (Fig. 46.7a). Although revision SCR can occasionally be performed in this setting, we generally favor revision to reverse shoulder arthroplasty for the failed SCR since it provides the most reliable pain relief and improvement in function (Fig. 46.7b, c). We treat these patients under our infection protocol due to the possibility of infection

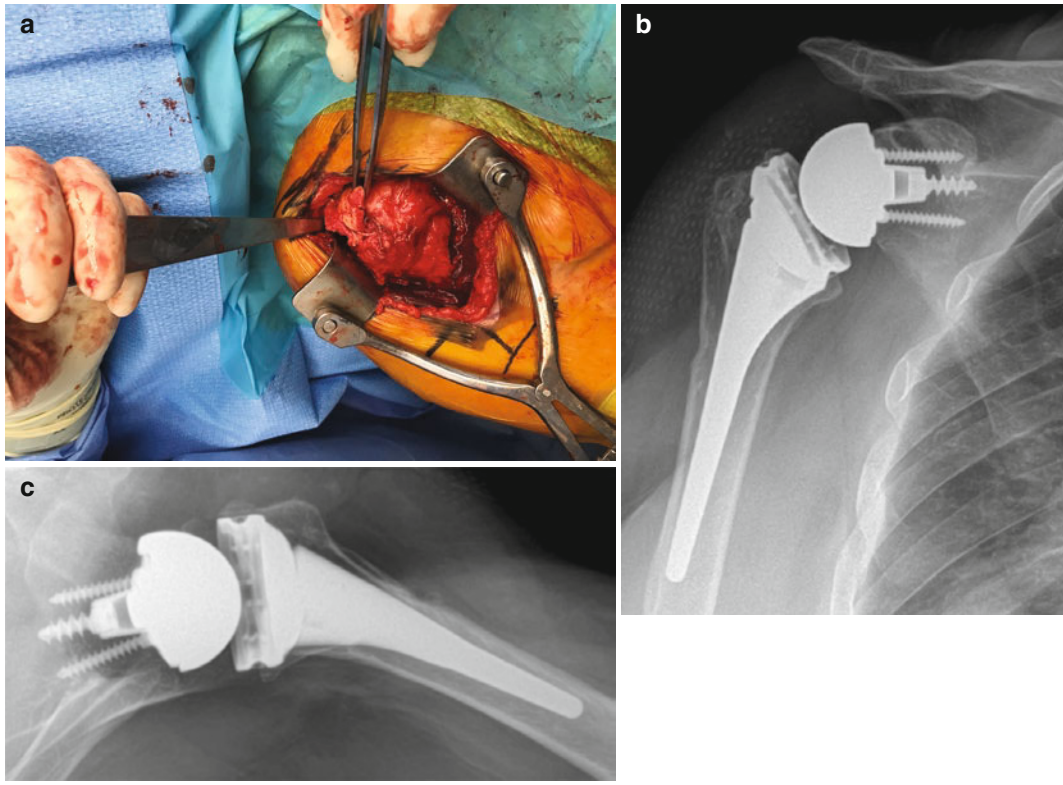

Fig. 46.7 A case with failure of healing of the SCR graft on the humeral side is shown (**a**). The patient received revision to reverse shoulder arthroplasty as shown on postoperative AP and axillary radiographs (**b** and **c**)

with an indolent organism such as *P. acnes*, although the majority had failure of SCR graft healing without infection. Briefly, antibiotics are held until five intraoperative cultures are obtained. As long as suspicion for infection is low, patients receive reverse shoulder arthroplasty and are discharged on 21-day course of Augmentin, while the cultures are followed for 21 days. Five cultures are used in order to attempt to account for the high rate of achieving false-positive cultures in this setting.

46.8 Conclusion

Irreparable rotator cuff tears present a challenging problem for the treating surgeon. In young patients without significant arthritis, a SCR can be attempted to decrease pain and possibly increase function. Meticulous attention to detail and modern surgical techniques can afford good to excellent outcomes in the short term. Long-term outcomes of the SCR are still uncertain.

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Part V

RC in Old Patients (Age> 70)

Cuff Tear Arthropathy with Bone Loss (Acetabular Acromion)

47

Giuseppe Milano, Maristella F. Saccomanno, and Andrea Grasso

47.1 Introduction

The cuff tear arthropathy (CTA) was first described by Neer in the early 1980s [1] as "degenerative changes of the glenohumeral joint consequent to a massive rotator cuff tear" and further defined by Jensen in 1999 [2] as a disease characterized by three main findings: (a) massive rotator cuff tear associated with shoulder pain, muscle atrophy, and loss of motion; (b) degenerative changes in the glenohumeral joint; and (c) upward migration of the humeral head observable on X-rays in anteroposterior (AP) view.

Subsequent radiological classification aimed to define and correlate progressive stages of the disease and consequent treatment strategies [3, 4].

Interestingly, management of CTA has largely changed in the last decades in a way that probably nothing else did in orthopedics. At present, improved arthroscopic techniques and emerging technologies, such as superior capsule reconstruction, may provide a possible treatment solution for certain stages [5]. However, when degenerative changes and bone loss occur, reverse shoulder arthroplasty (RSA) does remain the best treatment option. As imaging tools, design and biomechanical rationale of RSA, and surgical techniques improved, there have been expanding options in augmentation techniques and baseplate fixation, which widens the opportunity to improve the functional outcomes even in the late stages of CTA.

The aim of the present chapter is to provide an overview on pathology, classification, and treatment of CTA with bone loss.

47.2 Pathogenesis

From an epidemiological standpoint, CTA has been reported to be more common in women, in the 6th–7th decades, particularly involving the dominant shoulder [6]. Several risk factors have been identified: rotator cuff tear, rheumatoid arthritis, crystalline-induced arthropathy, and hemorrhagic shoulder (hemophiliacs/anticoagulants) [6]. Recently, Gumina et al. [7], based on the assumption that the instability consequent to massive cuff tear may worsen in patients with joint laxity and that joint laxity is notoriously more common in women, hypothesized that generalized joint laxity could be a risk factor for development of CTA. However, the authors finally showed no correlation at all between joint laxity and glenohumeral osteoarthritis.

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Two main etiopathogenetic theories for CTA have been developed: (a) crystal-mediated and (b) rotator cuff tear-mediated.

In 1981, Halverson et al. [8] proposed a crystal-mediated theory at the origin of CTA. They coined the term "Milwaukee shoulder syndrome" and hypothesized that the trigger point was an immunologic cascade activated by calcium phosphate-containing crystals in the synovial tissue. Subsequently, McCarty et al. [9] showed that basic calcium phosphate crystal accumulation in the glenohumeral joint actually correlates with rotator cuff deficiency. Synovial cells phagocytize the crystals, releasing prostaglandins and proteases that destroy articular cartilage. A positive feedback cycle accelerates degeneration of the rotator cuff and biceps tendon, leading to glenohumeral joint degradation.

On the opposite, Neer et al. [1] hypothesized the rotator cuff theory, which involves both mechanical and nutritional factors. Rotator cuff tears are thought to produce at least two simultaneous negative effects:

- A muscle unbalance that, based on the force couple theory explained later on by Burkhart et al. [10], leads to the upward migration of the humeral head and consequently to glenoid and acromial wear as well as eccentric humeral head motion and premature wear of the articular cartilage in the areas of higher glenohumeral compression.
- Loss of the watertight effect (loss of negative pressure normally existing inside the glenohumeral joint), which allows extravasation of the synovial fluid and, consequently, leads to an impaired delivery of nutrients to the articular surface, so the cartilage is poorly nourished and would easily become atrophied.

Furthermore, pain associated with cuff tear and degenerative changes makes the shoulder range of motion (ROM) rather limited, leading by time to disuse osteoporosis and collapse of the subchondral bone of the humeral head.

47.3 Clinical Features

Patients with CTA are typically elderly and usually describe classical symptoms and functional impairment related both to osteoarthritis and cuff disease. They have a history of progressively worsening pain, accompanied by limited shoulder motion and stiffness. These symptoms may be precipitated by an acute, traumatic event. Patients with a diagnosis of rheumatoid arthritis or of another inflammatory arthropathy may also present with polyarthralgia and a prior history of medical treatment for their systemic disease [11].

The physical examination always starts with a global inspection of both shoulders. Any difference between shoulders in muscle atrophy should be noticed. Swelling and clinical evidence of anterosuperior escape of the humeral head are not uncommon and indicate a gross deficiency of subscapularis and supraspinatus tendons.

Both active and passive ROM are usually very limited by weakness, pain, and stiffness, but at varying degrees. Tests for evaluation of cuff integrity are positive both for pain and strength deficit.

Cervical spine disorders as well as complete deltoid deficiency and any sign of neurological disorders must be ruled out.

47.4 Imaging

Diagnosis of CTA is essentially clinical and radiographic, as standard X-rays in the AP and axillary views may demonstrate characteristic findings. Magnetic resonance (MR) could be helpful in evaluation of cuff tendons and muscle status. A computed tomography (CT) scan is mandatory for preoperative planning especially in the setting of bone loss.

47.4.1 X-Rays

A true AP and axillary views are enough. No specific views are required either for CTA diagnosis or for preoperative planning.

Pathognomonic radiographic signs of CTA are:

- Superior migration of the humeral head, represented by decreased acromiohumeral distance.
- Femoralization of the humeral head, which means erosion of the greater tuberosity.
- Acetabularization of the acromion, represented by a thinning of the coracoacromial arch and superior glenoid erosion.
- Posterior glenoid erosion.
- Glenohumeral subluxation as a result of rotator cuff insufficiency.
- Osteopenia in both the proximal aspect of the humerus and the glenoid.

Joint space narrowing and osteophytes are common findings in CTA as well as in primary osteoarthritis (Fig. 47.1).

CTA has been classified on radiographic imaging according to Hamada [3] and Seebauer [4].

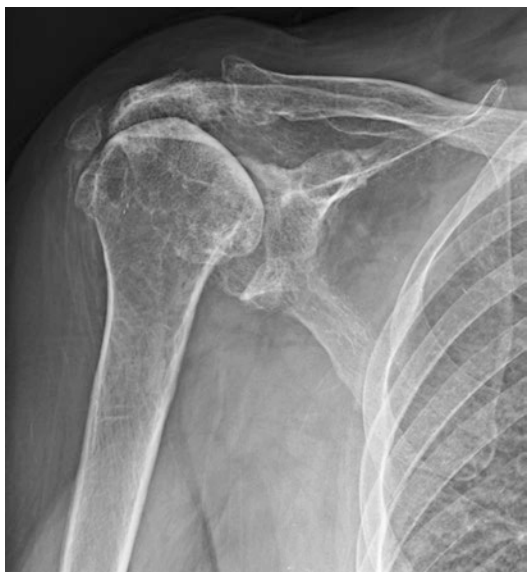

Fig. 47.1 Anteroposterior X-ray view of a right shoulder with some pathognomonic radiographic signs of cuff tear arthropathy (CTA)

The Hamada classification [3] (Fig. 47.2) depicts the process of progressive superior migration of the humeral head:

- Stage 1: the acromiohumeral interval is >6 mm.
- Stage 2: the acromiohumeral interval is <5 mm.
- Stage 3: the acromiohumeral interval is <5 mm, and acetabulization of the coracoacromial arch is present.
- Stage 4: the glenohumeral joint is narrowed, either without acetabulization (Stage 4a) or with acetabulization (Stage 4b).
- Stage 5: humeral head osteonecrosis results in collapse.

The Seebauer classification [4] is quite more complicated and therefore less widespread in clinical practice. It is a biomechanical description of CTA, in which each type is distinguished according to the amount of upward migration of the humeral head from the center of rotation and the amount of instability. The amount of decentralization seen on radiographs is dependent on "the extent of the rotator cuff tear, the integrity of the coracoacromial arch, and the degree and direction of the glenoid bone erosion" [4].

Plain radiographs have also been employed as a tool for preoperative planning. Several classifications have been proposed to assess glenoid wear [12–15]. As a matter of fact, it is important to highlight that bone loss is always multiplanar; therefore, assessing glenoid wear means a comprehensive evaluation of glenoid version [12], inclination [13, 14], and medialization [15]. Glenoid version is usually evaluated on axillary view, whereas inclination can be evaluated on a true AP view, and medialization has been classified on AP and axial views.

Nyffeler et al. [12], after comparing measurement of glenoid version on X-rays and CT scans, actually showed that glenoid retroversion can be overestimated on X-rays in up to 86% of cases; therefore, up to now CT scan is the modality of choice for the estimate of glenoid version.

On the contrary, radiographic classification systems for glenoid inclination and medialization are still valid.

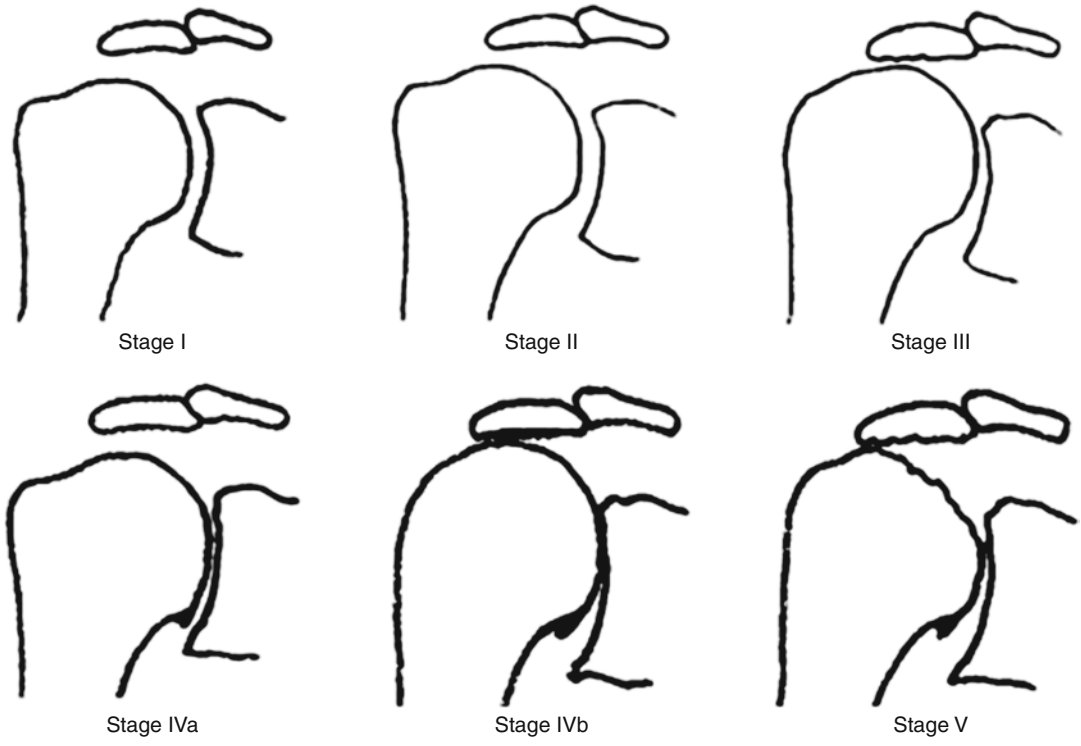

Fig. 47.2 Radiographic classification of CTA according to Hamada [2]

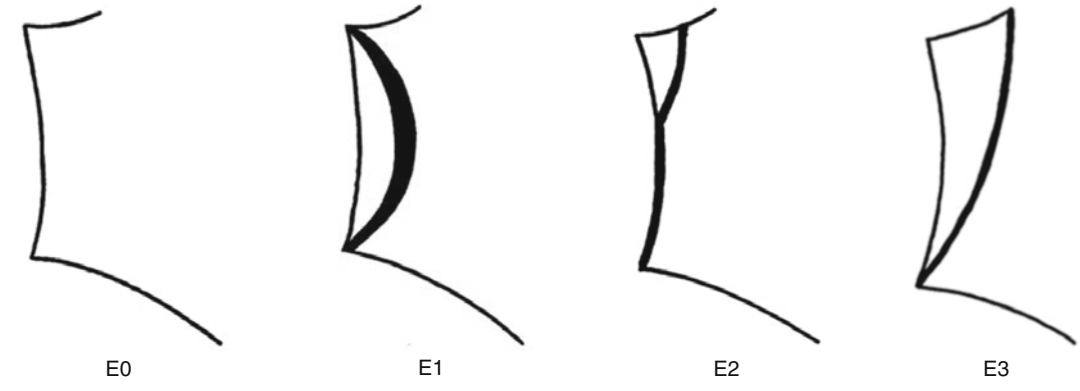

Fig. 47.3 Radiographic classification of glenoid tilt in the coronal plane according to Sirveaux et al. [14]

Anatomically, the angle of inclination of the glenoid is equivalent to the amount of glenoid tilt in the coronal plane and defines the position of the humeral head relative to the subacromial space. The normal glenoid tilt in the coronal plane has been reported to range from −8° to 15.8° (average, 4–5°) [16]. Two classification systems are available [13, 14].

Sirveaux et al. [14] (Fig. 47.3) defined four types of glenoid in order to describe the progression of superior erosion:

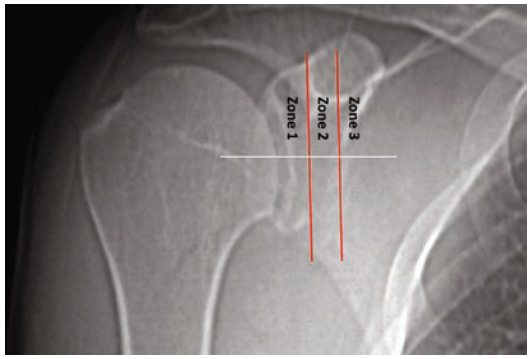

Fig. 47.4 Radiographic classification of glenoid medialization according to Kocsis et al. [15]

- Type E0: the head of the humerus migrated upward without erosion of the glenoid.
- Type E1: concentric erosion of the glenoid.
- Type E2: erosion of the superior part of the glenoid.
- Type E3: erosion extended to the inferior part of the glenoid.

Conversely, Habermeyer et al. [13] depicted the evolution of eccentric inferior glenoid wear. The glenoid inclination angle was measured with the use of one line drawn along the superior and inferior glenoid rim (the glenoid line) and another line drawn along the lateral base of the coracoid process (the coracoid base line) from the superior glenoid rim perpendicular to the bottom margin of the radiograph. Four types of glenoid were identified:

- Type 0: normal glenoid, the coracoid baseline and the glenoid line run parallel.
- Type 1: the coracoid base line and the glenoid line intersect below the inferior glenoid rim.
- Type 2: the coracoid base line and the glenoid line intersect between the inferior glenoid rim and the center of the glenoid.
- Type 3: the coracoid baseline and the glenoid line intersect above the coracoid base.

Very high interobserver reliability was found by the authors [13].

Classification of glenoid medialization has been recently described by Kocsis et al. [15] on AP and axial views. Two anatomical reference points were used to define limits of three zones: the most medial point of the spinoglenoid notch and the most lateral edge of the base of the coracoid (Fig. 47.4). Three types have been recognized:

- Type 1: the most medial (or lowest) point of the intact glenoid articular surface is at the level of or lateral to the base of the coracoid (zone 1).
- Type 2: the most medial (or lowest) point of the intact glenoid articular surface falls between the base of the coracoid and the most medial point of the spinoglenoid notch (zone 2).
- Type 3: the most medial (or lowest) point of the glenoid articular surface reaches the level of the spinoglenoid notch or is medial to it (zone 3).

Excellent inter-method reliability, interobserver reliability, and test-retest reliability were reported by the authors [15].

47.4.2 Magnetic Resonance

Although not essential for diagnosis, MR is useful for assessing the extension of the rotator cuff tear and, even more, muscle atrophy and fatty infiltration (Fig. 47.5). Recent studies showed that degree of rotator cuff muscle fatty infiltration is associated with glenoid type [17]. Moreover, Donohue et al. [18] showed that high-grade fatty infiltration of rotator cuff muscle is associated with increased pathologic glenoid retroversion and increased joint-line medialization.

47.4.3 Computed Tomography

CT scan evaluation is paramount for the preoperative planning. It provides accurate visualization and quantification of glenoid bone stock as well as detecting competence of the coracoacromial arch and/or eventual presence of an acromial stress fracture.

As already mentioned, CT scan is up to now considered the gold standard for definition of glenoid version. Unfortunately, assumptions about how much of the measured glenoid version are

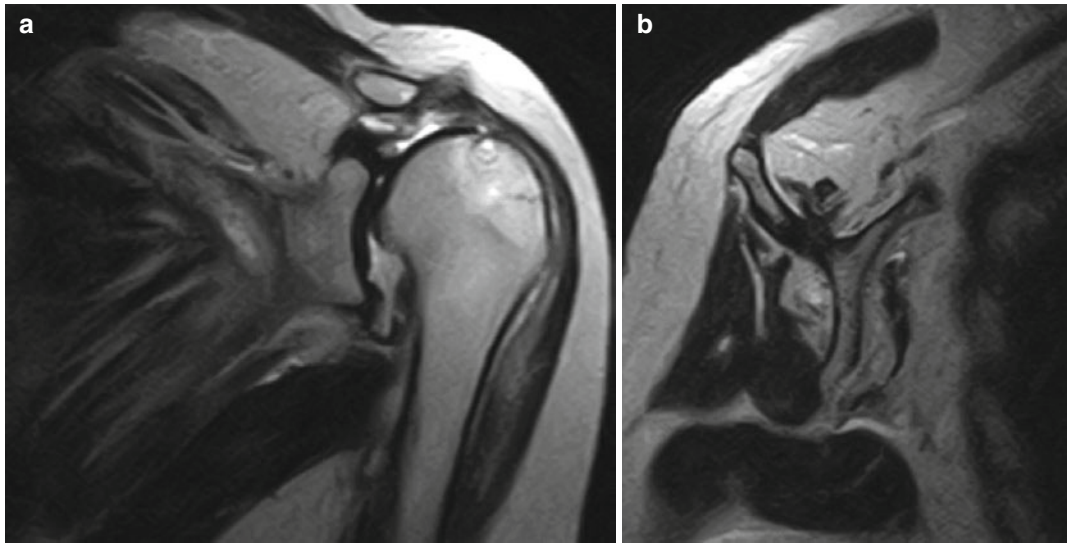

Fig. 47.5 MR is useful for assessing the extension of the rotator cuff tear (**a**) and, even more, muscle atrophy and fatty infiltration (**b**)

physiologic, and how much is pathologic in any one patient is quite complicated due to the fact that native glenoid version has been reported to vary over a 25° range from −14° (retroversion) to +12° (anteversion) [16, 19].

Walch et al. [20] first developed a classification system to describe glenoid version in cases of primary glenohumeral osteoarthritis by using two-dimensional (2D) CT scan. It includes five categories of glenoid patterns:

- A1: centered humeral head, minor erosion.
- A2: centered humeral head, major central glenoid erosion.
- B1: posterior subluxated head, no bony erosion.
- B2: posterior subluxated head, posterior erosion with biconcavity of the glenoid.
- C: dysplastic glenoid with at least 25° of retroversion regardless of erosion.

Recently, the original Walch's classification system was modified by adding new glenoid subtypes [21, 22]. Bercik et al. [21] added the following subtypes (Fig. 47.6):

- B3: monoconcave glenoid and posteriorly worn, with at least 15° of retroversion or at least 70% posterior humeral head subluxation, or both.
- D: glenoid with any level of anteversion or with humeral head subluxation of less than 40% (i.e., anterior subluxation).
- A more precise definition of the A2 glenoid: "cupula" describes a glenoid in which a line drawn from the anterior to posterior rims of the native glenoid transects the humeral head.

Intra- and interobserver reliability were also successfully proved [21].

Davis et al. [22] described the C2 glenoid: a glenoid with greater than 25% of retroversion in addition to posterior subluxation of the humeral head with respect to the glenoid face (Fig. 47.7).

In both studies, glenoid were evaluated by using three-dimensional (3D) CT scan reconstructions. It has been proven that 3D CT reconstructions portray glenoid version more reliably than 2D CT because 3D reconstructions allow reorientation of the scapula as a free body [19, 23–26] (Fig. 47.8).

Advancement in 3D CT reconstruction software and awareness of the wide range of anatomic variations in glenoid version led to define a new 3D glenoid vault model [27]. The internal architecture of the glenoid vault was found

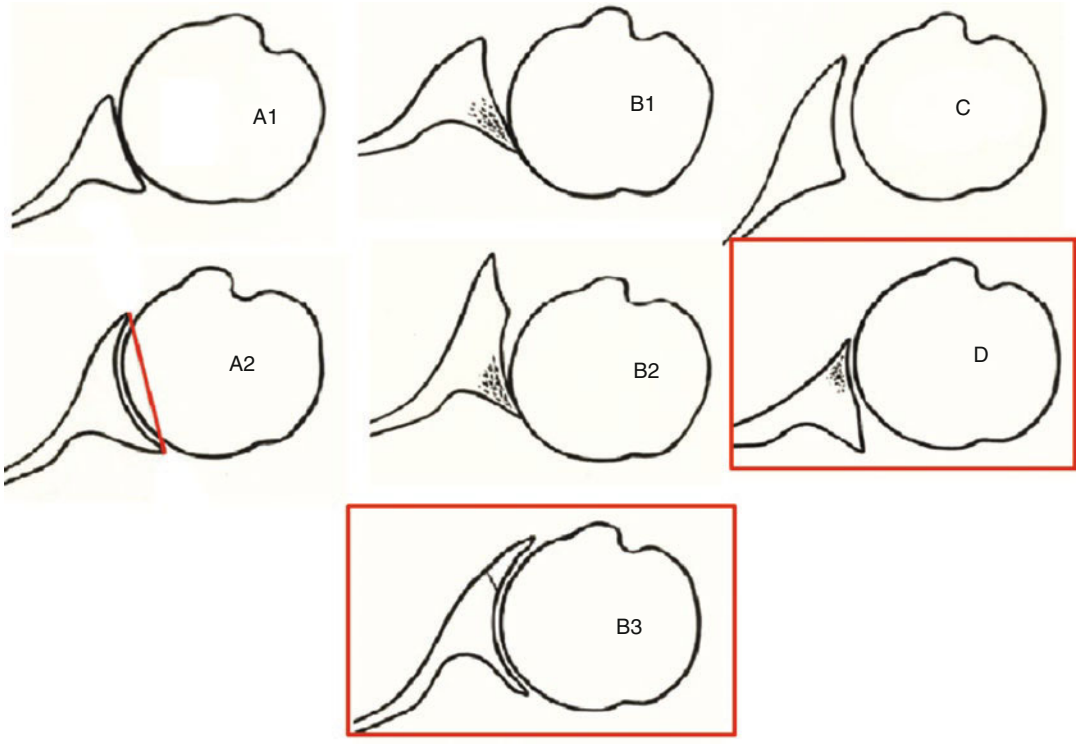

Fig. 47.6 Classification of glenoid version according to Walch et al. [20] modified by Bercik et al. [21]

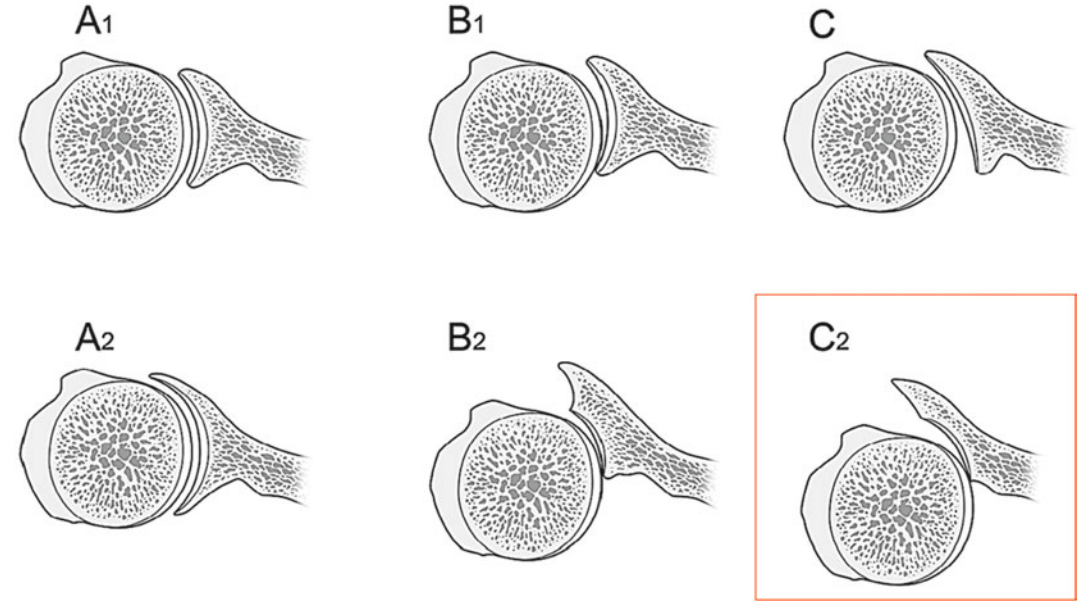

Fig. 47.7 Classification of glenoid version according to Walch et al. [20] modified by Davis et al. [22]

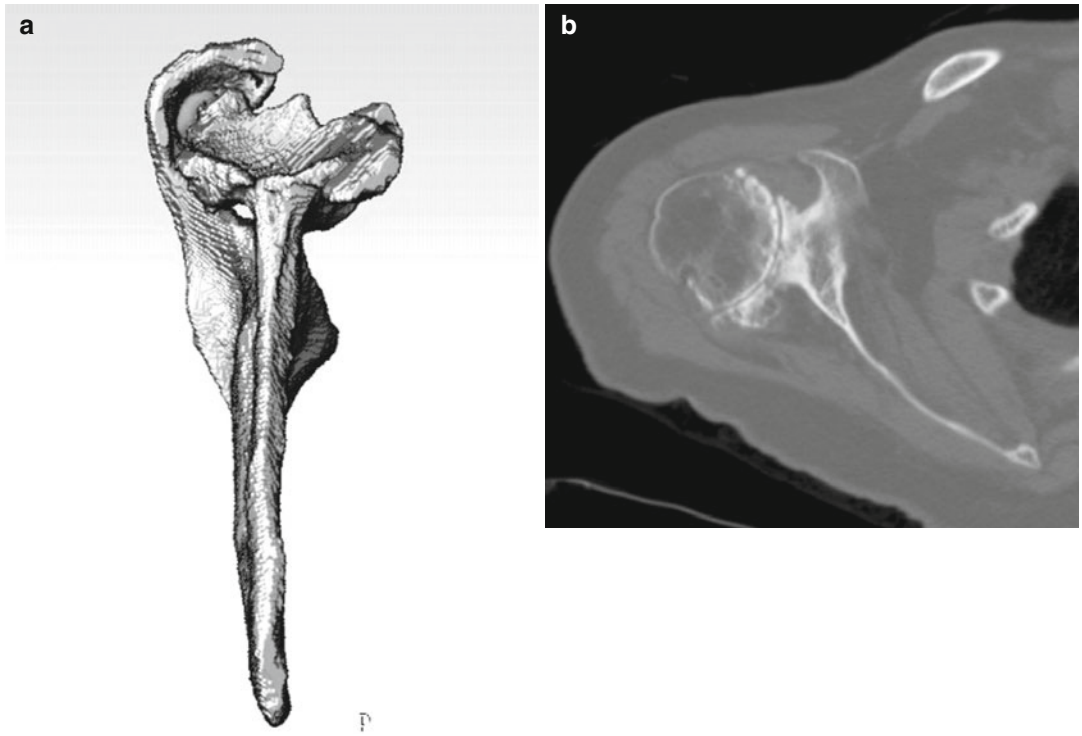

Fig. 47.8 3D CT reconstructions (**a**) are more reliable than 2D CT reconstructions (**b**) in estimating the true glenoid version

to have a reproducible triangular morphology, defined by the endosteal surfaces of the vault. This technique has been first applied to the contralateral, normal glenoid as a template for initial model orientation [27], but subsequently it has been shown that when placed in the best-fit position, the vault model could be used to estimate the physiologic glenoid version in an individual with severe glenoid disease, independent of knowledge of the contralateral glenoid version [28, 29]. Besides the glenoid vault model, several commercial software able to quantify volume, severity, and morphology of glenoid bone loss, with or without the assistance of patient-specific instrumentation (PSI), have been recently developed in order to improve surgeon's ability to place the glenoid implant in the desired location or to understand preoperatively when a standard implant cannot be used [30–33].

47.5 Addressing Glenoid Wear in CTA

Managing severe glenoid bone loss in CTA poses a unique surgical challenge. Historically, these patients were treated with hemiarthroplasty avoiding glenoid implantation. However, clinical studies showed uncertain pain relief and poor functional outcomes [34, 35]. Therefore, up to now, RSA is the best and only treatment option in Stage IVb and V CTA according to Hamada's classification [3]. Shoulder arthroplasty is one of the fastest-growing fields in orthopedic surgery. The goal of glenoid implantation is to correct the glenoid version and use the glenoid vault anatomy to maximize fixation and minimize medialization [29]. Based on size and morphology of glenoid wear, different strategies have been developed.

47.5.1 Asymmetric Reaming

Eccentric reaming prior to glenoid component insertion is a common technique used to improve excessive glenoid retroversion. From a technical standpoint, it is quite easy to perform, requiring only attention to the direction of the reamer in order to avoid worsening of the defect. Cannulated reaming systems allow placement of a guide pin to assess planned version correction before reaming.

Indeed, it has been shown that aggressive reaming can reduce the subchondral bone available for implant support, medialize the joint line, and allow cortical perforation of the polyethylene implant [36]. Studies that have attempted to define the limits of eccentric reaming in order to minimize the removal of subchondral bone while maximizing version correction showed that correction of 10° resulted in a significant decrease in anteroposterior glenoid diameter and correction of 15° of retroversion led to either implant peg penetration or inadequate bone support, which means high risk of implant loosening [37, 38]. Although biomechanical studies showed no micromotion when at least 50% of the baseplate is supported by glenoid bone [39, 40], based on clinical studies, it is safer to limit eccentric reaming to mild defects with no more than 10–15° of glenoid retroversion [41].

47.5.2 Bone Grafting

Bone grafting provides a biologic solution in cases of severe bone loss that do not guarantee secure seating of a glenoid component and that are not amenable to adequate correction of glenoid version by standard methods, such as asymmetric reaming or small changes in glenoid or humeral component version.

Indications for bone grafting, based on the previously described radiological features, can be summarized as follows:

- >15° of retroversion (B2-B3-C-C2 glenoid) [21, 22].
- Superior tilt (E3 glenoid) [14].
- Excessive medialization (Type 2–3) [15].
- Loss of depth: 10–15 mm (axial CT) [33].

Basing treatment on bone loss classifications allows meaningful evaluation of surgical options [42].

Theoretically, advantages of bone grafting in the setting of glenoid wear include preservation of available glenoid bone stock, maintenance of a quite normal joint line that avoids altered joint kinematics secondary to shortening of the glenoid vault, and a permanent restorative solution by biological osseous integration. On the other hand, concerns have also been raised, due to the risk of nonunion, resorption, fixation failure, or subsidence [41, 43]. Moreover, differently from an eccentric reaming, bone grafting is a technically demanding procedure.

Multiple graft sources have been proposed, including humeral head autograft [44, 45], iliac crest autograft [42, 46], cancellous autograft [47, 48], cancellous allograft [49], femoral neck allograft [47], and femoral head allograft [50, 51] (Fig. 47.9).

In 2011, Boileau et al. [44] popularized a standardized technique, which required a specific instrumentation for graft harvesting, preparation, and implantation, called “bony increased offset reverse shoulder arthroplasty” (BIO-RSA; Wright Med Group, Memphis, TN, USA). Recently, the BIO-RSA technique has been updated by introducing the angled BIO-RSA, an asymmetric BIO-RSA which adds more flexibility in managing multiplanar defects by using a trapezoidal bone graft in order to correct not only version and medialization but also the superior tilt [52], based on the assumption that uncorrected superior glenoid erosion (E2, E3 glenoid) [14] can lead to superior tilt of the baseplate which can result in increased scapular impingement, instability, inferior scapular notching, and medial polyethylene wear [53, 54]. At the same time, several companies designed their own instrumentation for symmetrical and asymmetrical bone grafting (Fig. 47.10).

Bateman et al. [47], in order to maximize integration and stability, also proposed a hybrid graft glenoid reconstruction by using a peripherally seated cortical femoral neck allograft acting as a sleeve bushing to provide a stable ring under compression in which to house impacted cancel-

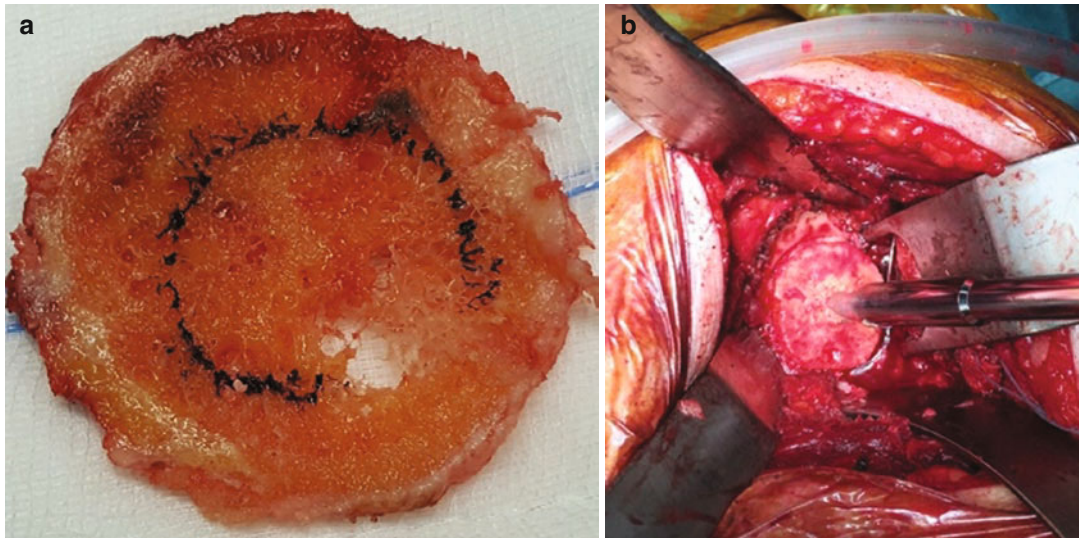

Fig. 47.9 Impaction graft of autologous humeral head to treat a A2 glenoid (**a**, **b**)

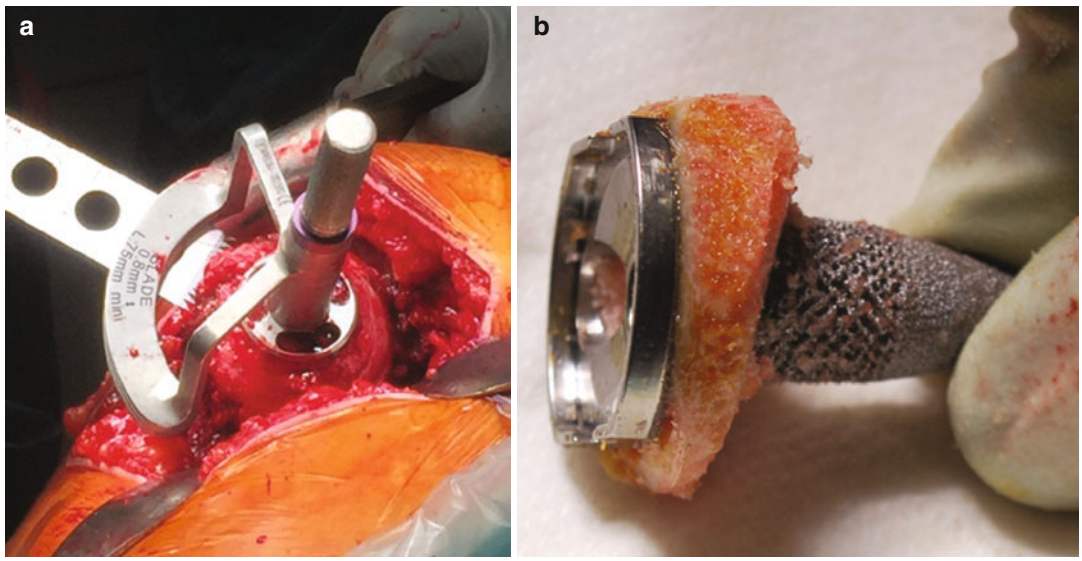

Fig. 47.10 Instrumentation for bone grafting from the humeral head (**a**). Asymmetrical bone graft (**b**)

lous autograft centrally for early incorporation and ingrowth.

Applying the principles of BIO-RSA (symmetric and asymmetric), it is authors' preference to use distal tibial allograft as a bone graft source, when the autologous humeral head is not available (e.g., osteoporosis, humeral head collapse, revision cases) (Fig. 47.11). Distal tibial allograft has been recently introduced as a viable treatment option for glenoid bone loss in anterior and posterior shoulder instability [55, 56]. Main advantages over other bone graft are mainly related to the radius of curvature of the lateral aspect of the distal tibia, which resembles that of the native glenoid, thus providing a more anatomical reconstruction. Besides, the graft contains a cartilaginous layer, so the subchondral bone is thick and dense and acts as adequate support for baseplate fixation [57].

Unfortunately, results of glenoid bone grafting in RSA remain controversial. A high rate of graft

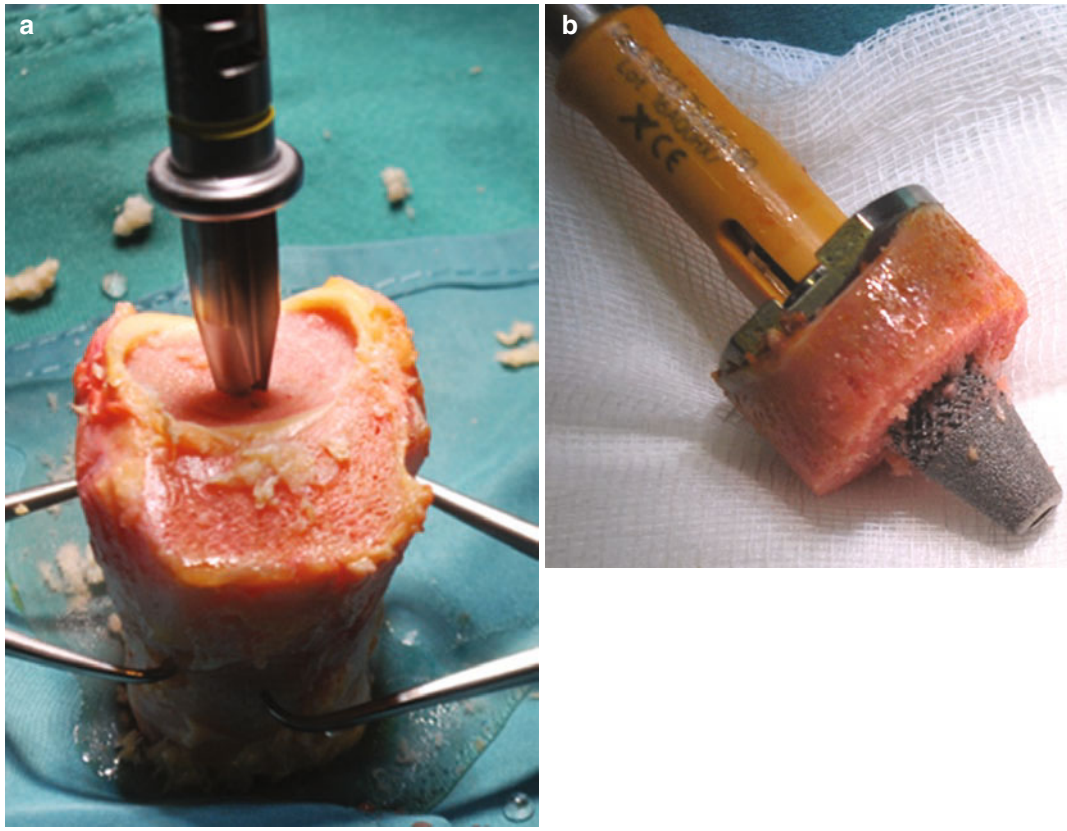

Fig. 47.11 Distal tibia allograft for treating large glenoid bone defects (**a**, **b**)

subsidence, graft resorption, and instability has resulted in early glenoid component loosening and early failure in some studies [58, 59], while some others showed encouraging results with rates of graft incorporation ranging between 76% and 98% [44, 48]. Also, optimal graft source and technique for placement and stabilization remain controversial because of comparison of cohort studies including different grafting techniques and implants and with uncontrolled confounding patient-related variables.

47.5.3 Augmented Baseplate

New prosthetic solutions to glenoid bone loss have been proposed to overcome concerns raised about previously described options. However, similarly to bone grafting, augmented glenoid baseplate implantation is a technically demanding procedure that requires precise creation of a glenoid bone bed to seat the augmented component in order to avoid micromotion and risk of loosening [41].

Literature is still lacking on this topic, even if encouraging results in very small case series have been reported [60–63]. Different designs with various degrees of version and thickness have been described, such as wedged glenoid, usable with or without bone grafting, which allows multiplanar correction of glenoid wear [63], or a customized porous tantalum augment in order to improve lateralization [60] (Fig. 47.12).

Finite element studies comparing bone grafting versus augmented baseplate implantation showed that bony lateralization increases stress and displacement to a greater degree than prosthetic lateralization [64, 65]. Particularly, Denard et al. [64] showed that bony lateralization is not advisable if more than 5 mm are required. Clinical studies are needed.

Fig. 47.12 Augmented baseplate design with symmetrical porous tantalum augment

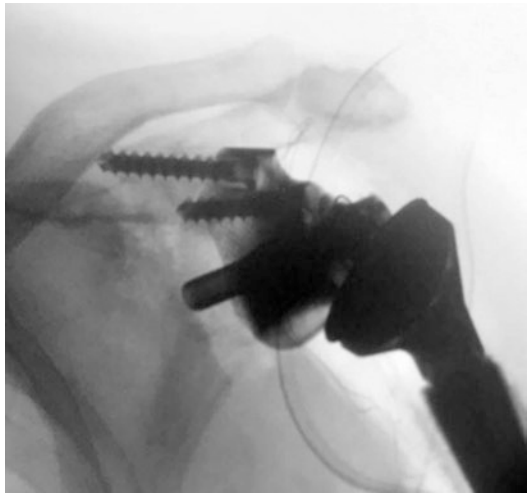

Fig. 47.13 Custom-made implants should be considered a salvage option in CTA or in revision after failed RSA with severe bone loss

47.5.4 Custom-Made Implants

Custom-made implants should be considered a salvage option in CTA or in revision after failed RSA with severe bone loss (Fig. 47.13).

First examples were CAD/CAM (computer-assisted design/computer-assisted manufacture) shoulder replacement resembling a total hip prosthesis [66–68]. Subsequently, more suitable designs, helped by PSI technology, have been proposed to treat massive glenoid defects [69].

However, further studies are needed before drawing any conclusion on actual results.

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Shoulder Arthroplasty: Intact Rotator Cuff Muscles

48

Francesco Franceschi and Edoardo Franceschetti

48.1 Introduction

The reverse shoulder arthroplasty (RSA) has recorded a considerable increase in the last decade [1]. This is due to good results and increased indications [1]. The first indication to the reverse shoulder prosthesis implant was the eccentric osteoarthritis in the framework of injury of the rotator cuff. The indication to the reverse shoulder prosthesis in this type of pathology arises from the failures, mainly from the glenoid side, of the anatomical arthroplasty [2]. In fact, the absence of the rotator cuff and therefore of its depressor effect on the humeral head creates an abnormal vertical movement of the humeral head which, on ascending, causes the mobilization of the glenoid component. This phenomenon is called Rocking horse effect [2]. Despite the excellent results of the anatomical prosthesis, there is a certain degree of failure even when the rotator cuff is intact, and this is to be found in the morphological changes to which the glenoid undergoes arthrosis. Knowing these changes can definitely allow the surgeon to understand why anatomical arthroplasty fail and how to avoid such failures.

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48.2 Morphological Changes During Shoulder Osteoarthritis

With the greater knowledge of the anatomy of the arthritic shoulder, it was possible to know the reason of some failures in the anatomical implants [3].

There are several morphological alterations developing with the progression of arthritis; among these the most important regard the version of the glenoid and the presence of a subluxation of the humeral head with respect to the scapular axis [3]. The physiologic version of the glenoid ranges between −2° and −8° [4]. Mullaj et al. showed that in the arthritic shoulders, the retroversion tends to increase and is generally higher than 12° [4]. Walch decided to classify the glenoids in such a way as to distinguish retroverted glenoid from non-retroverted glenoids [3]. In many cases, excessive retroversion is associated with the presence of a subluxation of the humeral head with respect to the scapular axis. The original classification includes five categories of glenoid patterns: (1) A1, centered humeral head, minor erosion; (2) A2, centered humeral head, major central glenoid erosion; (3) B1, posterior subluxated head (Fig. 48.1), no bony erosion; (4) B2, posterior subluxated head, posterior erosion with biconcavity of the glenoid; and (5) C, dysplastic glenoid with at least 25° of retroversion regardless of erosion. Recently Walch himself has perfected his own classification by

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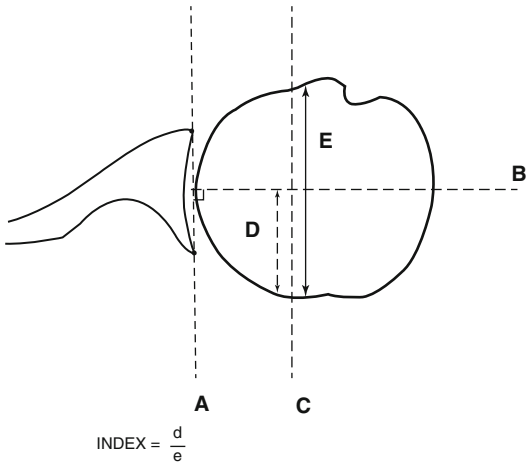

Fig. 48.1 Method used to evaluate humeral head subluxation according to the glenohumeral index. *A*, Line tangent to the anterior and posterior edges of the glenoid fossa. *B*, Line bisecting the glenoid. *E*, Diameter of the humeral head. *D*, Relative part of the humeral head posterior to *B*. The glenohumeral index is calculated by dividing *D* by *E* (Redrawn, with permission, from Walch et al. [3])

adding further subtypes; the author proposes the addition of the B3 and D glenoids and a more precise definition of the A2 glenoid. The B3 glenoid is monoconcave and worn preferentially in its posterior aspect, leading to pathologic retroversion of at least 15° or subluxation of 70% or both. The D glenoid is defined by glenoid anteversion or anterior humeral head subluxation. The A2 glenoid has a line connecting the anterior and posterior native glenoid rims that transects the humeral head [5] (Fig. 48.2).

48.3 Anatomic and Reverse Shoulder Arthroplasty Results in Patients with Shoulder Osteoarthritis and Intact Rotator Cuff

Hussey et al. [6] performed a comparative cohort study of 309 patients with a total of 344 anatomic total shoulder arthroplasty procedures, performed for primary glenohumeral osteoarthritis. The authors use computed tomography scans in all patients, characterized, according to preoperative glenoid wear pattern, as either concentric (196; follow-up time, 49.2 months) or eccentric (148; follow-up time, 52.3 months) according to a modified Levine classification. Similar clinical results and value can be expected with both concentric and eccentric glenoid wear patterns in TSA. Concerns arise, however, as the eccentric group demonstrated a more than twofold increased rate of glenoid component loosening compared with the concentric group.

Walch et al. [7] retrospectively evaluated 92 anatomic total shoulder arthroplasties performed in 75 patients with primary osteoarthritis and a biconcave glenoid. All patients underwent preoperative imaging with an axial computed tomography arthrogram. Measurements were taken for posterior bone erosion depth and ratio as well as humeral head subluxation. Clinical outcomes were evaluated with the Constant score. Performing TSA in patients with osteoarthritis and biconcave glenoids resulted in acceptable clinical outcomes but a very high rate of complications. Walch et al. found that the preoperative measurement of the neoglenoid retroversion was best for predicting postoperative complications in terms of glenoid loosening and dislocation.

Mizuno et al. [8] performed a retrospective review of 27 reverse shoulder arthroplasties that were performed from 1998 to 2009 for the treatment of primary glenohumeral osteoarthritis and biconcave glenoid. All patients had a preoperative computed tomography arthrogram to allow for the measurement of glenoid retroversion and humeral head subluxation. The mean preoperative retroversion was 32°, and the mean subluxation of the humeral head with respect to the scapular axis was 87%. Seventeen patients had a reverse shoulder arthroplasty without bone graft, whereas ten had an associated bone graft to compensate for posterior glenoid erosion. Clinical outcomes were evaluated with the Constant score and shoulder range of motion. Reverse shoulder arthroplasty for the treatment of primary glenohumeral osteoarthritis in patients with a biconcave glenoid without rotator cuff insufficiency

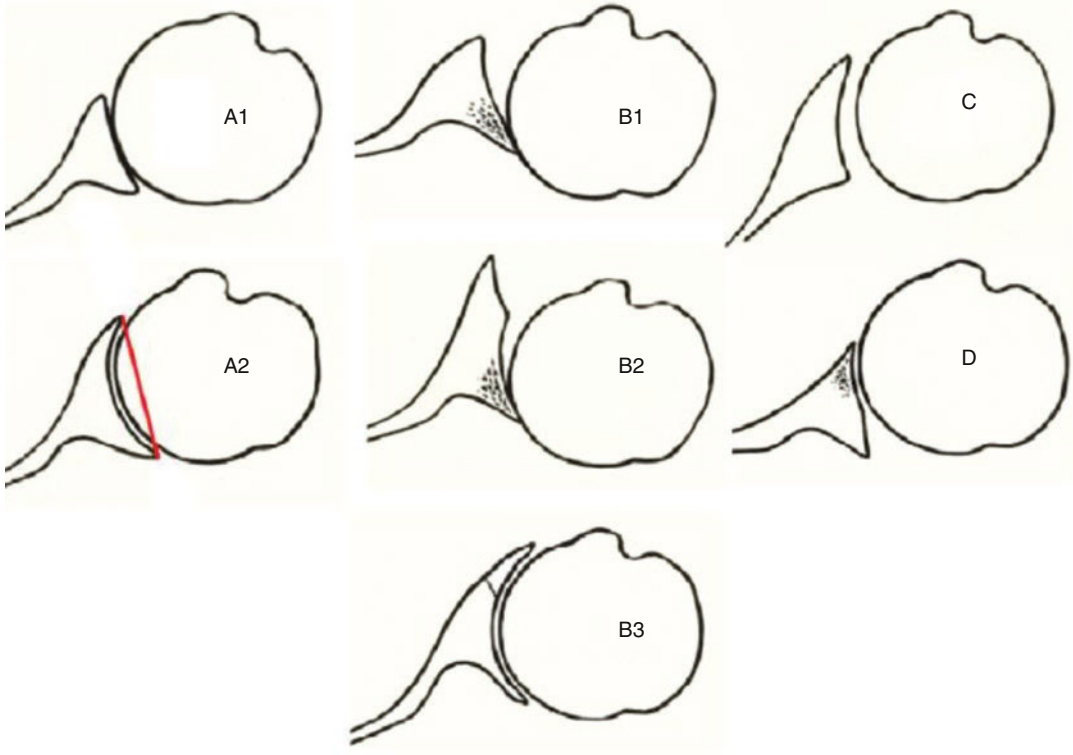

Fig. 48.2 Walch glenoid classification

can result in excellent clinical outcomes. The authors have shown that reverse shoulder arthroplasty is a viable surgical option to solve both the problem of severe static posterior glenohumeral instability and severe glenoid erosion.

48.4 Reverse Shoulder Arthroplasty Indications in Patient with Intact Cuff

On the basis of the previous results, we can say that during the preoperative setting, in order to implant a shoulder arthroplasty, in addition to the presence or not of a functioning rotator cuff, it is necessary to carry out a 3D assessment of the glenoid morphology in order to identify some fundamental parameters such as the glenoid version and subluxation of the humeral head.

Therefore the reverse shoulder prosthesis as well as in patients with rotator cuff arthropathy is also indicated in some patients with intact rotator cuff and with morphological changes of the glenoid.

It represents an indication to the reverse shoulder arthroplasty even if with intact rotator cuff the presence of a glenoid retroversion is higher than 25° and a posterior subluxation of the humeral head with respect to the scapular axis is superior to 80%.

48.5 Conclusion

The reverse shoulder arthroplasty represents an alternative indication to the anatomical shoulder arthroplasty in patients with primary arthritis and with important glenoid retroversion and posterior subluxation of the humeral head. In these patients the reverse prosthesis is able to reduce the rate of loosening that is observed with the anatomic arthroplasty.

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Primary Osteoarthritis

49

Ryan W. Churchill, Eric M. Padegimas, Meghan E. Bishop, Brandon J. Erickson, and Anthony A. Romeo

49.1 Introduction

Glenohumeral arthritis (GA) is a debilitating condition for patients afflicted by it. The incidence of GA has been reported to be as high as 32.8% on cadaver and radiographic analysis [1, 2]. As the incidence of this disease process has increased, significant advances have been made in the realm of arthroplasty for the surgical management of GA. The demand for surgical intervention in the form of arthroplasty is only expected to increase in this patient cohort over the coming years. It is estimated that by 2030 there will be a 333.3% increase in the demand for shoulder arthroplasty in patients under 55 years old [3]. The aim of this chapter is to examine the treatment options and outcomes for patients with primary glenohumeral osteoarthritis.

Glenohumeral arthritis is a broad-based term that encompasses a condition that can arise from numerous etiologies. Primary osteoarthritis is a process that is idiopathic in nature and develops without a clear antecedent cause. Secondary causes of GA include posttraumatic (e.g., prior proximal humerus fracture), glenohumeral instability, postsurgical (e.g., post-capsulorrhaphy arthropathy), avascular necrosis, infection, inflammatory arthropathy, neuropathic arthropathy, and rotator cuff deficiency (cuff tear arthropathy) [4, 5]. Patients with primary glenohumeral osteoarthritis typically present with an insidious onset of pain, especially with range of motion. Patients will often report pain at night, loss of range of motion, loss of function, as well as difficulty and pain with overhead activities. On examination patients will typically have loss of range of motion, most pronounced in external rotation, painful range of motion, crepitus with range of motion, and potentially muscle atrophy.

49.2 Radiographic Analysis

In addition to a thorough history and physical, the characteristic changes seen with GA highlight the importance of imaging in the evaluation of this condition. All patients should have standard radiographs consisting of AP, true AP (Grashey), and scapular Y and axillary views of the shoulder [6–8]. In cases of primary osteoarthritis, characteristic changes include joint space narrowing with posterior glenoid wear, posterior humeral head subluxation (up to 45% of cases), and inferior humeral head osteophyte formation (goat's beard osteophyte) (Fig. 49.1). This is in comparison to inflammatory arthritis which is characterized by medial glenoid wear and concentric joint space narrow-

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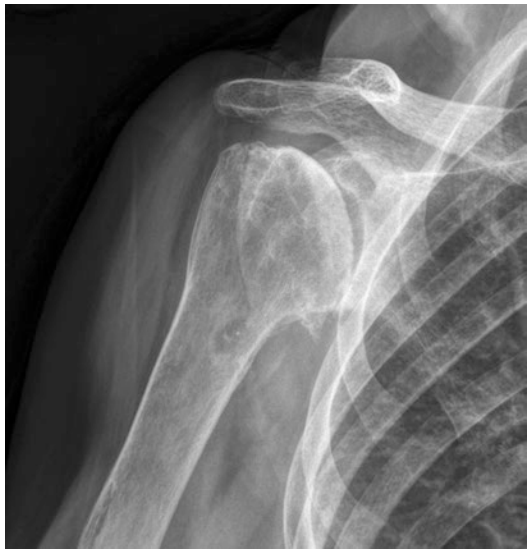

Fig. 49.1 AP radiograph of primary glenohumeral osteoarthritis

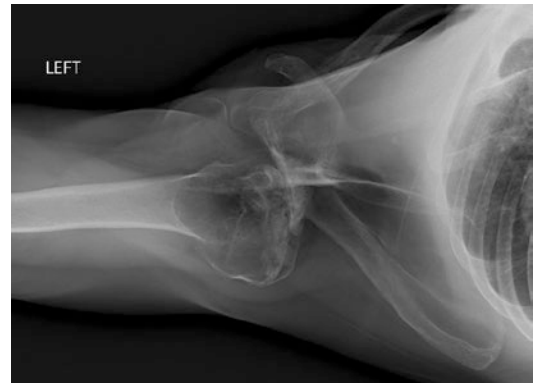

Fig. 49.2 Axillary radiograph of patient with a Walch B2 glenoid

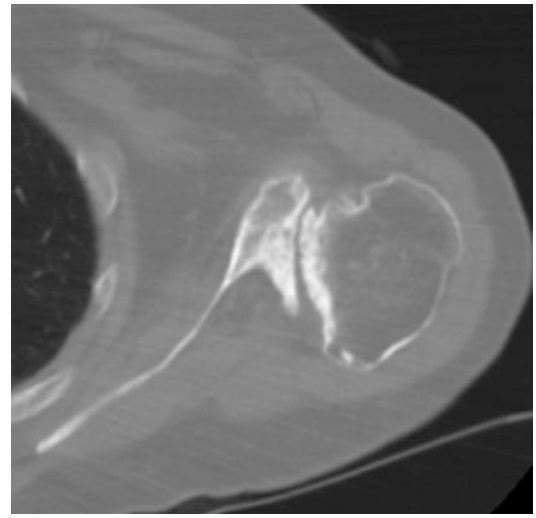

Fig. 49.3 Axial CT scan of patient with a Walch B2 glenoid

ing. This further differs from rotator cuff arthropathy in that GA arising from rotator cuff deficiency typically demonstrates superior glenoid wear, superior humeral head migration, and, in advanced cases, acetabularization of the acromion and femoralization of the humeral head [6].

In addition to standard radiographs, computed tomography (CT) may have utility in assessing both glenoid morphology and glenoid bone stock [9, 10]. CT also provides benefit in preoperative planning for potential management with shoulder arthroplasty. The value of CT is highlighted by the highly variable nature of the normal glenoid anatomy. For example, while the articular surface of the glenoid is classically described as pear-shaped, up to 29% of the population can have an ovoid shape, and while the average glenoid version is 2° of retroversion, this ranges from 12° anteversion to 14° retroversion [10]. Regarding the glenoid, Walch et al. classified the glenoid morphology resulting from GA osteoarthritis using CT imaging from 113 patients. They described three types of glenoid morphology. The type A glenoid, concentric glenoid wear without humeral head subluxation, was seen in 59% of shoulders in their study and is the most commonly encountered type in GA patients. Type B glenoid (present in 32% of shoulders) demonstrates asymmetric wear with posterior joint space narrowing, with the B2 subtype being a biconcave glenoid (Figs. 49.2 and 49.3). Lastly they described a type C glenoid in which there was greater than 25° of retroversion and attributed to a dysplastic origin [11]. The Walch classification system was further expanded by Bercik et al. to include a type B3 glenoid (a monoconcave glenoid that is considered the further erosion of a type B3 glenoid with pathologic retroversion and/or posterior subluxation of at least 70%, Figs. 49.4 and 49.5) and a type D glenoid (anteverted glenoid or anteriorly subluxated humeral head) [12]. This system was further expanded by Iannotti et al. once again to include a type C2 glenoid (a dysplastic glenoid with

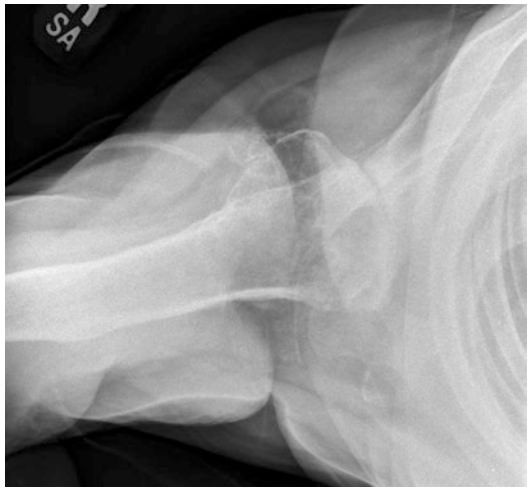

Fig. 49.4 Axillary radiograph of patient with a Walch B3 glenoid

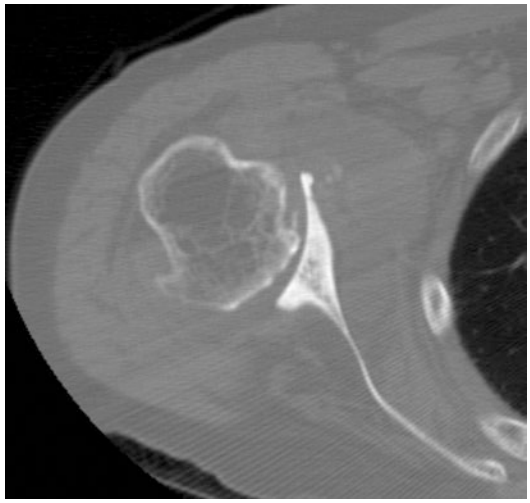

Fig. 49.5 Axial CT scan of patient with a Walch B3 glenoid

pathologic retroversion that has acquired a biconcavity due to posterior bone loss, differentiating from a B2 glenoid by the presence of pathologic premorbid retroversion) [13].

Magnetic resonance imaging (MRI) is a useful diagnostic tool for assessing soft tissue integrity, specifically the rotator cuff [14]. Given the high incidence of rotator cuff pathology in the general population, many patients that seek surgical treatment for shoulder pain often already have an MRI. While, MRI had previously been shown to have less accuracy when compared to CT in assessment of glenoid morphology and bone stock [15], more recent analysis suggests that these two modalities are comparable [16]. Surgeons should choose the preoperative imaging modality they are most familiar and comfortable with when evaluating these patients for possible arthroplasty.

49.3 Treatment Considerations

The treatment options available to orthopedic surgeons for the treatment of GA include non-operative and operative modalities. Non-operative modalities include pharmacotherapy (NSAIDs), activity modification, corticosteroid injections, viscosupplementation, and biologic injections. When non-operative modalities are exhausted, operative interventions include arthroscopic debridement, resurfacing arthroplasty, hemiarthroplasty, hemiarthroplasty with concentric glenoid reaming ("ream and run"), hemiarthroplasty with biologic resurfacing of the glenoid, total shoulder arthroplasty (TSA), reverse total shoulder arthroplasty (RTSA), and arthrodesis [17, 18]. The use of arthroplasty in treatment of this GA has increased dramatically over recent years with a 319% increase in TSA between 1993 and 2007 and RTSA rising to encompass one-third of all shoulder arthroplasties performed since its FDA approval in the United States 2003 (although RTSA has been used for a much longer time in Europe) [5]. As stated earlier, the demand for arthroplasty in treatment of GA in the young patient population is only expected to increase in the coming years with an estimated increase of 8.2% per year, while the demand for arthroplasty in treating patients greater than 55 years old is expected to increase by 755.4% by 2030 [3].

49.4 Non-operative Management

There are numerous non-operative measures that can be utilized for the treatment of early GA in both the young and elderly patient. These treatment options include activity modification, pharmacotherapy consisting of NSAIDs and acetaminophen, corticosteroid injections, and viscosupplementation (AAOS comp review). Kwon et al. performed a

multicenter, randomized, double-blind controlled trial comparing sodium hyaluronate to saline injections. The results approached statistical significance in favor of sodium hyaluronate for all patients, and if patients with concomitant shoulder pathology ($n = 37$) were removed, then the results became statistically significant favoring sodium hyaluronate [19]. Blaine et al. also performed a randomized controlled study investigating the effect and use of glenohumeral sodium hyaluronate injections. While they had a more diverse patient population in terms of diagnoses used for enrollment, they found a statistically significant improvement favoring the use of sodium hyaluronate injections for patients with GA. They concluded sodium hyaluronate injections are an effective and well-tolerated intervention for patients with GA who have failed other non-operative modalities [20].

One potential drawback of corticosteroid injection is the risk of infection. Institutionally, there is a 3-month waiting period after corticosteroid injection before any surgical intervention, specifically arthroplasty, is considered to limit infection risk. This policy is based on analysis by Werner et al. that found an increased in infection risk with surgery that occurred within 3 months of corticosteroid injection [21]. This rule applies to both arthroscopic and open surgical cases.

While non-operative measures may be effective early in treatment, operative interventions are employed once the patient has pain and disability recalcitrant to these non-operative measures and elects to undergo operative intervention. It is important to consider that in almost all clinical scenarios, operative management of primary osteoarthritis of the shoulder is purely elective and based entirely on the patient's symptoms and their ability to tolerate them.

49.5 Operative Management Overview

The operative treatment of the patient with GA can be challenging. Younger patients afflicted with GA can be especially challenging as they are usually more active and eager to return to a higher demand lifestyle [3, 17, 22]. The goal in treating all patients is to alleviate pain and allow the patient to return to being able to perform daily activities. To this end, there are multiple treatment modalities that are available.

49.6 Arthroscopic Debridement

The use of arthroscopic debridement for treatment of GA has been described with varying adjunctive procedures performed simultaneously. Millett et al. described their comprehensive arthroscopic management (CAM) procedure and the early follow-up results in a group of 29 patients with a mean age of 52 years old. Their extensive arthroscopic procedure consisted of glenohumeral chondroplasty, removal of loose bodies, osteophyte resection, capsular release, subacromial decompression, axillary nerve neurolysis, and biceps tenodesis [23, 24]. They had a 2-year survival rate of 85% in their cohort with six patients going onto shoulder arthroplasty at an average of 1.9 years. Of the patients who did not go onto arthroplasty, they saw a decrease in pain scores and an increase in their outcome scores. Notably, they found that patients with less than 2 mm joint space had a statistically significant increased likelihood to go onto shoulder arthroplasty early [24]. It is unclear if having an arthroscopic debridement prior to shoulder arthroplasty effects outcomes after shoulder replacement.

Skelley et al. performed a retrospective review looking at the clinical outcomes and time to conversion to TSA for 33 patients with an average age of 55 years old who underwent arthroscopic debridement and capsular release for the diagnosis of primary GA osteoarthritis over a 5-year period. While there was an initial improvement in range of motion and patient-reported pain scores, they found that patients returned to their preoperative levels at an average of 3.8 months, and at the time of final follow-up, over 60% of patients were not satisfied with their outcomes. Furthermore 42.4% of the cohort underwent conversion to total shoulder arthroplasty at an average of 8.8 months after the initial arthroscopic debridement and capsular release

[25]. To this end, Spiegl et al. looked at the role of arthroscopy and arthroplasty in improving quality-of-life years for patients with GA osteoarthritis using a Markov decision model. In their model, they found the theoretical patients had 8.8 years in a well state before requiring TSA after arthroscopic debridement and patients who had a primary TSA had 20 years in a well state before requiring revision. Given these results, they concluded arthroscopic debridement was useful for management in patients under 47 years old, while TSA was the preferred treatment for patients over 66 years old. For patients that fell in between these age groups, they felt that either treatment option was a viable choice [26]. While these results are potentially encouraging, there is a lack of long-term studies that support patients enjoying close to 9 years of improved quality of life. Sayegh et al. noted in their meta-analysis of the literature on treatment of GA in the young patient that the average follow-up of studies on arthroscopic management was 27 months [17]. While arthroscopic debridement may be a viable option for the young patient with early GA without significant joint space narrowing, it is a temporizing measure that lacks long-term follow-up to support its routine use.

49.7 Hemiarthroplasty

Humeral hemiarthroplasty is an option for younger patients that leaves the glenoid unresurfaced. Concerns for prosthesis longevity in younger patients may lead some to prefer hemiarthroplasty to total shoulder arthroplasty. While total shoulder arthroplasty is a reproducible option for end-stage GA [27, 28], concerns exist regarding increased stress to the glenoid component. While total shoulder arthroplasty has been successful in young patients under 55 years old at 5 years (98% survivorship), this robust survivorship has shown substantial deterioration at 10 years (62.5%) [29]. Unfortunately, hemiarthroplasty has exhibited inferior functional results to total shoulder arthroplasty [7, 30–34]. Patients with posterior wear and a loss of glenoid concentricity do particularly poorly [35]. These concerns led to utilization of nonresurfacing options for management of the glenoid in younger patients such as biologic resurfacing or concentric glenoid reaming.

49.8 Hemiarthroplasty with Concentric Glenoid Reaming ("Ream and Run")

Hemiarthroplasty with concentric glenoid reaming (the "ream and run" procedure) was first described by Matsen et al. as a biologic solution for glenoid resurfacing [36]. Animal models had shown fibrocartilage development over the glenoid with reaming through the subchondral bone [37]. Additionally, if glenoid deformity exists, concentric reaming of the glenoid has been utilized to re-center the humeral head and correct glenohumeral subluxation [38]. Matsen et al. found an early revision rate of 13.8% and significant improved function in 56/65 patients under 55 years old at a minimum of 2-year follow-up [8]. At over 5-year follow-up, Matsen et al. found that 28/176 patients went on to a subsequent operation (however, 41/176 were deceased or had insufficient follow-up) [39]. This cohort of patients had an average simple shoulder test of ten "yes" answers at over 5-year follow-up. However, this study did not have a lower age cutoff [39].

Institutionally, we analyzed 24 patients who underwent a "ream and run" in the setting of a biconcave glenoid. The average age at time of surgery was 50 years old, and 21/24 reached 2-year follow-up or underwent revision surgery. In our population, four patients required early revision (less than 2 years), while two required late revision (one at 4.9 and one at 7.2 years). Five of the six revisions were conversions to anatomic total shoulder arthroplasty, while one underwent a downsizing of the humeral head and capsular excision. In this cohort, 62.5% of patients exhibited good or excellent clinical results, while 37.5% exhibited either fair or poor results (this includes all revisions). Importantly, postoperative stiffness correlated significantly with both frequency of revision arthroplasty and patient outcomes [40]. In our experience, careful

patient selection and early physical therapy aimed at maintaining range of motion are crucial for an optimal outcome in the "ream and run" procedure.

49.9 Hemiarthroplasty with Biologic Resurfacing

Biologic resurfacing of the glenoid in conjunction with humeral head resurfacing or humeral hemiarthroplasty for the treatment of GA was first described in 1988 by Burkhead and Hutton [41]. This technique was developed as an option to treat the young patient with GA due to concern for increased risk of accelerated glenoid wear, osteolysis, and loosening with the use of TSA to treat this more active patient population. The technique for preparing the glenoid generally involves removing any remaining articular cartilage on the glenoid, reaming the glenoid the minimum to create a concentric surface followed by fixation of the interposition graft to the glenoid [8, 41–44]. The role of the interposition graft is to aid in pain relief and provide a surface for articulation with the humeral arthroplasty in an attempt to prevent glenoid erosion, which was a significant complication of patients treated with hemiarthroplasty alone for GA [7–9, 42, 45–48]. There are numerous graft options described in the literature, with common ones used being lateral meniscus allograft, Achilles tendon allograft, fascia lata autograft, joint capsule, and human acellular dermal matrix [41, 42, 49]. On the humeral side, the technique has been described using a stemmed hemiarthroplasty or stemless resurfacing implant [7–9, 42, 45–48]. The advantage to using the stemless resurfacing technique is it preserves humeral bone stock, while some of the disadvantages are a greater tendency to be placed in varus and potential greater difficulty with glenoid exposure [44, 50, 51]. While this procedure has been extensively discussed in the literature, the results in this patient population are still mixed.

In a study by Wirth et al., 30 patients with an average age of 43 years old were treated with humeral hemiarthroplasty and glenoid resurfacing with lateral meniscal allograft. Results were available for 27 of these patients with an average of 3-year follow-up. He found a statistically significant improvement in pain, outcomes scores, and function in these patients. His patients gained an average of 39.1° ± 36.1 of forward elevation and 29.6° ± 16.2 of external rotation. Of note, none of the patients in the study had gone onto revision to TSA during the follow-up time period [42]. While these positive results are encouraging, similar results have not been found in the majority of literature.

In a multicenter review, Muh et al. looked at the results of humeral arthroplasty with glenoid resurfacing with human acellular dermal matrix and Achilles allograft in 16 patients with an average age of 36 years old. At an average of 60-month follow-up, they found minimal improvements in range of motion, and 44% of the patients had undergone revision to TSA [52]. Strauss et al. reported the results of 45 patients with an average age of 42.2 years who underwent humeral arthroplasty with glenoid resurfacing with lateral meniscus allograft or human acellular dermal matrix. There were 41 patients with results available with an average follow-up of 2.8 years. While there were improvements in range of motion and pain, they reported a 51.2% clinical failure rate in their cohort [41]. Lee et al. had similar disappointing outcomes with 17 patients with a mean age of 57 years and mean follow-up of 4.25 years. All of their patients had glenoid resurfacing with meniscal allograft and humeral hemiarthroplasty. While there were improvements in pain, they reported a 32% complication rate that included three patients revised to TSA and another with a hemiarthroplasty revision [9]. These results are consistent with other studies in the literature, with Bois et al. publishing a 30% reoperation in their cohort of patients with an average of 8.3 years of follow-up [44, 45, 53]. While this remains a potential option for treatment of this patient population, improvements need to be made so as to provide greater longevity to pain relief and improved function.

49.10 Anatomic Total Shoulder Arthroplasty

The use of TSA and more recently RTSA is the main workhorses for surgical treatment of primary glenohumeral OA. Shoulder arthroplasties use has expanded to encompass a large age range of patients. Some concerns with the young patient population are that this group will develop accelerated glenoid wear which could result in increased polyethylene-induced osteolysis and glenoid loosening requiring early revision surgery. The most common long-term complication of TSA is glenoid loosening, which is the cause of an estimated 24% of all TSA complications [10]. The underlying reason for this concern is because of the anatomy of the glenoid, specifically the glenoid vault. The glenoid vault becomes narrower medially, and if excessive medialization of the glenoid occurs because of bone loss or reaming, then there will be a lack of supporting bone for the glenoid component [10]. If this occurs, it can be partially mitigated today with the use of bone grafting and the development of glenoid augments [10, 54]. Nonetheless, there has been an increased interest in the use of these procedures in the treatment of GA in these patients.

Specifically in younger patients, Bartelt et al. compared the outcomes and survival rates of TSA and hemiarthroplasty in patients under 55 years old. There were 46 patients with an average age of 49 years in the TSA and 20 patients with an average age of 49 years in the hemiarthroplasty group. They found that there was a statistically significant improvement in pain, increase in active elevation, and higher patient satisfaction in those patients undergoing TSA. In addition the survival rate at 10 years was 92% in the TSA group and only 77% in the hemiarthroplasty group. The idea that TSA is the treatment for GA in this patient group is further supported by the results of Dillon et al. who reviewed the results of 2981 patients treated with arthroplasty and stratified patients based on age and treatment. They found that while younger patients had an increased risk of revision, those patients treated with TSA had better outcomes and lower risk of revision than patients treated with hemiarthroplasty or RTSA [55]. In another study, Denard et al. reported the functional outcomes as well as 5- and 10-year survival rates of TSA in patients under 55 years old. They found statistically significant increases in functional outcomes and range of motion in their cohort of 49 patients with a mean age of 50.5 years. The authors also reported a 5-year survival rate of 98% and 10-year survival rate of 62.5%. Of note, there were only 18 of the original patients who had 10-year follow-up data [29].

There are many options available now to the orthopedic surgeon for implants for anatomic TSA. These options range from long stem diaphyseal fit to stemless components on the humeral side and multiple different iterations of pegged and keeled glenoid components [10, 56]. On the glenoid side, one of the major considerations is the degree of glenoid deformity. Keys in this situation involve ensuring adequate peg support, avoiding peg perforation, and avoiding excessive medialization with removal of glenoid vault bone stock. Options to avoid this include reaming the high side (if under 15° of deformity), placing the component in slight retroversion, bone grafting, and more recently using augmented glenoid components to correct version and maintain bone stock [10]. Humeral component loosening rates have been reported to be between 7% and 55% on radiographs [56]. However this radiographic loosening does not necessarily correlate to clinical effects in those patients. While proponents of short stem and stemless implants argue that the implant can be placed in a more anatomic position, with mitigation of stress shielding of the proximal humerus, diaphyseal fit components are still a valid option for the humeral component in total shoulder arthroplasty [56].

49.11 Reverse Total Shoulder Arthroplasty

Reverse total shoulder arthroplasty is used in cases of rotator cuff arthropathy and revision arthroplasty and more recently described for patients with a biconcave glenoid or patients with glenoid deformity that requires greater than 15° of correction [10, 18, 57, 58]. Muh

et al. published the follow-up results of RTSA used in a cohort of 66 patients with a mean age of 52.2 years. At an average of 36.5 months of follow-up, they found a statistically significant improvement in range of motion, pain, and functional outcomes. They reported 81% patient satisfaction rate and 15% complication rate that included two revisions [52]. This trend with use of primary RTSA in patients without rotator cuff arthropathy has also been seen in patients that fall outside of the young patient category. There has been an increasing amount of literature looking at broadening the indications for use of RTSA. Day et al. found that 22% of RTSA performed in the Medicare population in 2011 was done under the CPT code for primary GA osteoarthritis [59]. Recent literature has shown improved outcomes in elderly patients sustaining proximal humerus fractures treated with arthroplasty when primary RTSA is utilized as compared with hemiarthroplasty [53, 60–62]. Primary RTSA for GA osteoarthritis has been investigated in patients with a biconcave glenoid and shown to have excellent results [57]. Steen et al. reported the results of primary RTSA used to treat patients with GA osteoarthritis. These patients were originally scheduled to undergo TSA but were converted intraoperatively for glenoid component difficulties or instability. They compared these patients to a matched cohort who had undergone TSA and assessed costs and outcomes. They found that the patients who underwent RTSA had comparable outcomes to the TSA group but had a higher initial cost ($7274 more than the TSA group) at midterm follow-up [63]. In a multicenter study by Young et al., they found a 16.8% rate of secondary rotator cuff dysfunction in patients who had undergone TSA at an average of 103.6 months of follow-up. In the patients who had secondary rotator cuff dysfunction, there were statistically significant worse functional outcomes and a total of 30 cases of revision arthroplasty. The authors speculated that age-related degenerative changes in the rotator cuff contributed to the secondary cuff dysfunction [64]. Given these findings in the literature, the use of primary RTSA has the possibility of altering the approach to the treatment of GA in this age group.

Some of the perioperative complications with revision shoulder arthroplasty were discussed in a study by Saltzman et al. comparing complications after primary and revision RTSA. They reported a 69% complication rate after revision RTSA with 31% transfusion rate in their revision cases [65]. Griffin et al. examined the rate of postoperative inhospital complications and mortality rates in patients over 80 years old and compared these results in patients between 50 and 79 years old undergoing TSA or hemiarthroplasty. In the older age group, they found a statistically significant increased mortality rate (0.5%) as well as longer hospital stay and increased incidence of postoperative anemia [66]. The increased mortality is in contrast to a study by Ricchetti et al. comparing postoperative complications after TSA in patient greater than 80 years old to patients less than 70 years old. They found no difference in complications with the exception of an increased rate of transfusion in the older cohort [67]. Waterman et al. investigated risk factors associated with 30-day morbidity and mortality after primary TSA. They found that in addition to comorbid cardiac conditions, increasing age was an independent predictor of increased mortality [68].

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Shoulder Arthroplasty in Rheumatoid Arthritis

50

Mike H. Baums

50.1 Introduction

Involvement of the shoulder is a common source of disability in patients with rheumatoid arthritis (RA). Approximately 50% of patients with newly diagnosed RA are suffering from shoulder girdle pain [1], and 90% of patients with RA are estimated to have severely affected shoulder joints during the long-term run of the disease [2]. Nevertheless, an initial affection of the shoulder joint itself in the classical RA is a rare condition in comparison to a primary manifestation of RA in the older patient [3]. In this latter case, a primary affection of the shoulder joint is seen in a minimum of one fourth of the patients that are attended with high activity of inflammation resulting in a poor prognosis.

With introduction of traditional disease-modifying antirheumatic drugs (DMARDs) and immunosuppressive medications (so-called biologicals), the percentage of those patients with rapid destruction of their joints decreased significantly. Nevertheless, almost one fifth of patients with RA still experience an inadequate response to pharmacological therapy and therefore need sufficient surgical reconstructive treatment. But due to today's pharmacological treatment and more knowledge regarding diagnostic tools, age at time of surgery (i.e. arthroplasty) could be increased significantly in these inflammatory diseases [4].

However especially in patients with a destructed shoulder joint, several challenges are remaining. An immunosuppressive medication increases the risk of periprosthetic infection [5] and osteopenia, which is additionally generated by the entity itself. Furthermore, erosions and concentric joint involvement may lead to decreased bone stock and therefore increase the risk of periprosthetic fracture and component loosening [5, 6]. In addition, insufficiency and extended tears of the rotator cuff (RC) as well as atrophy of the shoulder girdle muscles after progression of the disease impede surgical treatment [7]. Thus, Charles Neer already noted that 'the secret of an easier and more successful arthroplasty in patients with RA is to perform it before there is severe loss of bone and rotator cuff' [8].

50.2 Pathomechanisms and Challenges

Synovitis in RA is not only limited to the glenohumeral joint itself resulting in destruction of the joints cartilage but also may be connected to the periarticular zones. The subacromial space, the acromio-clavicular joint as well as

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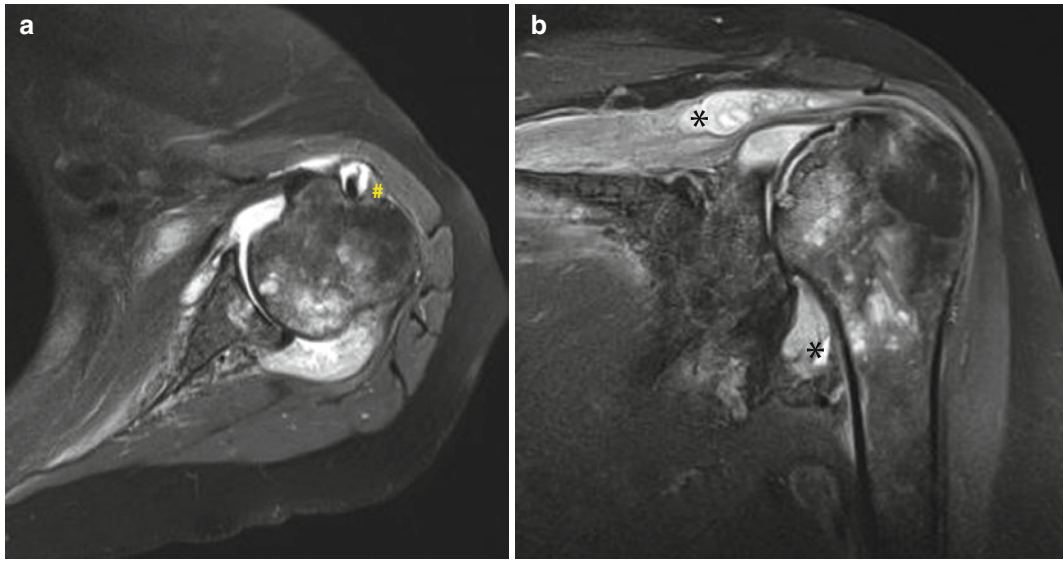

Fig. 50.1 (**a**) Expanded accumulation of intra-articular fluid and eccentric glenohumeral adjustment with posterior accented narrowing of the joint space. Pronounced halo sign of the long head of the biceps (#). (**b**) Cranial abrasion of the glenoid and incipient subchondral head collapse. Rheumatoid pannus tissue within the axillary pouch and along the thinned rotator cuff including fatty infiltration (*)

the long head of the biceps tendon including the bicipital groove may be compromised as well (Fig. 50.1a, b).

Especially, involvement of the numerous periarticular recesses (Fig. 50.2) and bursae will cause a wide range of damaging including secondary osteoproliferative shoulder arthritis up to a progressive humeral head collapse and joint destruction. In addition, the use of corticoid and immunosuppressive medication may pander to further destruction by infection or avascular humeral head necrosis.

Moreover, involvement of the periarticular RC, which is present in most of the patients, often leads to progressive upward migration of the humeral head as a long-term consequence [9, 10]. Not only tendon tears but also fatty infiltration of the muscles may significantly compromise shoulder function [11].

Specifically, pathology of the RC is an important prognostic factor in RA but not only accelerating the joint destruction as a result of the diseases course. Cuff tears are common in patients with RA and often result in a condition similar to rotator cuff arthropathy [10, 12]. Additionally,

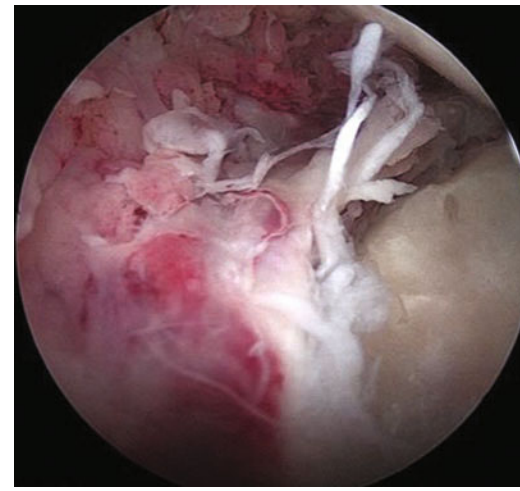

Fig. 50.2 Arthroscopic view from a posterior portal in a left shoulder joint: Mixture of active and burnt out synovitis with inflamed pannus in the axillary pouch of a left shoulder

they may lead to inferior outcome after shoulder arthroplasty as well because of superior humeral migration, increased shear forces or instability resulting in eccentric wear and component loosening [12, 13].

50.3 Classification Systems

Several classification systems are known, basically geared to radiological changes during the diseases course. Nevertheless, joint destruction in RA does not follow a consistent pattern. Depending on the diseases progression and activity of inflammation, its appearance can be similar to a primary joint arthritis as well as a cuff arthropathy.

A well-established categorization is the classification according to Larsen et al. [14] (Table 50.1). The system is used for other joints as well and has been shown to have a good reproducibility. Additionally, it is mostly used to evaluate the radiological progression of the rheumatic disease. Lehtinen et al. indicated that stage III and IV may come along with superior humeral head migration [15].

Another classification according to Neer has a high prognostic value as well [8]. The author differentiates a (1) type I, a (2) type II and a (3) type III glenohumeral affection. Whereas type I ('wet-type') is accompanied by an aggressive synovitis, progressive bony erosions and rapid joint destruction, type II ('dry-type') shows osteoarthrosis-like changes with centred joint parts and clinical joint stiffness. Finally, type III ('resorptive-type') is formed by a rapid bone loss, a flat humeral head and progressive joint destruction.

Levigne and Franceschi established a classification that does not only consider the bony destruction but also the insufficiency of the surrounded RC [16]. The authors distinguish between a (1) concentric (C), (2) ascendant (A) and (3) destructive (D) form. Depending on the extent of the glenoid erosion, two subtypes (1 and 2) in each form are characterized.

Table 50.1 Classification system according to Larsen et al. [14]

Stadium no.	Type and dimension of radiological changes
Stadium 0	• No pathological findings
Stadium I	• Incipient narrowing of the joint space • Proliferated periarticular swelling of soft tissue
Stadium II	• Distinct joint space narrowing • Initial formation of bony erosions
Stadium III	• Considerable narrowing of the joint space • Obvious bony erosions • Slight superior migration of the humeral head
Stadium IV	• Unapparent joint space • Destruction of joint partner but with preserved bony configuration • Obvious superior migration of humeral head
Stadium V	• Massive destruction with deformation of glenoid and humerus • Major tuberosity in 'articulation' with thinned acromion • Mutilation including subluxation or osseous ankylosis

50.4 Indications, Implants and Challenges

Perioperative outcome after receiving a total shoulder replacement arthroplasty in patients suffering from RA could be similar to patients without this disease. Even patients with RA seem to have a shorter and less costly hospital stay [17] with complications that are more long-term in nature (e.g. component loosening, high incidence of RC pathology). But this is barely the case if following a differentiated way of treatment.

Because of an early involvement of the periarticular anatomical structures (i.e. insufficiency of the RC, adverse effects to the soft tissue (Fig. 50.3), parchment-like skin because

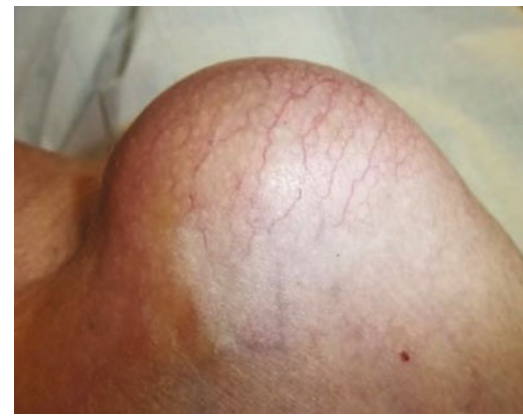

Fig. 50.3 Immense bursitis bulging out the skin over the antero-superior part of the shoulder joint

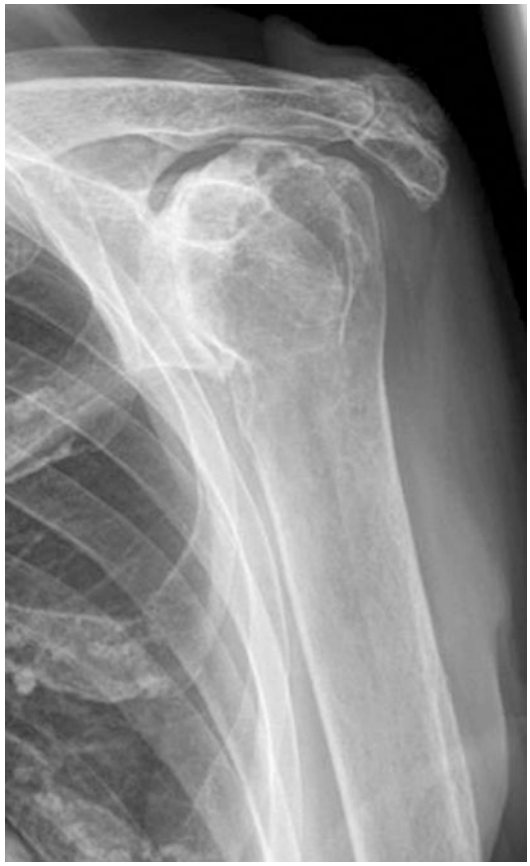

Fig. 50.4 Abrasion of the craniomedial humeral head following substantial loss of glenoid bone stock and therefore loss of lateral offset (type A2 according to Levigne and Franceschi [16])

of immunosuppressive medication) or massive bone loss (Fig. 50.4), shoulder arthroplasty in RA requires a patient-related individual and extremely sophisticated approach. The use of implants usually depends on single pathological findings as well as the patients' age. Unfortunately, very limited research evidence exists to give guidance for clinical decisions about shoulder arthroplasty in RA [18].

In the author's experience, a close collaboration between the orthopaedic surgeon and an internal rheumatologist is important to reach a good outcome and to reduce the risk of complications.

50.4.1 Hemiarthroplasty Versus Total Arthroplasty

In principal, hemiarthroplasty (HA) in patients with RA suffering from a defect RC seems to result in better long-term outcome. HA may avoid an early loosening of the glenoid component due to eccentric loads that are based on superior humeral head migration. Nevertheless, functional impairment has been confirmed in these cases [19].

Barlow et al. found pain relief after total shoulder arthroplasty (TSA) as well as HA in patients that were treated for inflammatory arthritis [5]. Nevertheless, decrease in pain was significantly better in patients with TSA and presence of an intact RC. Collins et al. also have confirmed these findings [20]. In cases with a ruptured or thin RC, no significant differences in pain between TSA and HA could be shown. Ten Voorde et al. found an overall 5-year revision rate of 7% in their studied group [21]. Interestingly, revisions only occurred in patients that received HA and by most far frequently in patients with a resurfacing arthroplasty. The reason for this observation remains unclear but was assumed to reflect the accessibility for revision in resurfaced shoulders.

In summary, TSA seems to result in better outcome than HA in patients with RA, but a high rate of radiolucent lines of the glenoid component is demonstrated [5]. But other studies could not confirm a fundamental association between radiographic and clinical findings [22]. In addition, the high incidence of radiolucent lines in approximately 75% of the patients does not automatically result in component revision [5].

An evident flaw in patients with RA remains the RC. Insufficiency of the RC consequences an increased malalignment of the humeral head resulting in eccentric strains on the glenoid component and therefore its early loosening. On the other hand, a RC defect may lead to a significant craniomedial migration of the humeral head with the result of a significant loss of function. Therefore, intact RC influences pain and function crucially [5].

Another influence on the result may arise due to a previous acromioplasty or massive erosions of the acromio-clavicular joint producing a high risk of antero-superior migration of the humeral head because of a destroyed fornix humeri.

If a glenoid component is not possible, i.e. in cases with insufficiency of the RC resulting in eccentric glenoid erosion, a fascia lata or Achilles tendon patch could be used for covering the glenoid to gain a smooth surface [23].

50.4.2 Surface Replacement and Stemless Arthroplasty

Especially in inflammatory juvenile arthritis and concentric abrasion of the glenoid surface, replacement or stemless shoulder arthroplasty is used. Moreover, these types of implants should be subjected to patients with adequate bone stock applied to the humerus as well as the glenoid (Fig. 50.5a–d). Surface replacement could

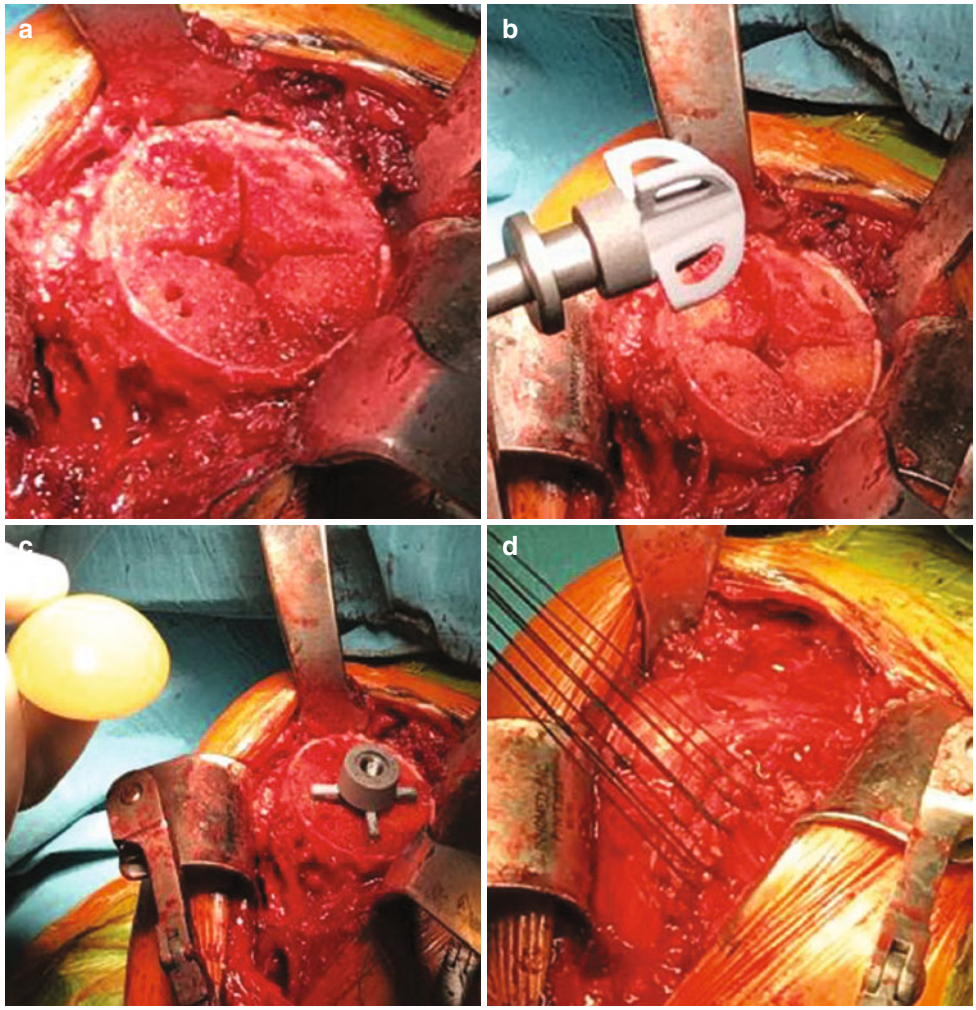

Fig. 50.5 (**a**) Appropriate bone stock after preparation of the anchorage of the humeral component in a patient with RA. (**b**) A short humeral stem, calcium phosphate coated, is inserted into its bony bed in press-fit technique. A sufficient primary stability is mandatory when using a short implant to gain a good long-term result. The stem geometry allows a bone-preserving revision in case of loosening or in case of rotator cuff insufficiency. (**c**) A ceramic head is put on the inserted stem. (**d**) A stable closing of the layers and reattachment of the subscapularis tendon are done in a double-row technique using a combination of braided, non-absorbable USP No. 2 polyester suture, a Polyfile and absorbable USP No. 2 suture to restore the rotator cuffs' function

provide good long-term functional results in patients younger than 50 years of age in a mixed group amongst others including patients with RA [24]. Small dimensions of the concerned joint parts have to be expected especially in juvenile types of RA and often make the use of custom-made implants necessary.

50.4.3 Reverse Arthroplasty

Basically, reverse shoulder arthroplasty (RSA) (Fig. 50.6a, b) should be used in older patients with irreparable defects or an extensive fatty infiltration of the RC to gain satisfactory function. Recent systematic reviews confirmed comparable results after RSA in inflammatory shoulder arthritis and RSA in cuff arthropathy [25] as well as similar complication rates compared to RSA in a population of mixed aetiologies [26]. Hence, good clinical results can be expected (Fig. 50.7a–c). Nevertheless, different problems are remaining that are limiting especially the insertion of the glenoid component.

Cystic erosions, significant loss of bone stock and osteopenia associated with glucocorticoid medication may lower the chance of a sufficient bony anchorage of the baseplate. Additionally, the risk of acromion fracture may arise in cases with erosive arthritis of the acromio-clavicular. Furthermore, patients with affection of the lower extremity caused by RA are reliant on the use of crutches that may limit the use of RSA functionally.

In cases of large bony erosions, resulting in excessive retroversion or inclination of the glenoid bone grafts (i.e. harvested form the humeral head or the iliac crest) could correct the glenoid deficiency. Bone grafts can be fixed on a long-peg (i.e. 25 mm) baseplate [27]. With the use of allografts and augmented baseplates, the same

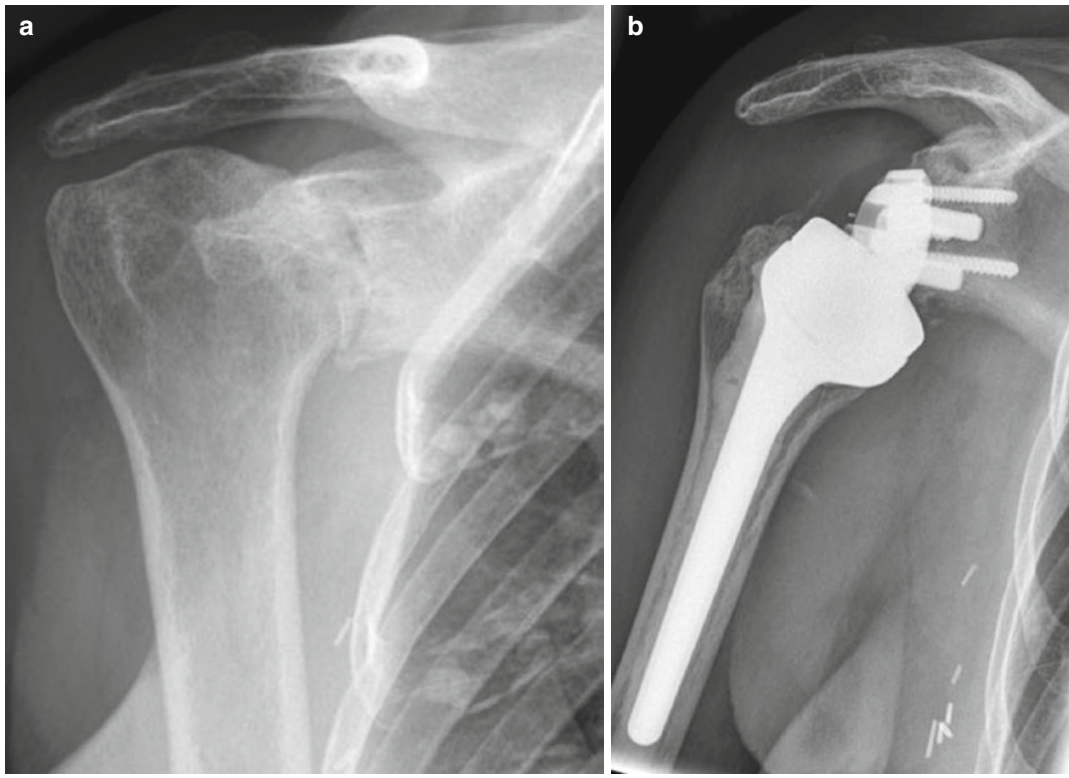

Fig. 50.6 (**a**) Craniomedial and superior humeral head migration in a 75-year-old female patient with RA and a non-repairable RC defect. Enough bone stock is present to fix the glenoid baseplate (type A1 according to Levigne and Franceschi [16]). (**b**) Postoperative X-ray after a reverse shoulder arthroplasty with a cemented humeral stem

Fig. 50.7 (**a**–**c**) Clinical result after RSA (X-ray see Fig. 50.6) of the right shoulder in a 75-year-old patient with RA. Range of motion in (**a**) abduction, (**b**) external rotation and (**c**) internal rotation. Subscapularis tendon could be fully restored using the above-mentioned double-row technique (see Fig. 50.5d)

result can be achieved but with higher costs. Long-term studies have to prove the benefit of these techniques in patients with RA and the influence of immunosuppressive medication on the bone grafts.

50.5 Subscapularis Strength After Arthroplasty

To achieve access to the shoulder joint, the subscapularis tendon (SSC) may be released using several alternative techniques ranging from tenotomy to osteotomy of the lesser tuberosity. To improve stability as well as postoperative function of the shoulder, it is mandatory to fix the SSC complex securely. Nevertheless, poor healing or rupture of the SSC is not a rare complication and often results in weakness, instability or pain [28].

In principal, postoperative strength of SSC increases over time [28]. But this recent study found that only a minority of the patients reached normal strength after a follow-up of 2 years. In most cases, compared to the contralateral arm, strength was significantly lower during the whole follow-up. No differences between the used techniques of SSC release could be stated to date [29]. This was validated for postoperative strength, healing rates as well as postoperative tendon integrity [30, 31].

Some studies confirmed the grade of fatty infiltration of the SSC muscle belly associated with a positive belly-press test [32], but others observed no correlation between fatty infiltration and functional outcomes [33]. Lapner et al. [28] did a multivariate regression analysis that could not prove that any of the investigated factors could be named a significant predictor of SSC strength in the outcome of shoulder arthroplasty (i.e. sex, age, baseline strength, surgical technique, baseline external rotation, fatty infiltration).

Unfortunately, to date no study investigated the postoperative SSC strength especially in patients with RA. But in principal, one has to assume that SSC strength could not be fully restored after arthroplasty as well with respect to the special healing conditions in these groups of patients. Therefore, more research is necessary to reduce the risk of a lower level of SSC strength after shoulder arthroplasty in RA as well.

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Shoulder Arthroplasty for Humeral Head Osteonecrosis

51

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51.1 Introduction

ON of the HH is defined as cell death within the osteocytes of the HH. Previously known as "avascular necrosis," ON is the currently accepted description as the etiology may be idiopathic or multifactorial; however, all roads lead to cell death and eventual loss of structural support of the HH. ON occurs in the setting of lack of vascularity to the HH and may be a result of a traumatic or atraumatic insult to the proximal humerus. Typically, in the traumatic case, ON is a result of fracture or fracture with dislocation of the proximal humerus. There are several risk factors, both modifiable and non-modifiable that are associated with increased risk for ON of the HH. This section will focus primarily on atraumatic causes, as well as a brief overview of treatment options with special emphasis on arthroplasty for treatment of ON of the HH.

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51.2 Epidemiology, Pathogenesis, and Risk Factors

Although less common than ON of the hip, ON of the HH has similar prevalence to ON of the knee [1]. Some of the most common causes of ON of the HH include corticosteroid use (56%), trauma (19%), Gaucher's disease (2%), and sickle cell disease (2%) [2]. Men are affected twice as often as women, with a predilection for the disease during the second and fifth decades of life, especially when related to sickle cell disease [3, 4]. The true incidence of ON of the HH is likely underreported as it frequently follows an indolent course. ON of the HH is frequently accompanied by involvement in other joints, especially the hips. L'Insalata et al. found 69% of patients with ON of the HH had hip involvement, with two thirds of those affected with bilateral hip involvement [5]. The converse is not necessarily true, however, with only 20% of patients with an initial diagnosis of ON of the femoral head having concurrent ON of the HH.

51.2.1 Atraumatic Causes (Table 51.1)

Corticosteroid use is the most common associated risk factor for ON of the HH [2]. Although the exact pathogenesis remains unconfirmed, it is believed that increased intraosseous pressure caused by adipocyte hypertrophy leads

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Table 51.1 Risk factors for osteonecrosis of the humeral head

Atraumatic causes	Post-traumatic causes
Corticosteroid use	Fracture-related proximal humerus vascular interruption
Alcoholism	Post-intervention idiopathic chondrolysis/osteonecrosis
Hemoglobinopathies (sickle cell disease, thalassemia)	Latrogenic direct vascular injury
Dysbarism (caisson disease)	
Storage disorders (Gaucher's)	
Vasculitis	
Radiation-induced	
Idiopathic	

to local ischemia to the HH [6]. This mechanism is proposed in a similar manner to that of Gaucher's disease, in which lipid-laden Gaucher cells cause a mass effect on the local intraosseous arterioles, thus resulting in avascularity to the HH [6]. Another potential mechanism is fat embolism to the small arterioles of the proximal humerus resulting in lack of blood flow to the HH [7]. Increase in systemic lipids may potentially affect multiple areas, thus resulting in multifocal disease. ON of the HH has been reported after intra-articular injections of steroid, as well as a possibly linked to steroid dose packs—although clinical significance is uncertain [8, 9].

Alcoholism may lead to ON of the HH in a pathologic mechanism similar to that of corticosteroid-induced ON. Excessive NADH as a result from the breakdown of excessive EtOH is turned into fatty acids in the liver and leaked into the bloodstream. Increased systemic lipid levels may embolize to the subchondral bone, thus resulting in avascularity. This leads to venous stasis and further necrosis of the bone [10]. Regular consumption of alcohol in excessive quantities has been shown to increase the risk of ON of the hip eightfold, with a dose-dependent relationship [11].

Hemoglobinopathies have shown increased risk for ON of the HH as well. Patients with sickle cell disease have a stronger association with ON of the femoral head compared to ON of the HH; however, it remains an immutable risk factor. Deformed sickled cells collect within the small arterioles of the subchondral bone leading to microinfarctions [3]. Higher blood viscosity due to higher hematocrit levels in patients with sickle cell disease has also been implicated to play a role in the pathogenesis, and this pathologic process can be extremely painful in those with sickle cell disease.

Systemic diseases such as systemic lupus erythematosus (SLE) and rheumatoid arthritis (RA) have also been implicated as risk factors for ON of the HH [12]. Although the pathogenesis remains unclear, there appears to be a relationship with vasculitis and development of ON. This association, however, is clouded by the frequent use of systemic and local corticosteroid administration in these patient populations.

51.3 Diagnosis and Classification

A thorough patient history is essential to understand the etiology of ON of the HH. Both modifiable and non-modifiable risk factors should be assessed, including but not limited to history of alcoholism, family history of arthroplasty at a young age, multiple joint involvement, remote or recent use of corticosteroids, inflammatory arthritis, and trauma. This is essential to establish the cause as the surgeon may be able to intervene to mitigate damage to other joints. The diseased portion of the HH is frequently located in the superomedial aspect of the HH, and pain may be elicited with flexion to 90° and abduction to 60°. The patient should be counseled to avoid overhead activities so as not to aggravate this area of the HH.

Much of the current basis for understanding humeral ON was based on early research in ON of the hip. The Ficat-Arlet staging classification was initially described for hip ON [13] and later adapted to the shoulder by Cruess [1], and is currently the most widely used [14].

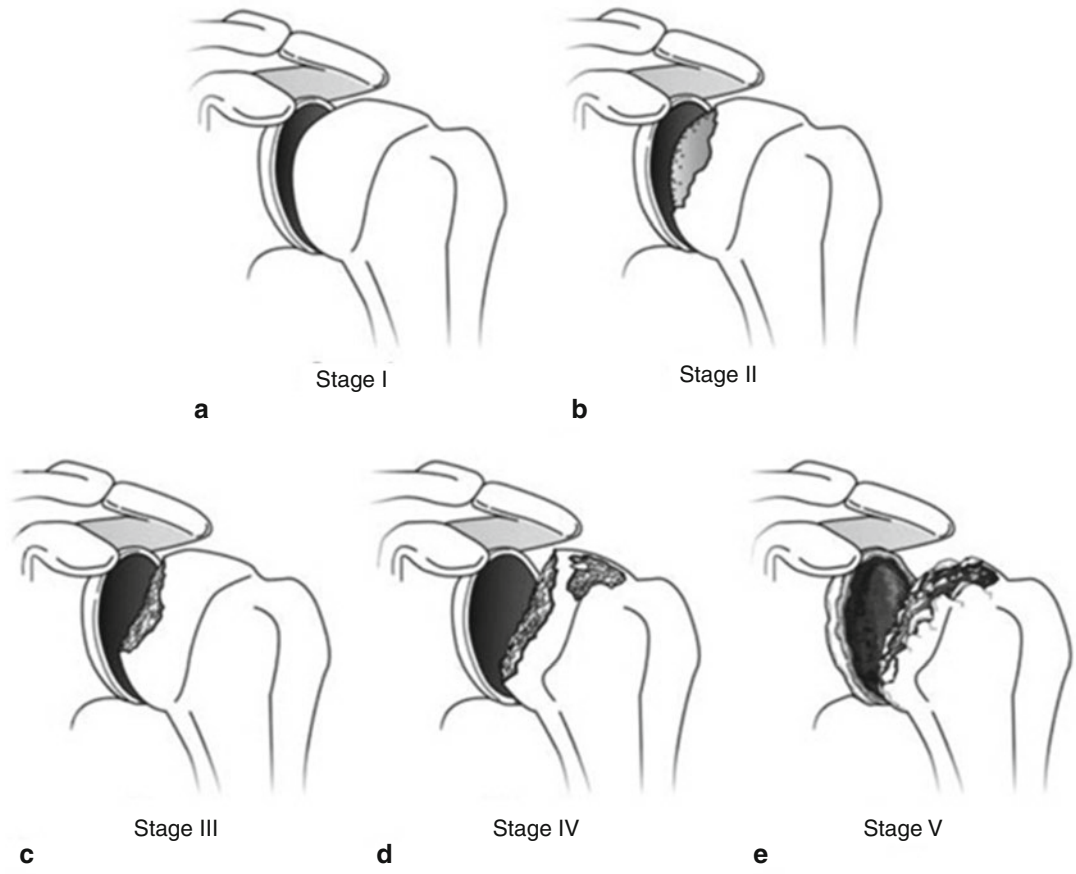

Fig. 51.1 Illustrations depicting Cruess stages of humeral head osteonecrosis. (**a**) Stage I, no radiographic changes, normal humeral head without sclerosis, MRI findings only. (**b**) Stage II, mottled sclerosis on radiographs, curvature of humeral head is intact. (**c**) Stage III, the presence of a crescent sign is noted on radiographs suggesting subchondral fracturing. The humeral head may be aspherical and early stage collapse may be seen. (**d**) Stage IV, progression to collapse of the subchondral bone. (**e**) Stage V, onset of degenerative changes of the glenoid. Image reprinted with permission from Harreld KL, Marker DR, Wiesler ER, Shafiq B, Mont MA (2009) Osteonecrosis of the Humeral. J Am Acad Orthop Surg 17:345–355

Stage I involves only magnetic resonance imaging (MRI) or radionuclide imaging changes, in the absence of radiographic changes. Stage II involves early radiographic changes without evidence of collapse. Typically, sclerosis can be seen at the superior central portion of the HH without evidence of fracture. In Stage III a "crescent sign" is present and is pathognomonic for ON of the HH. This sign represents collapse of the subchondral bone with depression and delamination from the overlying cartilage. This sign is best identified on the AP view with the arm in external rotation. Mechanical symptoms may be present at this stage due to cartilage delamination and potential loose bodies in the joint. Stage IV is characterized by collapse of the subchondral bone with diffuse necrosis in the affected area and advanced arthritis of the HH. Stage V is a Stage IV humerus with arthritic involvement of the glenoid articular surface (Fig. 51.1).

51.4 Treatment: Non-arthroplasty

The treatment of HH ON ranges from nonoperative management to surgical interventions varying from arthroscopy to arthroplasty. The major determinants of what treatment to offer patients are a

combination of age, activity level, and disease stage. Nonoperative options are usually exhausted prior to discussing more invasive options, and those with more advanced disease are more likely to undergo joint replacing rather than joint-preserving interventions. The determination of whether to address the glenoid side is also determined by the stage of disease as well as the activity level of the patient. In certain post-traumatic cases where tuberosity position is suboptimal, nonanatomic procedures such as a reverse TSA may be the best option (Fig. 51.2) [15].

51.4.1 Nonoperative Management

Nonoperative treatment focuses on symptomatic relief, prevention of disease progression, and improvement of shoulder function. This may include changing any potentially harmful medications or substances (i.e., corticosteroids, excess alcohol consumption, etc.), although some substances or medications may not be able to be removed (e.g., chemotherapy). Symptomatic control with anti-inflammatory medication is often attempted and may be useful in the early stages of disease. Physical therapy to focus on stretching, range of motion, and scapular stabilization may also be a helpful adjunct.

51.4.2 Non-arthroplasty Treatment

In patients with Stages I–III idiopathic HH ON, surgical options for treatment can include arthroscopic and non-arthroplasty techniques. These techniques attempt to tap into any remaining regenerative ability of the native bone and tissue in order to avoid the need for an arthroplasty. Arthroscopy alone has been described to remove loose bodies and debride loose chondral flaps and other potentially irritating tissues [16, 17]. Similar to that in the femoral head, core decompression, a procedure where, under fluoroscopic guidance, drilling is performed into the osteonecrotic area up to the subchondral surface, has also been described as a treatment option for Stages I–III HH ON. The goal of core decompression is to reduce pressure, increase blood flow, and slow or halt ON progression. However, results have been shown to have poorer outcomes with advancing stage, especially in those who have gone on to collapse [5, 18]. Open techniques for core decompression were initially described with good results [5, 18–20], and, more recently, arthroscopic-assisted techniques have also shown promise [21, 22]. There have also been small case series and studies of bone grafting for Stages III–IV HH ON [23–25], but these series are very small when compared to arthroplasty treatment outcomes for later stage disease.

51.5 Treatment: Arthroplasty

For later stages of HH ON (late Stages III to V), arthroplasty has demonstrated a long track record of success. In later stages, the HH and glenoid (in Stage V) have been so significantly damaged, that reparative techniques are unable to recreate native anatomy. In these cases, replacement of the HH and possibly the glenoid is central to surgical treatment. In regard to arthroplasty, the treatment may range from resurfacing of isolated lesions of the HH with preservation of subchondral bone, hemiarthroplasty (HA) that removes the HH, and total shoulder arthroplasty (TSA) that includes HH replacement with glenoid resurfacing and reverse TSA. These treatments correspond in part to the stage of disease but also to the patient age, activity level, and deformity.

51.5.1 Focal Resurfacing, Hemiarthroplasty, and Total Shoulder Arthroplasty

HA has been described as a treatment for HH ON as early as 1955 by Neer when he described his early results with a cemented, stemmed HA [26]. Cruess reported satisfactory early results of five shoulders that underwent HA 1976 at 1–7 years follow-up [1]. Early case series of both HA and TSA that included multiple diagnoses for surgery found patients with HH ON did well, but sample sizes were very small, and there was no spe-

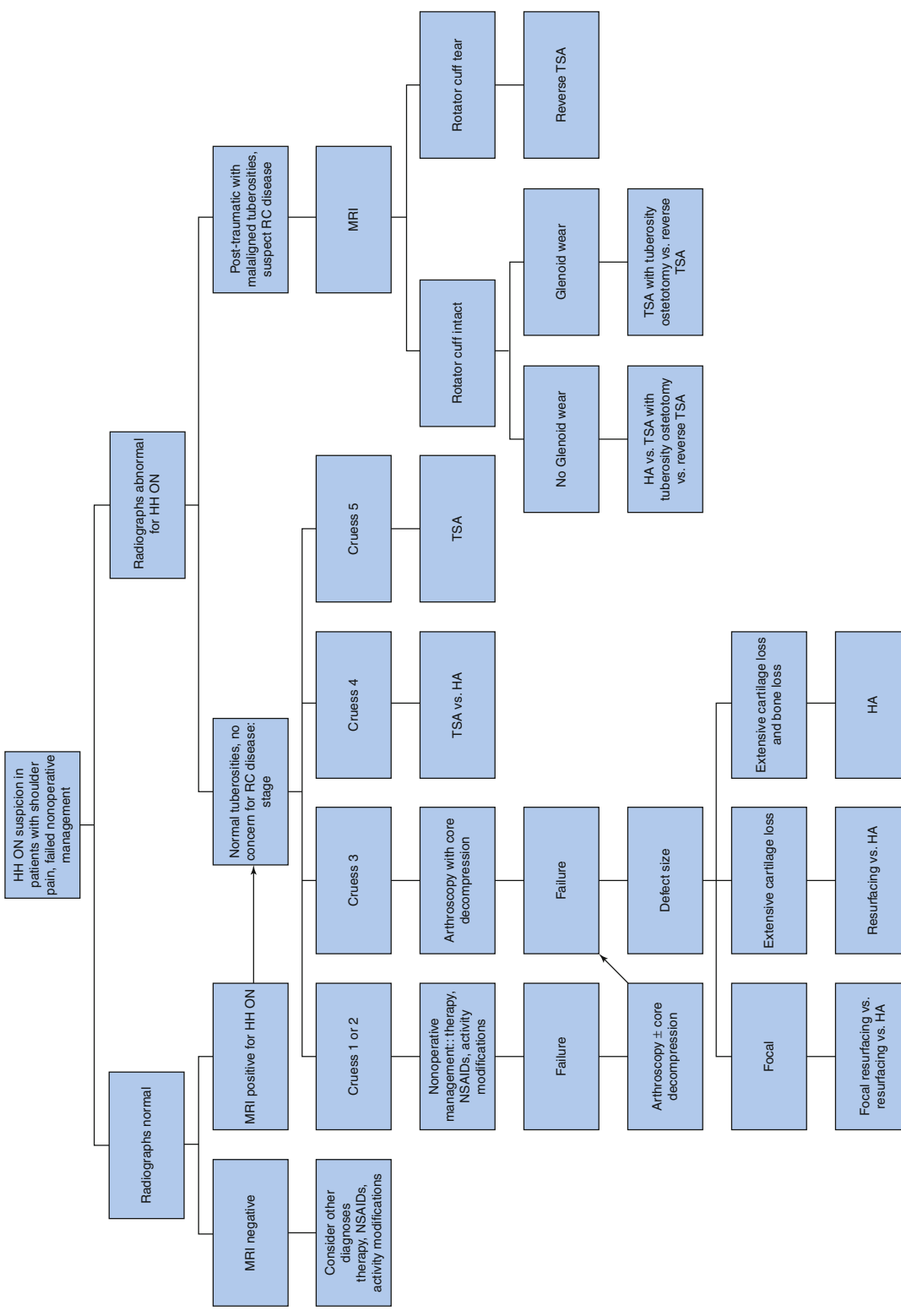

Fig. 51.2 Treatment algorithm for humeral head osteonecrosis based on imaging findings and etiology

cific analysis of HH ON patients [27–29]. More recently, HH resurfacing has been described to treat HH ON with good early success [30]. Some of these designs allow the surgeon to more selectively target ON lesions and preserve a large portion of the HH, and early data has shown favorable results [31] (Fig. 51.3). Cementless resurfacing designs have also been found to have good outcomes as well with improvements in Constant score from 31 to 62 points [32].

When looking at case series that focused on HH ON as the only diagnoses, there are large case series and some comparative studies between HA and TSA highlighting the risks and benefits of each intervention. Earlier studies found no major differences as Hattrup and Cofield retrospectively identified 52 HA and 36 TSA who underwent surgery for HH ON. At mean 8.9 years follow-up, there was no difference between median ASES scores for HA vs. TSA (69 vs. 63 $p = 0.60$) [33]. Mansat presented the French experience which found 16/19 satisfactory results at average 7 years follow-up with TSA and HA (Constant score of 58). There was glenoid component loosening in 3/5 patients and glenoid pain in HA in 2/14 at final follow-up [34]. However, Orfaly et al. also followed consecutive HA vs. TSA patients and found that although their cohorts improved significantly, their outcomes were not as good as those who underwent HA or TSA for primary OA concurrently [35]. Also, Parsch et al. followed a cohort of 13 patients who underwent HA and TSA and found that patients >65 years did not do as well, and their average Constant score at follow-up was 51 [36]. A more recent study from Fealy et al. in 2008 compared TSA and HA in 64 shoulders for HH ON, found TSA had a higher complication rate (22% vs. 8%) as compared to HA, and suggested TSA should be reserved for the most severe cases. A more recent insurance database study from 2018 revealed that patients who underwent TSA for HH ON had higher rates of postoperative complications compared to patients without a diagnosis of HH ON, including infection, dislocation, revision arthroplasty, stiffness, periprosthetic fracture, and medical complications [37]. Although not a first-line surgery for HH ON, reverse TSA has been shown to be an option in severe cases of deformity with good success [38]. Thus, it appears that even in appropriate Stages IV and V cases, both HA and TSA have a higher complication profile, and results may not be as predictable as primary OA patients. Although both are good options that lead to significant improvements in pain and function, there does appear to be a higher complication rate of glenoid wear or glenoid loosening, and patients should be counseled appropriately when offering these treatment modalities.

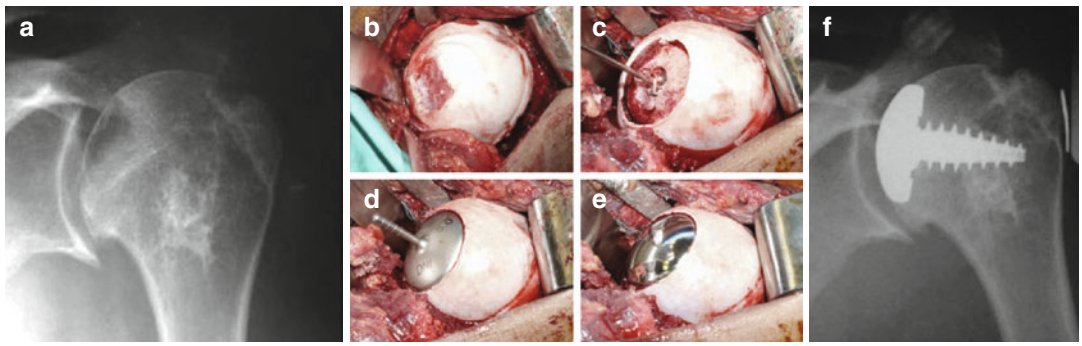

Fig. 51.3 (**a**) Radiograph demonstrating a humeral head defect with relative preservation of the glenohumeral joint space. (**b**) Intraoperative image of large humeral head chondral defect. (**c**) After guide pin placement, the defect is reamed to subchondral bone. (**d**) Sizing of the defect with a focal resurfacing implant allows assessment of defect coverage and contour assessment. (**e**) Postimplantation photo showing intact peripheral cartilage. (**f**) Postoperative radiograph showing HemiCAP (Arthrosurface, Franklin, MA) implant filling humeral head defect while recreating normal humeral head contour. Image reproduced with permission: Scalise JJ, Miniaci A, Iannotti JP (2007) Resurfacing Arthroplasty of the Humerus: Indications, Surgical Technique, and Clinical Results. Tech Shoulder Elb Surg 8:152–160

There have been a few smaller studies looking specifically at HH ON from sickle cell disease, and Lau et al. found that patients who had HH ON due to sickle cell disease had improvements in ROM, but pain relief was less reliable [39]. A more recent study by Kennon et al. found that core decompression for HH ON in sickle cell disease patients does not alter ON progression and HH collapse and that resurfacing and HA are viable treatment options for Stage III patients, whereas shoulder replacement for Stage IV/V disease appears to offer better functional results [40].

51.5.2 Arthroplasty for Post-traumatic Humeral Head Osteonecrosis

Patients who have HH ON due to post-traumatic or postsurgical etiologies create a unique set of challenges different from idiopathic HH ON cases. Many have had fractures and tuberosity malalignment or concurrent injury to the rotator cuff. In addition, postsurgical patients may also have an underlying risk of indolent infection [41]. Both must be worked up thoroughly through imaging and, when indicated, aspiration and blood tests. If tuberosities are aligned and not significantly malaligned, an anatomical replacement with or without resurfacing is a viable option. However, if tuberosities are significantly malaligned, reverse TSA may be a better option. In older patients especially, reverse TSA may be a better option for fracture-related necrosis as their cuff function is less predictable and anatomical tuberosity healing is hard to predict. Anatomical replacement with tuberosity osteotomies can also be considered, but it is a technically challenging procedure as it requires perfect tuberosity reduction, as prior literature has shown that malaligned tuberosities predict poor outcome [42].

Prior literature has shown that HA for malunion, nonunion, or osteonecrosis postfracture is possible and may lead to improved results, although the authors recommended avoidance of tuberosity osteotomy when possible [43]. A European study from 2012 looked at 55 patients with postfracture necrosis treated with TSA (44/55) or HA (11/55) without tuberosity osteotomy and found that their results were predictable with 93% satisfied, but those that did poorer had more varus deformity and increased fatty infiltration of the rotator cuff [44]. The authors suggested that those patients with postfracture sequelae without deformity (thus not needing tuberosity osteotomy) may be treated successfully and predictably with TSA or HA. Looking at locking plate fracture sequelae, Jost et al. found in their referral practice, over 50% of patients after locking plate fixation needed a secondary arthroplasty procedure, and regardless of HA, TSA, or reverse TSA treatment, ROM and functional improvement were still modest, with an average Constant score of 48 [45]. Alentorn-Geli et al. looked at fracture sequelae treated with HA or reverse TSA and found that reverse TSA had higher Constant scores and lower complication rates. Although not just a HH ON cohort, this study does suggest the more predictable nature of the reverse TSA vs. HA in fracture sequelae treatment. There have also been some case studies discussing post-arthroscopic HH ON treated successfully with reverse TSA [46].

51.6 Conclusion

In summary, HH ON is a diverse and complex disease state to treat. There are many etiologies to take into account, and each patient requires a unique approach depending on their symptoms, structural deformity, and disease stage. In general, nonoperative management is the first step in managing these patients. In later stages (III–V) of HH ON, arthroplasty may be the first-line treatment and almost assuredly in post-traumatic cases. Those with significant glenoid wear or deformity should be strongly considered for TSA rather than HA. Resurfacing or HA may be options and should be considered on a case-by-case basis. Regarding stemless or stemmed humeral components, there is data to support both types of prostheses, but long-term data is pending on shorter stems. Patients with significant rotator cuff disease and tuberosity malalignment should be strongly considered for reverse TSA as

tuberosity osteotomy with TSA or HA is a difficult and less predictable operation. Finally, in postsurgical patients a strong understanding of the bony deformity and suspicion for infection need to be part of the clinical work-up. Overall, by taking into account a patient's age, activity level, and disability in addition to their disease stage and structural abnormalities, an optimal treatment can be devised for patients with HH ON.

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Reverse Shoulder Replacement for Massive Rotator Cuff Tears

52

Steven M. Andelman and Kevin P. Shea

52.1 Introduction

Management of chronic, massive rotator cuff tears presents a unique challenge for the treating surgeon. Patients present with a combination of pain and dysfunction that significantly impacts their activities of daily living. Due to poor tissue quality and significant tendon retraction, arthroscopic repair yields mixed results with high rates of re-tear and surgical failure. This has led toward a push to develop new treatment options that do not depend on rotator cuff integrity to restore pain-free range of motion to the shoulder.

Reverse total shoulder arthroplasty (RTSA) has emerged as an option for management of chronic, massive rotator cuff tears. Initially indicated primarily for rotator cuff-deficient glenohumeral arthritis, RTSA has demonstrated excellent short- and long-term results, allowing for restoration of pain-free shoulder range of motion with improvement in function and patient satisfaction. Such positive results have led to the expansion of indications for RTSA to include the management of symptomatic, massive, irreparable rotator cuff tears without arthropathy. This chapter will focus on the role of RTSA in the management of symptomatic massive non-repairable rotator cuff tears and will discuss the etiology and pathoanatomy of massive rotator cuff tears, treatment options, and the indications and outcomes of RTSA for treatment of this condition.

52.2 Pathoanatomy of Massive Rotator Cuff Tears

The rotator cuff muscles have a dual function in glenohumeral biomechanics. First, they are the primary dynamic stabilizers for the glenohumeral joint, functioning to keep the humeral head depressed, centered, and compressed within the glenoid to allow for stable glenohumeral range of motion. Second, they actively assist in shoulder abduction (supraspinatus), external rotation (infraspinatus and teres minor), and internal rotation (subscapularis).

Injury to one or more rotator cuff tendons can cause altered biomechanics during shoulder range of motion. The four rotator cuff tendons function as a force coupling unit, and tearing of one tendon can alter the function of the remaining tendons with regard to dynamic stabilization and active motion. Biomechanical studies have consistently demonstrated increased anterosuperior and posterosuperior translation of the humeral head on the glenoid with shoulder range with subscapularis and infraspinatus tears, respectively [1, 2]. Pathologic humeral head translation during shoulder range of motion leads to altered

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glenohumeral contact pressures which cause both pain and glenohumeral arthritis.

Neer et al. coined the term "rotator cuff arthropathy" in 1983, describing the progression of massive rotator cuff tears to glenohumeral arthritis [3]. He reported that massive rotator cuff tears cause instability of the glenohumeral joint and superior migration of the humeral head causing erosion of the undersurface of the acromion and acromioclavicular joint with the loss of normal glenohumeral contact pressures causing softening and degeneration of the glenohumeral cartilage. Further investigation of the effect of massive rotator cuff tears on the glenohumeral joint has suggested a multifactorial process for rotator cuff arthropathy. This process begins with a massive rotator cuff tear causing anterosuperior escape of the humeral head. This leads to mechanical abutment of the humeral head on the undersurface of the acromion causing cartilage fragmentation and particulate debris. This induces a cytokinetic inflammatory response that causes further damage to the cartilage. Resultant pain and immobility then causes disuse atrophy to glenohumeral cartilage causing glenohumeral arthritis. [4, 5]

A better understanding of the etiology of rotator cuff arthropathy has led to the development of improved classification systems. Hamada et al. described a radiographic classification system that has proven useful in determining the stage and treatment options for management of rotator cuff arthropathy [6, 7]. Grade 1 rotator cuff arthropathy describes a massive rotator cuff tear with maintenance of the acromiohumeral interval >6 mm. Grade 2 represents progressive anterosuperior escape with a decrease of the acromiohumeral interval <5 mm. In grade 3 there is acetabularization of the undersurface of the acromion from abutment of the superior humeral head. Grade 4 rotator cuff arthropathy represents the onset of glenohumeral arthritis with narrowing of the glenohumeral joint. Walch et al. further subdivided grade 4 rotator cuff arthropathy into patients without (4a) and with (4b) associated subacromial arthirits [8]. Finally, grade 5 is indicated by humeral head collapse and represents end-stage glenohumeral arthritis (Fig. 52.1).

52.2.1 Clinical Evaluation

It is important to note that patients with rotator cuff arthropathy can present with a range of symptoms independent of radiographic findings. Generally speaking, patients may present with no pain and reasonable function, pain but with maintained function, pain and shoulder dysfunction, and isolated shoulder dysfunction without pain. When determining options for treatment, it is important to take into account both the radiographic findings and the primary symptoms of the presenting patient. A number of treatment options have been identified and explored for the management of rotator cuff arthropathy with varying degrees of success. These range from non-operative modalities such as corticosteroid injections and deltoid-based physical therapy, arthroscopic debridement and biceps tenodesis, superior capsule reconstruction, total shoulder arthroplasty (TSA), hemiarthroplasty (HA), and RTSA.

The clinical evaluation begins with a careful history. Have the symptoms been slowly worsening or rapid in onset? Has the patient had previous surgeries either in the remote past or recently to treat the current complaints? Is the pain constant or only provoked by certain activities? What are the important daily functions that the shoulder condition is preventing? Are there any coexisting morbidities such as heart disease, diabetes, obesity, or smoking? This last question is especially important as recent studies have shown that these comorbidities can negatively affect the treatment outcomes related to pain [9].

The physical examination can vary substantially, and it is important to tabulate all exam features to formulate a treatment plan. Cervical spine examination and a complete neurologic assessment should be performed to rule out neu-

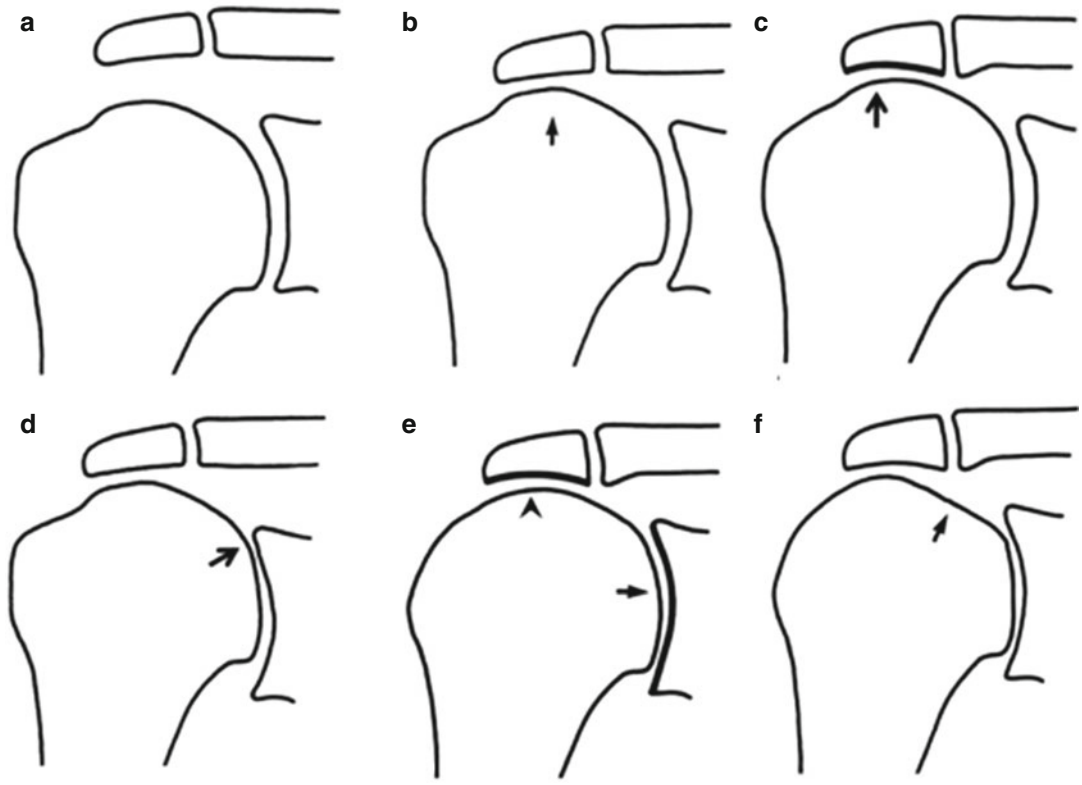

Fig. 52.1 Pictorial representation of Hamada classification illustrating radiographic changes seen with worsening rotator cuff arthropathy. (**a**) Grade 1, massive rotator cuff tear with maintenance of acromiohumeral interval; (**b**) grade 2, progressive anterosuperior humeral escape with decrease in acromiohumeral interval <5 mm; (**c**) grade 3, acetabularization of undersurface of acromion; (**d**) grade 4a, narrowing of the glenohumeral joint; (**e**) grade 4b, additional subacromial arthritis; (**e**) grade 5, collapse of the humeral head. Adapted from Hamada, K., Yamanaka, K., Uchiyama, Y., Mikasa, T. & Mikasa, M. A radiographic classification of massive rotator cuff tear arthritis. *Clin. Orthop. Relat. Res.* 469, 2452–2460 (2011) [7]

rologic paralysis. Visual inspection can show joint swelling indicative of inflammatory arthritis or "Milwaukee shoulder" described as glenohumeral joint swelling associated with end-stage destructive inflammatory glenohumeral arthritis. Many shoulder conditions can limit active shoulder elevation. However, the hallmark of cuff arthropathy is pseudoparalysis, characterized by inability to actively elevate the arm accompanied by an exaggerated shoulder shrug and internal rotation of the arm (Fig. 52.2). Inability to externally rotate the shoulder when the arm is placed in flexion is also characteristic. External rotation lag signs indicate loss of infraspinatus function, and teres minor function is assessed by evaluating external rotation in 45 degrees of abduction. Integrity of the posterior rotator cuff is critical to outcome. Subscapularis function is assessed with the belly-press test and/or lift-off test.

Passive range of motion is often normal, but advanced degeneration and osteophytes can limit motion. Assessment of active motion should include manual assessment of all three heads of the deltoid, supraspinatus, subscapularis, and the external rotators. While good outcomes can be achieved with RTSA if only the anterior deltoid is paralyzed, more severe deltoid palsy is a contraindication to RTSA.

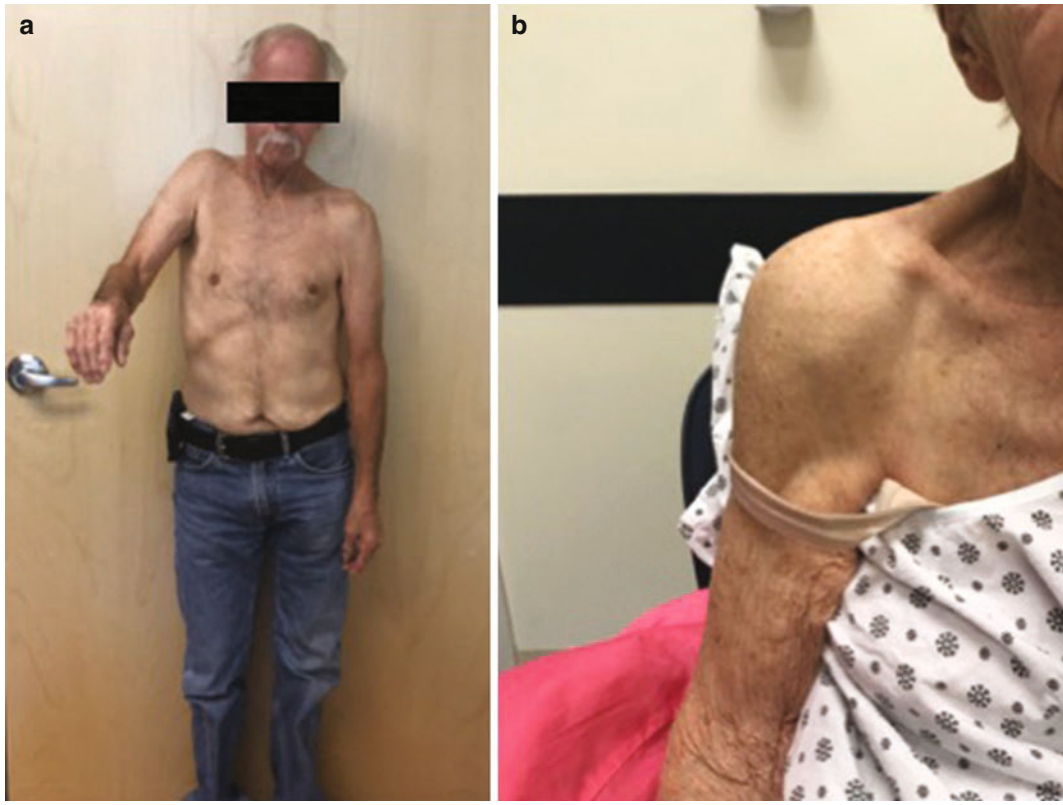

Fig. 52.2 Clinical demonstration of (**a**) pseudoparalysis of the shoulder with the inability to abduct or forward flex the arm and (**b**) glenohumeral joint swelling associated with the Milwaukee shoulder, described as glenohumeral joint swelling associated with end-stage destructive inflammatory arthritis

Radiographs should be assessed using the Hamada grade, and the glenoid should be assessed for abnormal wear in the axial plane (Walch classification) and coronal plane (Favard classification). A CT scan provides a more accurate understanding of the bony anatomy, and an MRI is indicated if non-operative treatment fails and surgery is considered.

52.3 Non-operative Treatment

The mainstay of non-operative management for massive rotator cuff tears and rotator cuff arthropathy is an anterior deltoid physical therapy program. The goal of this regimen is to strengthen and "retrain" the anterior deltoid to stabilize the shoulder during forward elevation and abduction of the arm to allow for increased active range of motion and regain the ability to perform overhead activities [10, 11]. Published results on the efficacy of an anterior deltoid program have been mixed, with reported rates of success ranging from 40% to 90% in small-scale trials [12, 13]. While the true efficacy of an anterior deltoid rehabilitation program is still unknown, it is clear that there is a subset of patients who can avoid surgical intervention with this approach. Anterior deltoid therapy can further be combined with periodic corticosteroid injections to improve both pain and function. This approach is suitable as a first line of treatment for a patient presenting with massive irreparable rotator cuff tears and rotator cuff arthropathy, for pathology in the non-dominant arm that does not significantly affect activities of daily living, for elderly and low-demand patients, and for patients with comorbidities that may preclude surgical intervention.

52.4 Reverse Total Shoulder Arthroplasty

While TSA and HA have not been able to provide reproducible, satisfactory results in the treatment of massive irreparable rotator cuff tears, RTSA has emerged as a popular option for treatment of this condition. Historically, the creation of a constrained reverse shoulder prosthesis was marked by multiple failures prior to the development of more modern systems currently in use. The concept, which still holds true today, was to create a fixed center of rotation on the shoulder to convert the superior-directed force of the deltoid into a rotatory force to allow for deltoid-driven forward elevation and abduction in the absence of a functioning rotator cuff. Early prosthetic designs in the 1970s and 1980s were based on total hip implants and attempted to recreate lateral offset to tension the deltoid. However, these designs had high rates of failure due to the fact that the center of rotation remained lateral to the scapula, causing significant torque on the components during deltoid activation leading to high rates of loosening and implant failure [14].

The creation of the Delta III prosthesis by Paul Grammont in 1985 proved a landmark development in RTSA. A number of significant improvements were made to the original RTSA systems. The glenosphere of the Delta III was larger than previous designs and lacked a neck component, placing the sphere in direct contact with the native glenoid. The humeral component differed in that it had a small cup and a non-anatomic angulation of 155°. Taken together, the large glenosphere and small humeral cup allowed for greater range of motion prior to impingement of the cup on the glenosphere. Perhaps more important, the medialization of the glenoid component and angulation of the humeral cup moved the center of rotation distal and medial to that of the native shoulder. This placed the fibers of the anterior deltoid under tension converting the normal superiorly directed force of the anterior deltoid to a rotatory force around a fixed glenohumeral component. Medialization and distalization of the center of rotation provided a biomechanical advantage to the deltoid in the absence of a functioning rotator cuff to allow for stable shoulder range of motion [12, 14].

The changes made in the development of the Delta III allowed for significant improvement in range of motion with lower rates of implant loosening as the center of rotation was taken medial to the scapula. The success of the Delta III led to an explosion in the usage of RTSA such that it is now the most common type of shoulder arthroplasty performed in the United States [15]. RTSA is now indicated for and utilized in rotator cuff-deficient arthritis, non-reconstructible proximal humerus fractures, revision TSA with rotator cuff deficiency, and, recently, massive irreparable rotator cuff tears and rotator cuff arthropathy. The usage of RTSA in massive rotator cuff tears, even in the absence of glenohumeral arthritis (Hamada 1, 2, and 3), arose from the poor outcomes treating this condition previously discussed.

52.5 Reverse Total Shoulder Arthroplasty: Surgical Technique and Rehabilitation

Successful outcomes with RTSA for massive rotator cuff tear begin with preoperative planning. Physical examination is necessary to determine the function of the deltoid and the external rotators. In particular, lag signs and inability to externally rotate are indicators of poor infraspinatus function. However, these tests should also be done with the shoulder in 45 degrees of abduction to test the teres minor. If no active external rotation is present, the patient is likely to have a horn blower's sign postoperatively. Consideration should be given to performing a latissimus transfer as part of the RTSA.

In cases where significant glenoid deformity, or rarely humeral deformity, is seen on the plain radiographs, a CT scan can be used to gain a three-dimensional understanding of the deformity. In cases of mild deformity, usually degenerative glenoid retroversion, the glenoid component can be placed with minimal corrective reaming.

However, if significant deformity is present that will make it difficult to anatomically orient the glenoid component, the CT scan can be used to assist in fashioning a bone graft or custom baseplate to correctly orient the baseplate and glenosphere. Computer software programs are now available from several implant companies that can more accurately plan surgical corrections.

RTSA can be performed via either the deltopectoral, superolateral, or anterolateral approach in either the supine or beach chair position depending on the experience of the surgeon. There are a number of modular systems that offer a variety of humeral offsets, neck-shaft angles, and glenosphere sizes and offsets to allow the surgeon to reconstruct to their specifications based on the preoperative planning. A full discussion of the advantages and disadvantages of each of these systems is beyond the scope of this chapter. Surgeons continue to debate whether to repair the subscapularis tendon or not and whether it is necessary to tenodese the long head of the biceps tendon. It is our preference not to repair the subscapularis as we feel that the repair may be too tight once the humerus moved lateral and inferior. We have not experienced any dislocations or instability in our series.

Postoperative rehabilitation begins immediately with passive range of motion in the plane of the scapula and gentle isometric periscapular strengthening exercises. The sling is worn for 2–4 weeks, and extension of the arm past the plane of the body is avoided. We have found that there is a tendency for the shoulder to quickly lose passive external rotation and early therapy exercises seem to prevent this from occurring. Isometric deltoid strengthening begins at 3 weeks as the patient is weaned out of the sling. At 6 weeks active range of motion in the scapular plane is initiated, and gentle strengthening begins. At 9 weeks deltoid strengthening begins, and active internal and external active rotation is initiated. This is progressed until 12 weeks when restrictions are lifted and the patient begins functional rehabilitation. While most patients demonstrate rapid improvement in the first 12 weeks, patients should be counseled that maximum improvement does not occur until 1 year after surgery [16]. Figure 52.3 illustrates pre- and postoperative imaging and full active postoperative range of motion 1 year after surgery, while Fig. 52.4 illustrates a Grammont-style prosthesis.

52.6 Outcomes of Reverse Total Shoulder Arthroplasty for Massive Rotator Cuff Tears

Recent long- and short-term outcomes for RTSA for treatment of massive rotator cuff tears and rotator cuff arthropathy have been favorable, especially when compared to other available treatment options. Multiple reports have demonstrated improvement in patient-reported outcomes, restoration of functional overhead range of motion, and excellent patient satisfaction [17–22]. Wall et al. reported in 2007 on 186 patients after RTSA for multiple indications with a minimum 2-year follow-up and noted that patients undergoing RTSA for massive rotator cuff tears demonstrated the best postoperative results when compared to all other indications for surgery, with a final average forward elevation of 142° and a 44 point increase in Constant score [23]. Likewise, Mulieri et al. reported in 2010 on 69 patients with massive rotator cuff tears without evidence of glenohumeral arthritis who underwent RTSA with an average of 4.3-year follow-up. They reported significant improvement in forward flexion (increase of 81°), abduction (increase of 76°), external rotation (increase of 24°), and internal rotation (increase of four vertebral levels) with an associated decrease in pain and improvement in functional outcome scores [24]. Samuelson et al. reported in 2017 on the survivorship of 61 patients with a mean age of 60, 51 of which underwent RTSA for massive irreparable rotator cuff tears, and noted a 90% 5-year implant survival rate with 90% patient satisfaction [25]. Presenting the longest-term data available in the literature, Gerber et al. reported in 2018 on 22 patients who underwent RTSA for irreparable rotator cuff tears with 15-year follow-up and noted a 27% failure rate. However, elevated Constant scores and improved range of motion were maintained with excellent patient satisfaction in those patients who did not have implant failure [26].

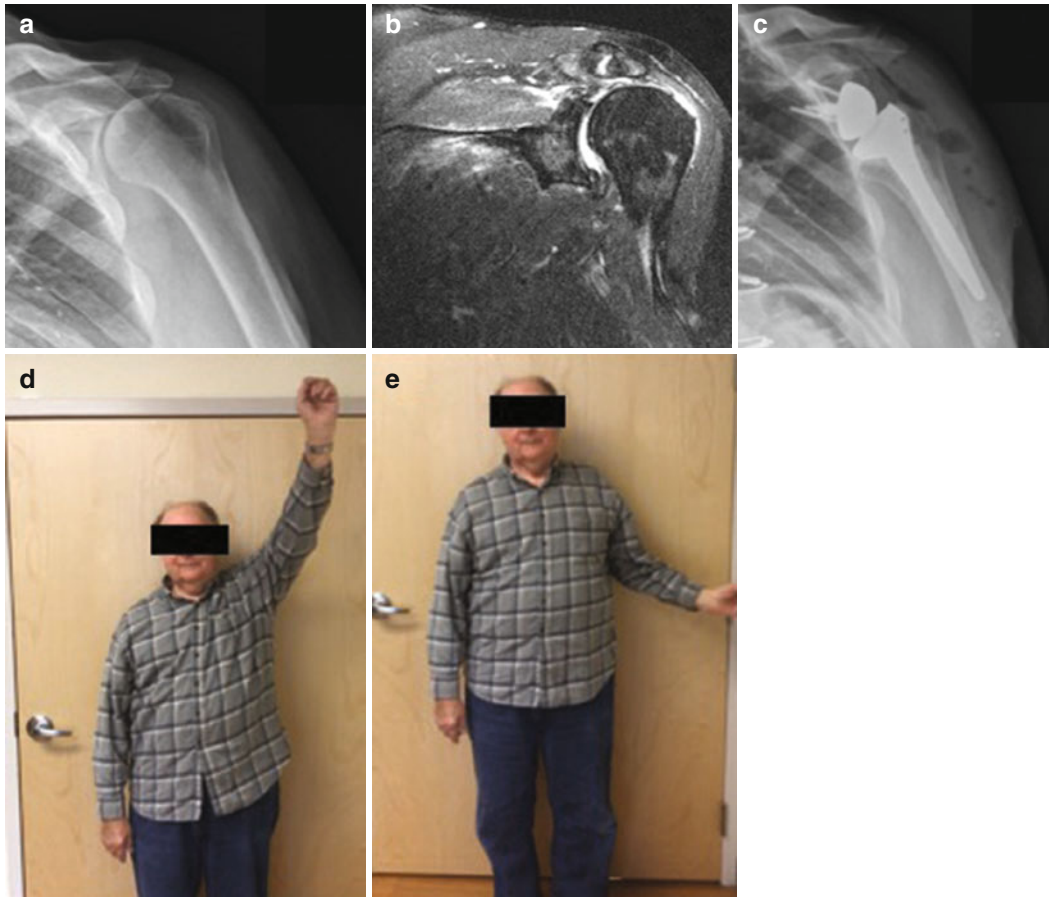

Fig. 52.3 Preoperative radiograph demonstrating Hamada grade 4a rotator cuff arthropathy (**a**) and MRI demonstrating a retracted massive rotator cuff tear (**b**). Postoperative radiograph after placement of a reverse total shoulder prosthesis (**c**) and postoperative examination demonstrating full forward flexion (**d**) and external rotation (**e**) 1 year postoperatively

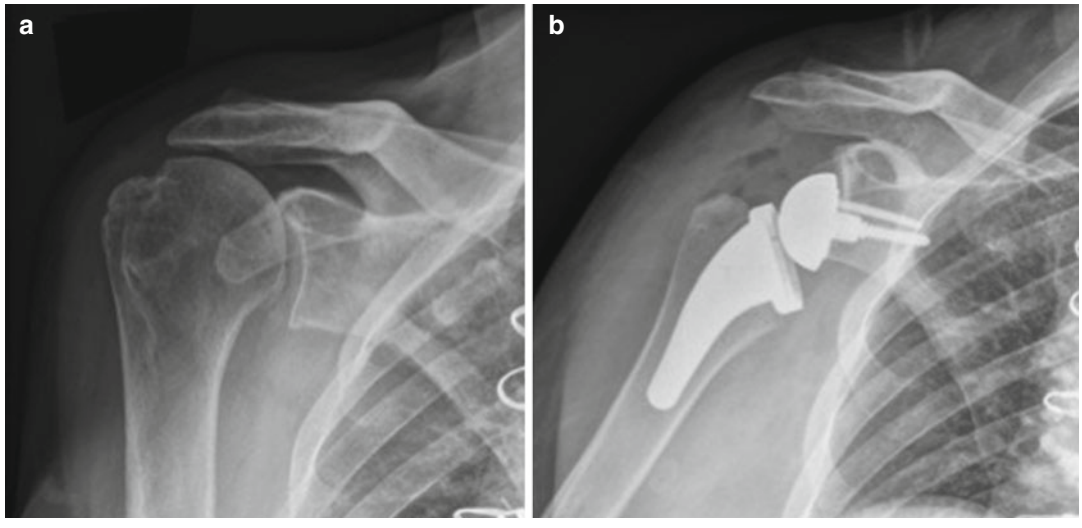

Fig. 52.4 (**a**) Preoperative radiograph demonstrating Hamada grade 3 rotator cuff arthropathy and (**b**) postoperative radiograph after placement of a reverse total shoulder prosthesis

52.6.1 Complications

Published rates of complication after RTSA for rotator cuff pathology range from 10% to 59% with the most common complication being scapular notching and the most severe being implant instability and infection [19, 22, 24–29]. Rates of scapular notching have been noted to be as high as high as 62% with an anterosuperior approach and a superior tilted glenosphere having been identified as risk factors [28]. Rates of instability are low (0%–10%) but can have severe consequences for the patient [19, 26].

52.7 Conclusion

Massive, irreparable rotator cuff tears and resultant rotator cuff arthropathy are a debilitating condition for patients marked by pain and decrease in shoulder range of motion. The first line of treatment is an anterior deltoid-based therapy regimen that can allow for restoration of motion; however, results are mixed, and this may not be an appropriate long-term treatment option for younger, active patients. RTSA has demonstrated the best long-term results for management of irreparable rotator cuff tears with regard to pain, function, and patient satisfaction. However, concern remains regarding the long-term complication rate, especially with regard to RTSA for young patients with rotator cuff arthropathy. Nevertheless, RTSA currently represents the treatment with the most predictable outcomes for management of massive irreparable rotator cuff tears and rotator cuff arthropathy.

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Part VI

Miscellaneous

53 Arthroscopic Suprascapular Nerve Release in the Young High-Risk Patient

Stephanie C. Petterson and Kevin D. Plancher

53.1 Introduction

Upper extremity peripheral nerve entrapment syndromes are challenging disease entities, as they often mimic more common shoulder pathologies or occur with other concomitant shoulder injuries, such as shoulder dislocation or rotator cuff tear, in the young, high-risk athletic population. Confirmation of suprascapular disease remains elusive at times due to vague etiology, and the indications for decompression of this nerve remain fraught with its advocates and critics. It has been reported that the suprascapular nerve is the second most common isolated nerve injury seen in shoulder dislocations, second to the axillary nerve. As a result, symptoms are often protracted with often a history of missed diagnoses. While this entity represents a small percentage of the average shoulder surgeon's practice, technological advancements in diagnostic testing and treatment options have brought this diagnosis of exclusion to the forefront and minds of many surgeons.

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53.2 Compression at Transverse Scapular Ligament

53.2.1 Pathophysiology

A compression lesion of the suprascapular nerve is often localized to a discrete portion of the length of the nerve due to its anatomical position, making it susceptible to entrapment. Extremes of scapular motion can cause the nerve to kink over the edge of the scapular notch (e.g., traction-friction theory), or extremes of shoulder motion, such as hyperabduction, may create an angulation against the transverse scapular ligament, leading to resultant irritation to the suprascapular nerve (e.g., sling theory) [1, 2]. Repetitive microtrauma, as seen in golf, may lead to direct injury by traction of the nerve or indirect injury by affecting the vascular supply to the nerve. Iatrogenic injury to the suprascapular nerve has also been reported in the literature upon distal clavicle excision or any posterior approach to the shoulder [3]. Trauma, such as a fracture through the scapular notch or even with a proximal humerus fracture caused by a direct blow to the shoulder, can also lead to suprascapular nerve injury. Tumors whether benign or malignant may also cause encroachment of the suprascapular notch by intrinsic or extrinsic masses. The ganglion cyst represents one of the most common of these lesions. Whatever the mechanism, compression or injury to the suprascapular nerve at the transverse scapular ligament will result in weakness, and if long term, atrophy

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of both the supraspinatus and infraspinatus muscles will occur.

53.2.2 Patient Profile

53.2.2.1 History

Compression at the transverse scapular ligament is rarely insidious in onset and more often than not occurs in young athletes. The patient will often give a history of trauma or of playing a sport with repetitive use such as volleyball, basketball, tennis, weight lifting, and swimming. While sports activities can often lead to suprascapular neuropathy, the heavy laborer performing repetitive, overhead work may also be plagued with this disease. A diffuse ache around the shoulder region is a common complaint; however, pain may also be localized to the posterolateral aspect of the shoulder, radiating down the posterior aspect of the upper arm, or even radiating into the posterior cervical region or along the upper anterior chest wall or described when reaching across his or her body. Weakness on external rotation and abduction may also be reported, which may confuse the examiner because he or she may think the patient has rotator cuff disease or even cervical disc disease.

In chronic cases, scapular motions may be painful leading patients to restrict or avoid certain motions mimicking the symptoms of adhesive capsulitis. Delay in diagnosis is the single biggest problem to help allow for full restoration of the muscle strength.

53.3 Compression of the Spinoglenoid Ligament

53.3.1 Pathophysiology

Injury to the suprascapular nerve may also occur at the spinoglenoid ligament. While most commonly thought of in the overhead athlete, injury to this nerve may occur from repetitive traction and microtrauma [4–8]. The spinoglenoid ligament has also been demonstrated to tighten when the shoulder is in a position for overhead throwing, resulting in increased pressure on the suprascapular nerve [9]. Early literature speculated that injury to this nerve occurred by intimal damage from microemboli in the vasa nervorum [10]. A stenotic notch or ossified spinoglenoid ligament or even superiorly oriented fibers of the subscapularis muscle may cause a suprascapular neuropathy [11, 12]. Compression by a soft tissue mass or ganglion cyst has known to occur because of the relatively fixed position of the suprascapular nerve as it traverses the lateral edge of the scapular spine combined with the close proximity of the infraspinatus muscle to the glenohumeral joint. These ganglia may form when a capsule or labrum tears and synovial fluid is forced into the tissues as a one-way valve, no different than meniscal cysts known to occur in the knee [13].

While rare, a patient may have a neuropathy from a Parsonage-Turner syndrome, although it is more common for this viral neuritis to attack the anterior interosseous and other nerves. Once again, whatever the mechanism, compression or injury to the suprascapular nerve at the spinoglenoid ligament will result in weakness and, if long term, atrophy of the infraspinatus muscle with little, if any probability, of return to normal muscle strength to occur.

53.3.2 Patient Profile

53.3.2.1 History

In contradistinction to the transverse scapular ligament, compression at the spinoglenoid ligament is often insidious in onset, and a delay in diagnosis is the single biggest problem which prevents full restoration of the muscle strength and alleviation of pain and reversal of muscle atrophy similar to compression at the transverse scapular ligament. Patients with compression of the suprascapular nerve at the spinoglenoid notch are commonly overhead athletes (e.g., volleyball, basketball, tennis, weight lifting, swimming, golf) and laborers that perform repetitive overhead activities. They are young and usually well-developed and complain of a diffuse ache

around the shoulder region. Their pain is more localized to 4 cm medial to the posterolateral corner of the acromion as well as near the posterior aspect of the glenohumeral joint.

Similar to compression at the transverse scapular ligament, a patient may complain of weakness on attempts of external rotation and abduction though weakness in these patients is often more profound. There are exceptions where compression can occur because of an acute trauma as in a forced external rotation of the upper extremity required in many racquet sports. This activity when discovered on history could produce a stretch on the suprascapular nerve and contribute to irritation at the compression point. Activities across the body are often difficult, and the motion of a follow-through, whether throwing a baseball or spiking a volleyball, can be quite painful at times that the athlete will avoid those movements. This position of follow-through or adduction in an extended position has been shown by our group to increase the tension and pressure within the spinoglenoid notch [4].

The patient may complain that their infraspinatus fossa appears different on comparison to the opposite side. As chronicity exists for many of these patients since their range of motion does not often decrease because of support from the serratus anterior, rhomboids, and latissimus, the chronic ache or pain will increase, become constant, and even affect or interrupt sleeping patterns. More present with spinoglenoid compression than compression at the transverse scapular ligament is a patient complaining of catching, locking, or clicking because of the frequent association of a labral tear.

53.4 Physical Examination

Clinical examination often has nonspecific findings in the early evolution of this disease entity. The differential diagnosis for suprascapular neuropathy therefore includes cervical disc disease, brachial neuritis (i.e., Parsonage-Turner syndrome), rotator cuff tendinopathy, labral pathology with or without a ganglion cyst, a mild form of adhesive capsulitis, osteoarthritis of the glenohumeral joint, bursitis of the subacromial space with or without impingement syndrome, AC joint degeneration, posterior instability, quadrilateral space syndrome, triangular space and interval disease or thoracic outlet syndrome, and the rare Pancoast tumor.

No different than any other disease entity, a full physical examination must be completed. The exam though must include the cervical spine and both shoulders with a full neurological examination. Cervical discogenic disease for the most part will have a more predominant component of neck pain with radicular symptoms. Pain arising from a C3–4 level will refer to the upper border of the trapezius, while pain from the C6–7 area will affect the inferior border of the scapula.

It is imperative that the patient put on a shoulder gown to allow for a complete inspection of the posterior shoulder girdle. Patients with compression at the transverse scapular ligament may exhibit atrophy in the areas of both the supraspinatus and infraspinatus fossa, whereas patients with compression at the spinoglenoid ligament may reveal painless wasting in only the infraspinatus. Atrophy though in a well-developed individual who participates in a weight-training program may at times be misleading due to the overlying trapezius and large bulk of the deltoid muscles. While tenderness may exist in the suprascapular notch between the clavicle and scapular spine, located 3 cm medial and anterior to Nevaiser's portal, this finding is commonly seen with many other disease entities. Palpation at the spinoglenoid notch can be very painful.

Range of motion and strength must also be tested. The marked weakness of external rotation should be tested with the arm at the side and will be present upon testing without any significant pain. The painless finding is because the sensory portion of the suprascapular nerve may be unaffected by the spinoglenoid notch. Patients may only exhibit a subtle loss of external rotation and abduction strength as we have found in long-standing disease that the teres minor and serratus anterior muscle will compensate for weakness of the infraspinatus to obtain near normal strength.

Provocative tests for any labral pathology must be confirmed as labral tears may be found in conjunction with a suprascapular neuropathy, more common with compression at the spinoglenoid ligament. While some patients may describe micro-instability as a part of their complaints, confirmatory physical findings are not commonly found. One of the best ways to help make the diagnosis of suprascapular neuropathy on physical examination is to perform the cross-arm adduction test. The patient puts their hand of the affected side on the opposite shoulder and lifts the elbow to the horizontal plane. The elbow is pulled by the examiner to the non-affected side and will provoke pain in the presence of a suprascapular nerve compression. The suprascapular nerve sends a branch to the acromioclavicular (AC) joint. Therefore, patients often have pain located in the AC joint with no evidence of AC joint degeneration on either x-ray (Zanca view) or profound tenderness on palpation. We have found confirmation of this disease entity prior to any EMG or radiological testing with palpation in the suprascapular notch, a positive cross-body adduction test with negative plain radiographs, observation of atrophy, and, when not present, a presentation of a dropping or protraction with slight winging of the scapula, and a confirmatory injection as described below when atrophy is not seen.

53.5 Radiographic Examination

Plain radiographs should always be obtained. We routinely have our technologist obtain a true (Grashey) AP, Y view, axillary lateral, Y supraspinatus outlet, Stryker notch, and Zanca view to observe the AC joint. An AP scapular view with the beam aimed 15–30° cephalad obliquely at the transverse scapular ligament may help to reveal any calcifications, exostosis, or previous trauma in the form of callous formation at the notch of osseous notch variants [14, 15]. This plain series will hopefully catch any fracture or minute trauma to the scapula, clavicle, coracoid, or glenoid neck.

Utilization of computed tomography is valuable to detect or confirm notch variants as described by Rengachary [2], fractures of the clavicle or scapula, and evidence of an ossified transverse ligament. We have though routinely used magnetic resonance imaging (MRI) as the best imaging modality in suspected suprascapular nerve pathology because of its soft tissue resolution and identification of any ganglion cysts.

MRI can be utilized to identify and determine the size and location of any soft tissue masses like a ganglion cyst though it does not necessarily indicate suprascapular neuropathy. Fritz has described the characteristic findings in asymptomatic patients with a ganglion cyst, as a homogenous signal, low T1 signal intensity with high T2 signal intensity, and rim enhancement if contrast is placed [16]. The MRI will detect labral tears which may arise from the glenohumeral joint producing secondary impingement on the suprascapular nerve, rotator cuff tendinopathy, neoplastic processes whether nerve in origin or not, and osteoarthritis of the glenohumeral joint. The course of the nerve can be well seen with T2-weighted sagittal oblique image. The presence or absence of muscle atrophy and fatty infiltration can be easily visualized of both supraspinatus and infraspinatus in compression at the transverse scapular ligament or isolated infraspinatus atrophy with compression at the spinoglenoid ligament. The presence of a soft tissue mass or ganglion cyst on MRI does not necessarily indicate suprascapular neuropathy. Some patients will demonstrate increased signal intensity on T2 fast spin echo with fat saturation with a normal muscle mass implying subacute denervation of the nerve caused by neurogenic edema. Chronic denervation seen best on T1 spin echo with increased signal intensity within the muscle mass will demonstrate muscle atrophy with fatty infiltration. Other authors have written about the presence of muscle edema as one of the earliest signs of suprascapular nerve entrapment [17].

Newer modalities such as the ultrasound may be helpful as well to identify ganglion cysts. This operator-dependent test can be very helpful not only in making a diagnosis but in assisting surgeons to complete an ultrasound-guided aspiration of the ganglion cyst.

53.6 Lidocaine Test Injection: How and Why

A 1% lidocaine anesthetic injection can be immensely helpful to accurately make the diagnosis of suprascapular nerve entrapment. For the transverse scapular ligament, the needle should be placed into the suprascapular notch from a posterosuperior injection 3 cm medial to Nevaiser's portal aiming anteriorly and aspirating first. It is important to understand the relationship of the artery to the nerve at the transverse scapular ligament. For the spinoglenoid ligament, the needle is placed 4 cm medial to the posterolateral corner of the acromion. The ultrasound may be used as an adjunct to guide the needle to ensure accuracy, although unlike the injection when placed in the transverse scapular ligament, this injection is simple because one feels the spine of the scapula and drops inferior to it by 1–2 cm and then aspirating and easily falling into the spinoglenoid notch. We have used a 25-gauge, 1½-inch needle with great success like others before us [18]. We have found pain relief to be dramatic and almost immediate. The cross-arm adduction test should be performed no different than when using a diagnostic injection for confirmation of AC joint impingement. The patient may not describe the absence of pain at the AC joint after this intervention, once again, helping the physician in ascertaining a definite diagnosis of a suprascapular nerve compression. The ultrasound may be used as an adjunct to guide the needle to ensure accuracy. A negative test for us doesn't rule out the disease in those patients who have a type 4–6 notch as the ability to deliver the lidocaine is quite difficult in those situations. Diagnostic injections in other areas of the shoulder may also be helpful to rule in or rule out other disease entities.

53.7 EMG

Electrodiagnostic testing with myography and nerve conduction studies can be helpful if positive when the suspicion of the diagnosis is suspected by physical exam and imaging studies are negative (i.e., no soft tissue mass is seen) and atrophy is not present. Testing should be bilateral to compare findings to the contralateral side.

When the suprascapular nerve is compressed by a ganglion cyst or soft tissue mass at the spinoglenoid notch, the nerve will show decreased innervation of the infraspinatus muscle with normal innervation of the supraspinatus muscle. Increased latency time often indicates impaired conductivity. The usual latency, or nerve conduction velocity, varies in a range of 1.7–3.7 ms for the supraspinatus. A value beyond 2.7 ms often indicates an abnormality. An increased latency beyond 3.3 ms (range 2.4–4.2 ms) signifies a positive result for compression to the infraspinatus. The stimulation point is typically performed at Erb's Point [19].

Other authors have classically stated that a decrease in the amplitude and spontaneous or marked polyphasicity of the evoked potentials are significant in confirming the presence of suprascapular entrapment [15]. Patients who have a long-standing neuropathy often have a reduction in the interference pattern in denervation to the supraspinatus and infraspinatus. The presence of positive sharp waves, fibrillation potentials, and absence or decreased numbers of motor unit action potentials in the infraspinatus and supraspinatus muscles are an additional or alternate finding noted on EMG that confirms a suprascapular nerve compression.

A classic positive electrodiagnostic study that detects compression at the spinoglenoid ligament will demonstrate a motor loss to the infraspinatus without changes in the supraspinatus muscle. One expects the report to reveal a delayed terminal latency to the inferior branch of the suprascapular nerve [20]. Evaluation of the sensory velocities is less useful as the sensory innervation of this nerve is not as well defined.

EMG and nerve conduction velocity may only be accurate 91% of the time in detecting nerve injury associated with muscle weakness [21, 22]. Therefore, suprascapular nerve dysfunction can be present with a normal nerve conduction study and EMG. EMG testing of the infraspinatus is even more difficult to detect as only one branch can be affected and the rest of the muscle may be unaffected, misleading the physician to think that

suprascapular nerve entrapment is not present. Nonetheless, the electromyogram may be a useful adjunct when taken as an additional piece of information with a history, physical examination, and appropriate imaging studies to confirm the diagnosis of compression of the suprascapular nerve at either the transverse scapular ligament or spinoglenoid ligament.

53.8 Physical Therapy and Non-operative Treatment

Most treating physicians believe that the initial treatment for an isolated suprascapular nerve compression is rest, activity modification, anti-inflammatory medications, physical therapy to maintain a normal range of motion, enhanced scapular stability, and strengthening of the shoulder girdle (i.e., trapezius, rhomboids, and serratus anterior) with return to sport after proprioceptive and plyometric exercises. While the natural history of this disease is not known, it is therefore not known how long to pursue a non-operative course. If there is a space-occupying lesion, we do not recommend non-operative treatment longer than 8 weeks. If there is a soft tissue mass, we have discussed how operative intervention in our hands is superior to avoid long-standing deficits. These lipomas or ganglion cysts can be easily taken care of arthroscopically along with any labral or other intra-articular pathology that may be seen at the time of surgery. Several studies have agreed with our philosophical approach to avoid a prolonged non-operative regime. Hawkins and his group reported 2/19 with a spinoglenoid cyst resolved their symptoms with conservative treatment [23]. Hawkins surveyed the group and found patient satisfaction was much higher with surgical intervention. Specifically, they reported this 18% failure rate for aspiration of the cyst and 48% recurrence rate for those cysts which were aspirated successfully. Ultrasound-guided aspiration of the ganglion cysts has also been reported with adequate results. Some authors have reported recurrence rates up to 75%, and while a safe technique, we have not recommended this to our patients as a disease-modifying procedure [23, 24].

In the absence of a space-occupying lesion and a negative MRI for atrophy and negative EMG, we believe that a reasonable program would be 6 months of conservative treatment with physical therapy and activity modification. It is important to manage the expectation of the patient and inform them that symptoms are often present for more than 6 months even with a strengthening program and that neuropathic symptoms, such as weakness and pain, may take more than a year to reach an improvement level satisfactory to the patient.

We have found like many before us that good results only come with early intervention to alleviate the pain and with release of the suprascapular nerve since this atrophy that has developed is most of the time irreversible in our young patients [25]. In newly presenting, advanced, and long-standing cases, in our hands, spinati atrophy almost never recover completely though the shoulder pain generally improves.

53.9 Arthroscopic Release of the Transverse Scapular Ligament

Arthroscopic release of the suprascapular nerve at the transverse scapular ligament provides the advantages of improved visualization of anatomy, faster postoperative recovery and return to sport or activities of daily living, and decreased morbidity (Figs. 53.1–53.8).

The patient is placed in the beach chair position with the arm placed at its side. It is important to prep and drape from the midsternum to the mid-posterior spine with the neck area included. We encourage the anesthesiologist to maintain a systolic blood pressure slightly below 100 mmHg. Our pump pressure is kept low at 30–45 mmHg to avoid unnecessary swelling.

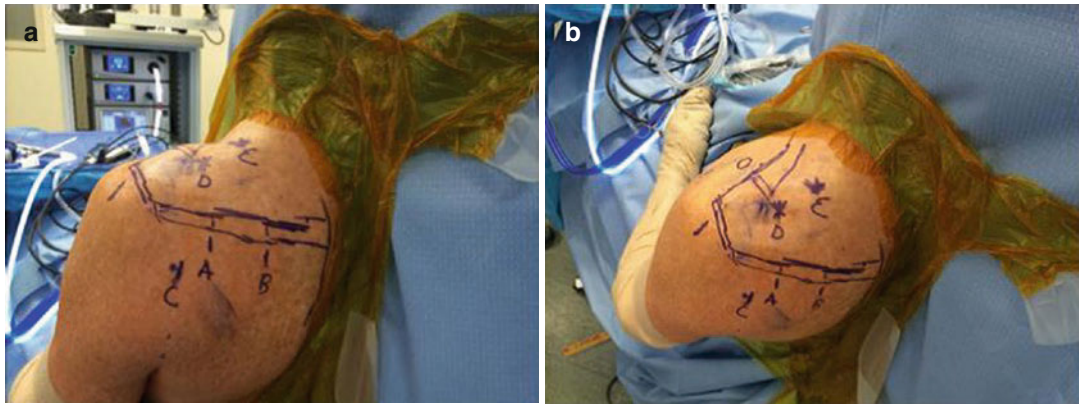

Fig. 53.1 (**a**) Intraoperative photo of a left shoulder prepped and draped in preparation for a transverse scapular ligament and spinoglenoid ligament release. The portals are labeled as follows: A—working portal for spinoglenoid ligament release; B—viewing portal with 30-degree arthroscope for spinoglenoid ligament release; C—standard posterior portal for intra-articular glenohumeral arthroscopy; D—Nevaiser's portal; E—portal for release of the transverse scapular ligament. Note vertical purple mark on the lateral aspect of the shoulder approximately halfway from anterior to posterior along the lateral margin of the acromion. This is the viewing portal for release of the transverse scapular ligament. (**b**) View from above showing the same portal in a left shoulder. The round circle anteriorly is the coracoid. Anterior to portal D is the acromioclavicular joint. The arthroscopic shaver or thermal device will be placed at the anterolateral edge of the acromion with the viewing portal shown as the solid purple line laterally off the acromion to allow us to release the transverse scapular ligament. Copyright K. Plancher

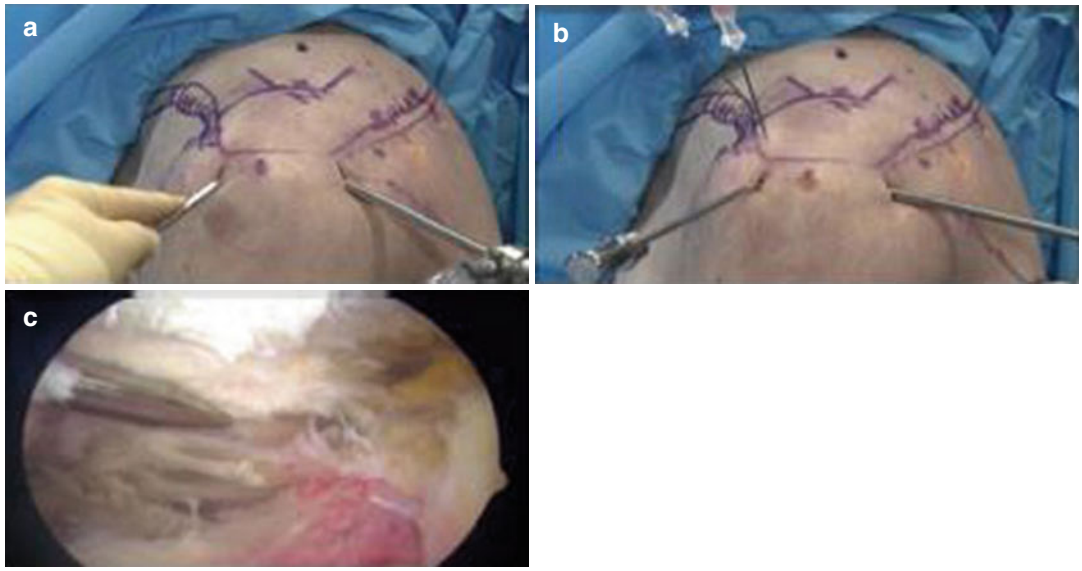

Fig. 53.2 (**a**, **b**) Clinical photo of a left shoulder in preparation for a transverse scapular ligament release. The arthroscope is placed in the posterolateral corner to begin a subacromial decompression with trochar sweeping tissue and in place to be replaced with a shaver in anticipation of resecting and following the CA ligament medially to the coracoid. (**c**) Arthroscopic inside view of a left shoulder showing the supraspinatus, its leading edge anterior to the left, with the trochar inside pointing to the CA ligament. Copyright K. Plancher

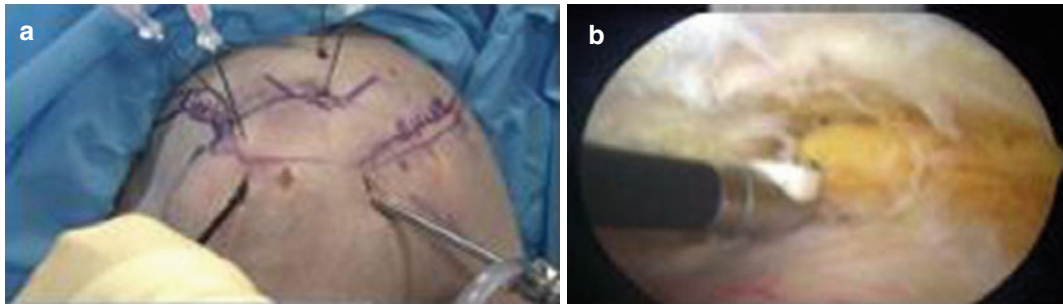

Fig. 53.3 (**a**) Left shoulder demonstrating spinal needles to accurately identify landmarks inside the subacromial space. Note the spinal needle in Nevaiser's portal. (**b**) Radiofrequency device clearing the soft tissue as it heads medially to identify the spinal needle coming from outside in of Nevaiser's portal. Copyright K. Plancher

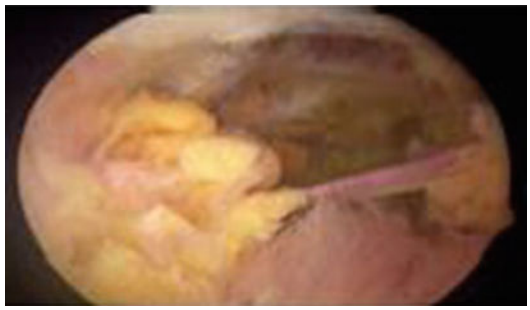

Fig. 53.4 Arthroscopic view of the same left shoulder demonstrating soft tissue cleared and visualization often with small tributaries of the suprascapular artery left unharmed. Copyright K. Plancher

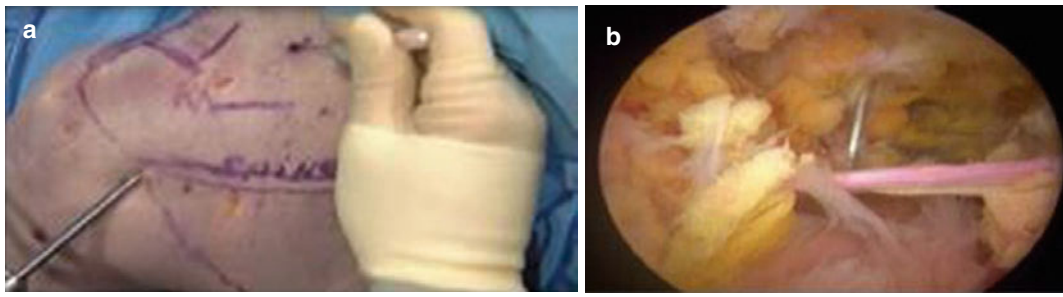

Fig. 53.5 (**a**) Clinical photo of left shoulder demonstrating 18-gauge spinal needle entering 3 cm medial to Nevaiser's portal to help identify the transverse scapular ligament. (**b**) Arthroscopic view of the same needle heading toward the transverse scapular ligament to aid in visualization of an accurate landmark. Copyright K. Plancher

The portals selected include the standard subacromial portals (e.g., lateral subacromial portal and anterolateral portal). The patient more often than not because of the young age might have had a subacromial decompression with utilization of a standard posterior portal. Additional portals are necessary for success of a decompression of the transverse scapular ligament. The added portal is a portal made from outside-in first with an 18-gauge spinal needle 3 cm medial to Nevaiser's

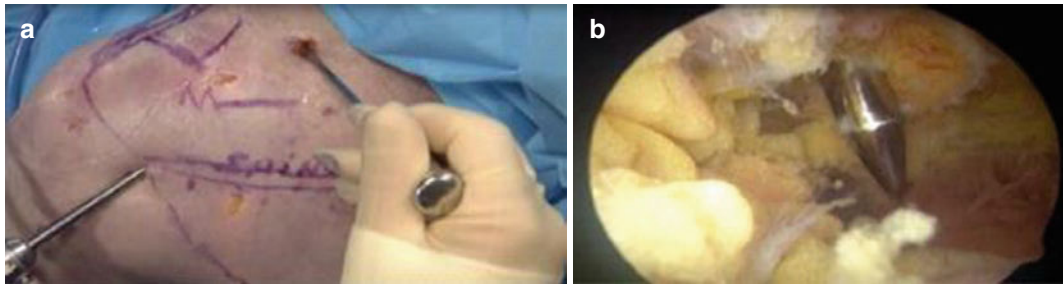

Fig. 53.6 (**a**) Clinical photo of left shoulder demonstrating a trochar entering 3 cm medial to Nevaiser's portal after a skin incision has been made. (**b**) Arthroscopic view of the same trochar heading toward the transverse scapular ligament to aid in retracting the artery and nerve out of harm's way. Copyright K. Plancher

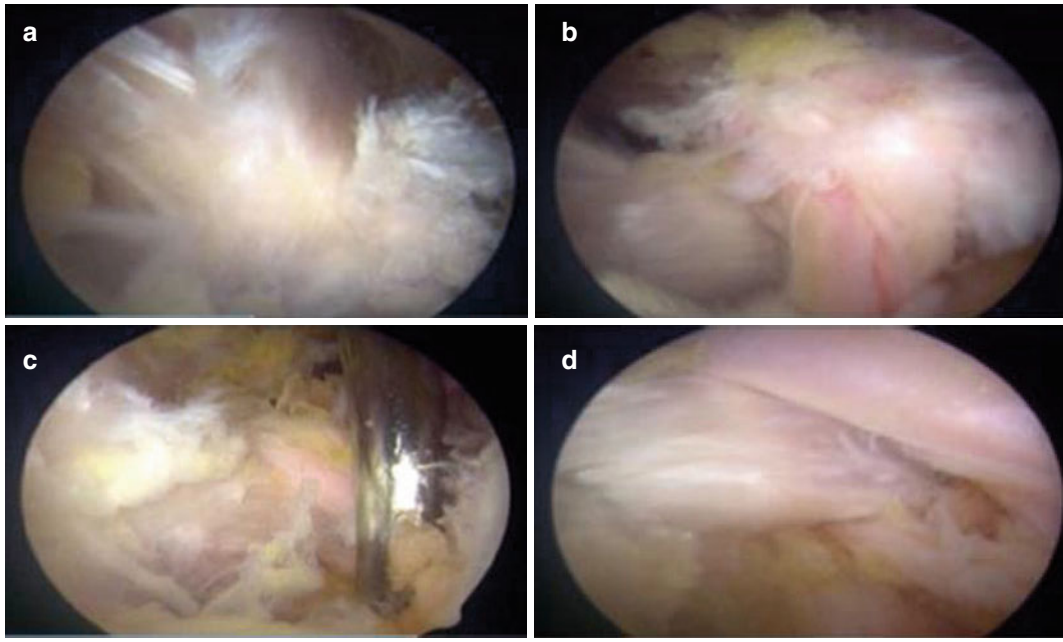

Fig. 53.7 (**a**) The conoid ligament recognized as the most lateral attachment of the transverse scapular ligament now with the transverse scapular ligament in sight but covered by soft tissue and the artery and nerve not protected. (**b**) Arthroscopic view of the suprascapular artery laying over "the transverse scapular ligament" in harm's way. (**c**) A blunt obturator/trochar retracting the artery out of harm's way revealing the suprascapular nerve adhered to the calcified and thickened transverse scapular ligament. (**d**) Arthroscopic view of the suprascapular nerve still not adequately retracted safely with the transverse scapular ligament in clear view. Copyright K. Plancher

portal ensuring that the portal is anterior to the supraspinatus leading edge. The portal is approximately 6–8 cm medial to the anterolateral border of the acromion in between the clavicle and scapular spine.

Release of the transverse scapular ligament does not begin with glenohumeral inspection, and if it was to begin with a full inspection, that part of the procedure should take no more than 5 minutes to ensure a limited amount of swelling occurs in the limb. Instead, the arthroscope is introduced into the subacromial space, and a subacromial decompression is completed to allow for adequate visualization. The arthroscope is moved midway to two-thirds of the way posterior along the lateral edge of the acromion or may be placed at the

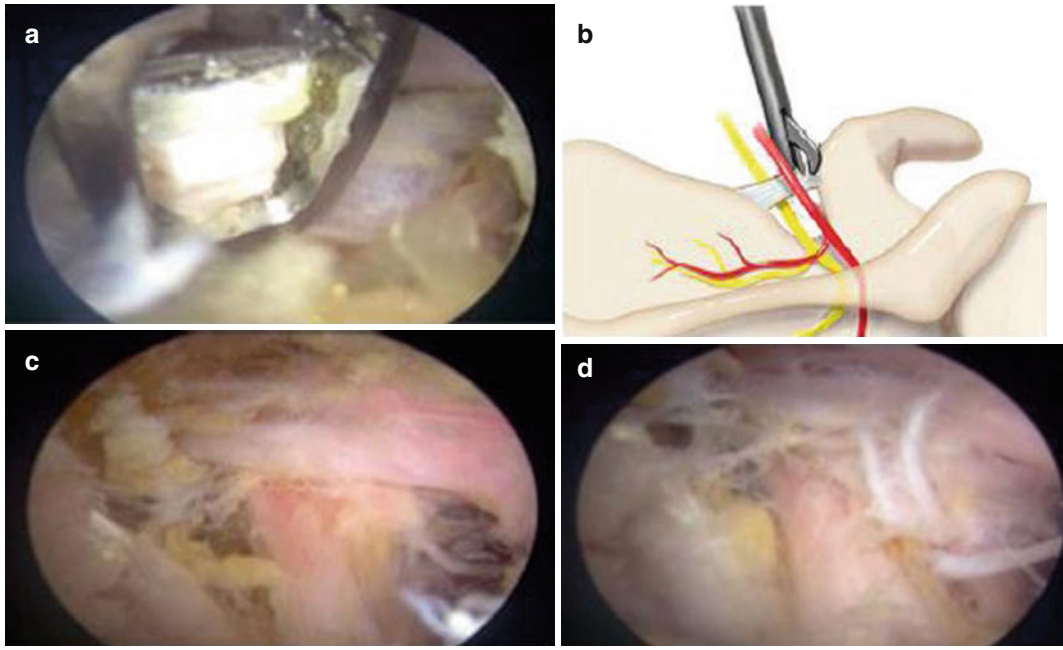

Fig. 53.8 (**a**) Arthroscopic view with the scissors attempting to cut and remove the calcified transverse scapular ligament. In this a lambotte osteotome was introduced to help remove the calcified transverse scapular ligament. (**b**) Artwork illustrating release of the transverse scapular ligament corresponding to the clinical photo in (**a**). (**c**) Arthroscopic view of successful release of the transverse scapular ligament revealing the suprascapular nerve to the right and the remnant of the calcified transverse scapular ligament to the left. Note superiorly and running diagonally to the right the suprascapular artery. (**d**) Close-up arthroscopic view of release suprascapular nerve with remnant of calcified transverse scapular ligament on the left side of the screen. Copyright K. Plancher

posterolateral corner. The shaver is introduced in a new portal created at the anterolateral edge of the acromion. This portal should be placed as close to the acromion as possible. This entry point will allow for adequate clearance of all soft tissue necessary to complete this operation.

Identification of the various landmarks is completed with the aid of 18-gauge spinal needles. One spinal needle is placed in the center of the AC joint, and a second needle is placed in Nevaiser's portal. The shaver releases the coracoacromial ligament laterally during a subacromial decompression and follows its medial side to the coracoid. Soft tissue is either ablated with a radio-frequency device or removed with a mechanical shaver, but ensuring hemostasis and perfect visualization is maintained throughout the procedure. The leading or anterior edge of the supraspinatus is always maintained in view while proceeding to release the transverse scapular ligament. Upon arriving at the coracoid, the coracoclavicular ligaments are identified first, then laterally the trapezoid, and subsequently the conoid or more medial ligament. The conoid is always more posterior in position, and there is usually an area of fat surrounding this ligament. It is recommended to clear this space with the use of a radio-frequency wand. The spinal needle placed in the AC joint will remind the surgeon of the location of conoid ligament, and the needle in Nevaiser's portal will keep visualization in the correct orientation as the arthroscope is placed more medially as the operation continues. The key to a successful operation is understanding that the most medial border of the conoid ligament is the most lateral attachment of the transverse scapular ligament. If the surgeon, as has been already stated, stays anterior to the supraspinatus, finding the transverse scapular ligament will not be difficult, but if the arthroscope strays posteriorly, then identification becomes more difficult. We realize as well when dealing with any

soft tissue mass that exists in the supraspinatus fossa, this must be evacuated as one continues the release and moves medially to the transverse scapular ligament. The stalk though of the soft tissue mass will almost assuredly be located alongside the transverse scapular ligament, and upon release of the ligament and protection of the nerve, the stalk may be excised.

An additional portal is now made upon recognition of the conoid ligament. The 18-gauge spinal needle is introduced 3 cm medial to Nevaiser's portal, and soft tissue is cleared up to this area. Rotation of the arthroscope to look down will identify the artery and or vein normally lying over the transverse scapular ligament. The outside-in technique allows for a safety factor, and a skin incision is made large enough to introduce the blunt obturator from the arthroscope that will aid in gently pushing away tissue to visualize the transverse scapular ligament and the suprascapular nerve. The blunt obturator will retract the supraspinatus muscle and fat posteriorly which will allow for an excellent view of the transverse scapular ligament, suprascapular artery, and suprascapular nerve. The obturator is then positioned to displace the nerve more medially so that the transverse scapular ligament is isolated. We then make a small incision in the skin and place an arthroscopic scissor in the anatomic position to divide the transverse scapular ligament close to the bone. If the ligament is calcified, we have used a lambotte osteotome in the past through this second small incision. A 3.5 mm burr or small 3.5 mm full radius shaver may be used safely to smooth any osteophytes that may be encountered. The blunt tip trocar is utilized to assess the mobility and adequate release of the suprascapular nerve.

53.10 Endoscopic Release of Spinoglenoid Ligament

Arthroscopic release of the suprascapular nerve at the spinoglenoid notch should be approached from the posterior shoulder (Figs. 53.9–53.16). We utilize a posteromedial and posterolateral portal in the infraspinatus fossa. Others have utilized a different approach when releasing the spinoglenoid ligament as they prefer subacromial approach [26]. The ability to visualize anatomy, return to sport, or activity of daily living is much faster and simpler than proceeding with the open technique in our opinion. The morbidity and postoperative recovery is much simpler and more pleasant for the patient as well.

The patient is placed in the beach chair position with arm placed at its side. It is essential to prep and drape from the midsternum to the midposterior spine with the complete scapula included. We encourage the anesthesiologist to maintain a systolic blood pressure slightly below 100 mmHg. Our pump pressure is kept low at 30–45 mmHg to avoid unnecessary swelling.

The portals selected include two portals: (1) the viewing portal which is placed 8 cm medial to the posterolateral corner of the acromion just inferior to

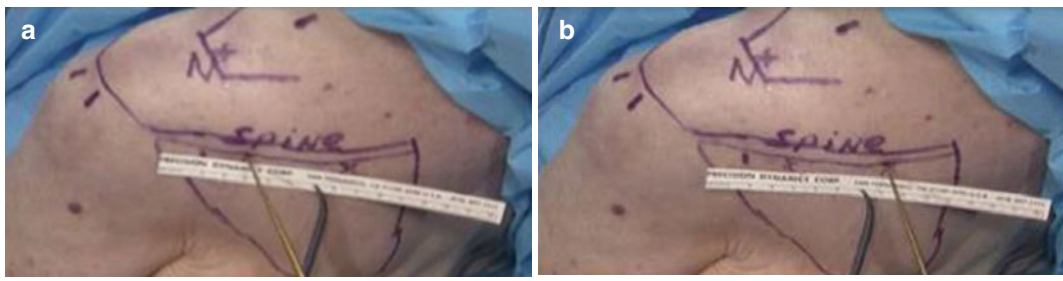

Fig. 53.9 (**a**) Clinical photo of a left shoulder posterior view. The gold probe is pointing 8 cm medial to the posterolateral corner of the acromion. This portal is the viewing portal for release of the spinoglenoid ligament compressing suprascapular nerve at the spinoglenoid notch. (**b**) Clinical photo of a left shoulder posterior view. The gold probe is pointing 4 cm medial to the posterolateral corner of the acromion. This portal is the working portal for release of the spinoglenoid ligament compressing suprascapular nerve at the spinoglenoid notch. Copyright K. Plancher

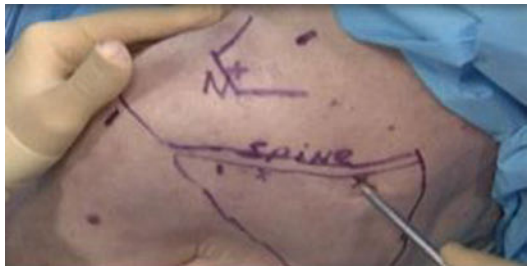

Fig. 53.10 Clinical photo of a left shoulder posterior view. The trochar is introduced in the following fashion. The tip of the blunt trochar palpates the spine of the scapula. The trochar is then moved inferiorly and gently swept to clear a space with the infraspinatus posterior and the tip of the trochar on the infraspinatus fossa. The tip of the trochar is then moved laterally toward the working portal 4 cm medial to the posterolateral corner of the acromion. The trochar as it is moved laterally sweeps the infraspinatus under the arch of its fossa to create a path for the arthroscope to allow visualization of the spinoglenoid ligament. Copyright K. Plancher

the scapula spine and (2) the working portal which is placed 4 cm medial to the posterolateral corner of the acromion just inferior to the scapula spine.

Release of the spinoglenoid ligament precedes any work done within the glenohumeral joint. We recommend that this part of the procedure should take no more than 5 minutes to ensure a limited amount of swelling to occur in the limb.

The blunt trocar is introduced into the viewing portal and heads straight toward the infraspinatus fossa. The tissue under the spine of the scapula is swept away, and the trocar heads to the working portal passing the suprascapular nerve heading and falling into the spinoglenoid notch. The key to this step, which allows for visualization, is to ensure that the trocar sweeps under the roof of the infraspinatus spine feeling the curvature.

The arthroscope replaces the trocar, and our first view of the spinoglenoid ligament is visualized. Identification of the various landmarks is completed. Success with this procedure will occur with visualization of the spine of the scapula to be maintained throughout the release of the ligament and decompression of the nerve.

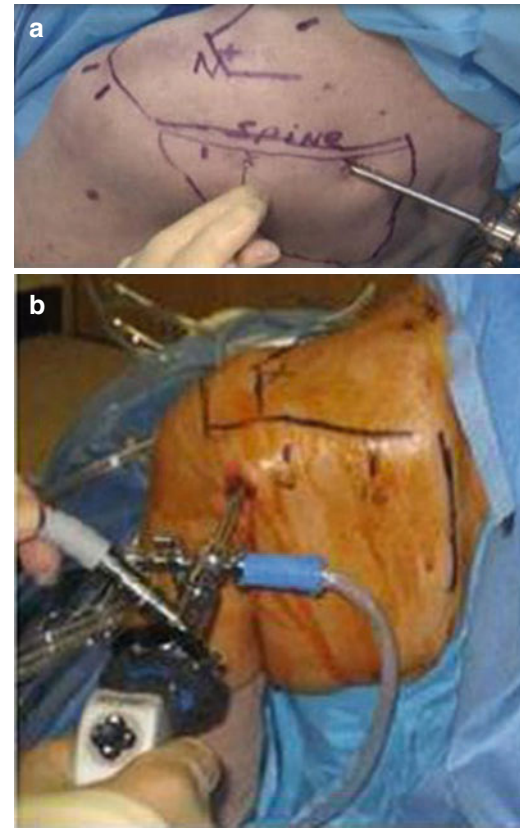

Fig. 53.11 (**a**) Clinical photo of a left shoulder posterior view. The 30° arthroscope is introduced into the viewing portal located 8 cm medial to the posterolateral corner of the acromion. Note the anesthesiologist is instructed to maintain a systolic blood pressure no higher than 100 mgHg mindful of the patient's health if this is not possible. We have always released the spinoglenoid ligament prior to proceeding with any intra-articular work or if needed any release of the transverse scapular ligament to avoid any undue swelling that will make this procedure more difficult. (**b**) Clinical photo of a left shoulder, posterior view, with the spinoglenoid portals marked out (SG). The arthroscope is in the standard posterior portal for intra-articular glenohumeral joint inspection. Note the relationship of the normal posterior portal to the spinoglenoid ligament portals. "X" represents Nevaiser's portal. Copyright K. Plancher

The trocar is now introduced into the working portal, and the soft tissue is teased away laterally as the course of the nerve can always be located in the medial side of the spinoglenoid notch. A radio-frequency wand of small

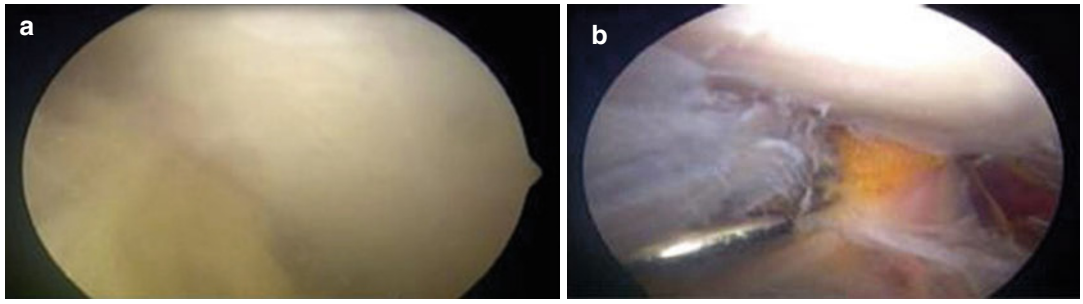

Fig. 53.12 (**a**) Arthroscopic picture of the same left shoulder after initial sweeping of the soft tissue away to expose the adipose around the spinoglenoid ligament. Clarity of the pictures occurs once the water is turned on. (**b**) Intraoperative photo of the same left shoulder showing perineural fat with trochar teasing the spinoglenoid ligament off the suprascapular nerve. The white above represents the spine of the scapula. The glenohumeral joint would be off to the left. Copyright K. Plancher

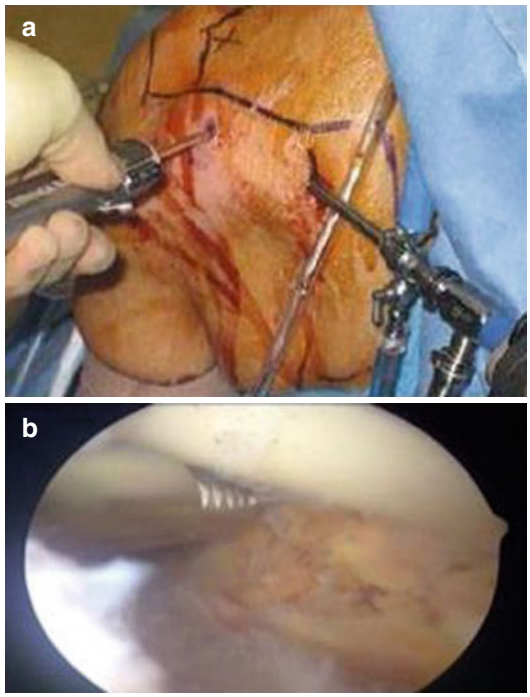

Fig. 53.13 (**a**) The arthroscope and shaver are now moved into the appropriate spinoglenoid portals for decompression of the suprascapular nerve at the spinoglenoid notch. (**b**) Intraoperative photo of the same left shoulder, posterior view. The spine of the scapula is above. The shaver is taking the spinoglenoid ligament directly off the spine of the scapula. All work is being completed lateral to the suprascapular nerve. No different than resecting the ligamentum mucosa/infrapatellar plica in a knee, all work is done on the bone or the notch (the knee), thereby safely avoiding injury to the nerve anterior and medially. Copyright K. Plancher

radius nonaggressive shaver with the suction turned off can be utilized at this point to clear the tissue and more specifically the spinoglenoid ligament. The ligament can be resected by staying on the spine of the scapula to avoid any bleeding. The ligament can be followed to the glenohumeral joint at its insertion to understand and visualize the complete resection of the ligament.

The blunt tip trocar is utilized now to assess the mobility and adequate release of the suprascapular nerve. We then head into the spinoglenoid notch to note any aberrations in anatomy such as a bifid nerve or a ganglion cyst that now may be compressing the suprascapular nerve. Decompression of the ganglion and excision of the stalk can now be easily completed. It is important to understand that the ganglion root may be heading toward the posterior-inferior quadrant of the glenohumeral joint. Observation of the released suprascapular nerve with the artery can now be seen hugging tightly as it wraps around the notch and heads medially giving its 2–4 muscular branches to the infraspinatus. Upon completion and full inspection, the equipment is removed from the body, and the portals are closed in routine fashion. The patient should wear a sling for 7 days for comfort to start. Thereafter, all activities can be resumed but is dependent on any other work that may have been performed to this same shoulder.

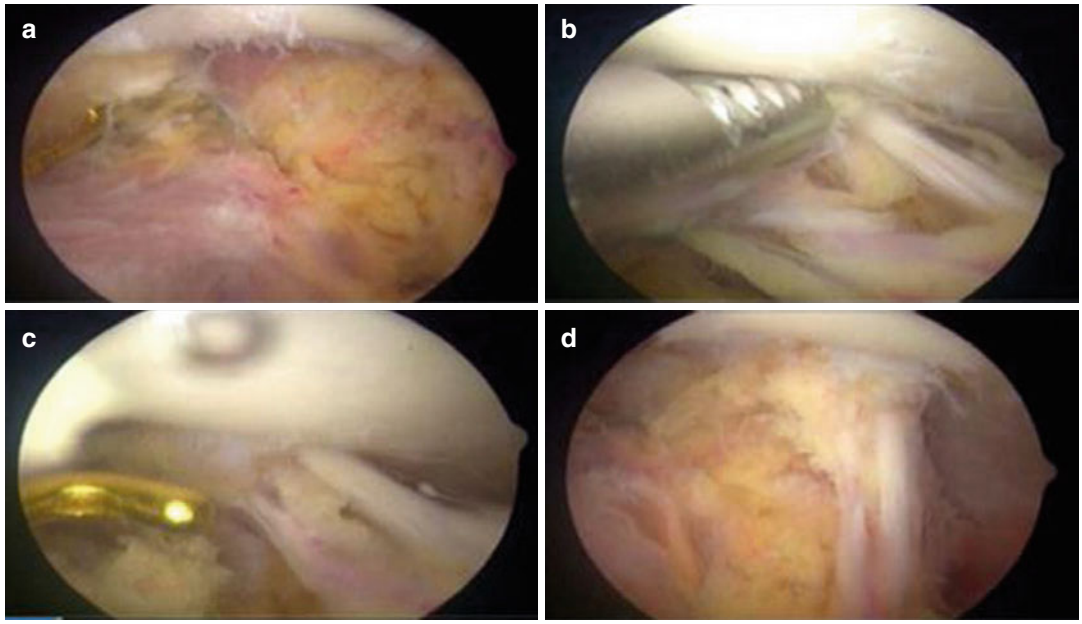

Fig. 53.14 Intraoperative photo of the same left shoulder, posterior view. The spine of the scapula is above (white). (**a**) The probe is teasing the spinoglenoid ligament off of the glenohumeral attachment laterally. The suprascapular nerve will reveal itself in the perineural fat with blunt dissection. (**b**) The dull trochar has been used to tease the tissue and expose the suprascapular nerve seen at the tip of the shaver moving obliquely to the right. (**c**) In this arthroscopic view, the suprascapular nerve is clearly seen off to the right and the slightly anterior to the nerve is the suprascapular artery. The gold probe on the left is being used to tease any remaining remnants of the spinoglenoid ligament or the tissues compressing the suprascapular nerve. (**d**) The suprascapular nerve is now freed and fully mobile as it exits the spinoglenoid notch to move medially now that it has been decompressed. Copyright K. Plancher

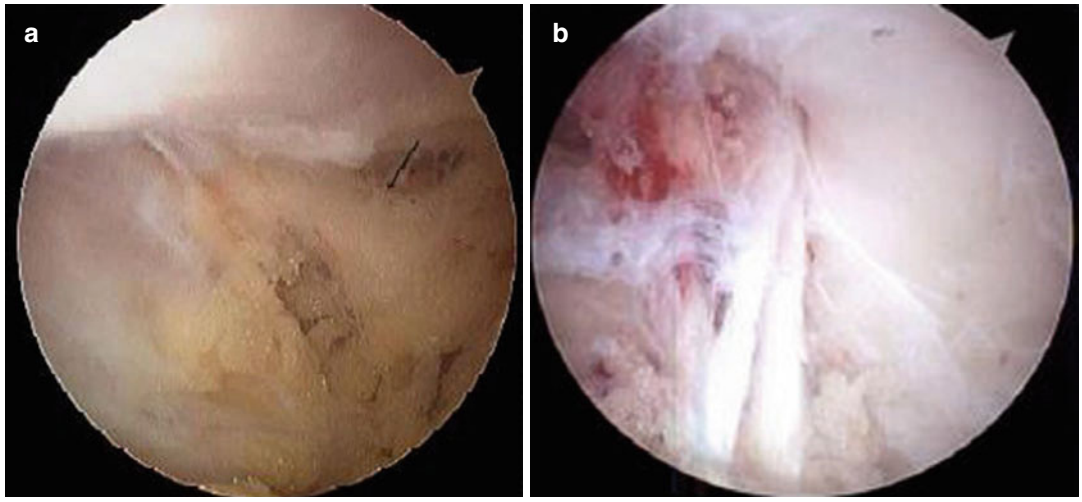

Fig. 53.15 (**a**) Arthroscopic view of the left shoulder, posterior view, with the arrow pointing to the suprascapular nerve heading medially. Note the bulging tissue to the left, representing a ganglion cyst not yet decompressed. The spine of the scapular (white) is above. (**b**) Arthroscopic view of a left shoulder, posterior view. Note the relationship of the suprascapular nerve as it always hugs tightly the suprascapular notch. This suprascapular nerve represents an anomaly which is yet to be described because of its bifid nature. The nerve branches will head medially toward the right. Arthroscopic decompression of the spinoglenoid ligament can be safely performed by staying lateral to the nerve which is fixed in position in the spinoglenoid notch. Copyright K. Plancher

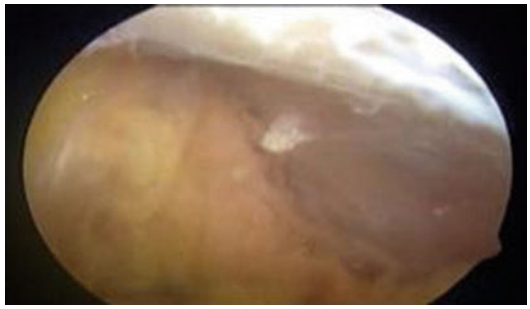

Fig. 53.16 Intraoperative photo of the same left shoulder demonstrating the most medial aspect of the spinoglenoid notch. This is the danger zone as the suprascapular nerve will always hug the most medial aspect of the notch as it heads midline giving off 2–4 muscular branches to the infraspinatus. Note the spine of the scapular up above (white). Note the curvature of the infraspinatus fossa seen to the right of the perineural fat surrounding the suprascapular nerve. Copyright K. Plancher

53.11 Outcomes

Results of close to 300 reported decompressions at transverse scapular ligament have been cited in the literature, although most utilizing an open technique [10, 27–36]. Recent investigations discuss outcomes with the arthroscopic technique [37]. Within the hands of surgeons that understand the anatomy surrounding the suprascapular nerve, very few complications have been reported, although it is discouraging as we reported above, the ability to restore muscle strength and reverse the muscle atrophy is very difficult, if not impossible. Restoration of strength to the supraspinatus muscle has been easier to accomplish over the infraspinatus; however, the reasons are unknown. In a large series of 42 releases, 90% restored strength of a grade 4 or better to the supraspinatus [32]. Restoration of muscle atrophy on the other hand, as discussed above, is quite difficult although as reported by Fabre et al. had a resolution in 52% of their patients with suprascapular muscle atrophy [33].

While many studies are reported as case series without a control group for comparison of treatment options and long-term follow-up is not available, the disease entity itself is not as common. Older studies like that of Martin et al. reviewed their results of non-operative treatment with physical therapy in a small series of 15 patients and a 3-year follow-up [38]. They stated with only 33% with excellent results that non-operative treatment in the absence of a well-defined lesion-producing mechanical compression is the correct clinical intervention. Larger studies reported on open resection of the transverse scapular ligament and found 91% of their patients pain-free with a long-term follow-up showing approximately 88% survival with results unchanged at 4 years postoperatively [31]. Post and Grinblat reported on open surgical decompression without evaluation of the labrum with excellent or good results in 88% of the patients [12]. Arriaza et al. reported complete pain relief by 2 weeks after surgical decompression of the nerve at the suprascapular notch in four elite swimmers with full return to sports by 7 months [39]. Most recently two systemic reviews have been published on over 250 shoulders with surgical decompression [40, 41]. Momaya et al. reported that 92% of patients are able to return to sport with a very low complication rate, 0.74% [40]. Memon et al. reported on 261 shoulders across 40 studies with 42% of patients having a spinoglenoid notch cyst [41]. Ninety-two percent of patients had significant pain relief in average 24 months with 4% complication rate.

53.12 Understanding Ganglion Cysts and Our Treatment Regime

If a ganglion cyst is seen upon open release, many authors have advised surgeons to inspect the glenohumeral joint for a labral tear and encourage repair of this lesion in an arthroscopic fashion. Using an arthroscopic technique with the cyst approached through a superior-posterior capsulotomy of the glenohumeral joint, Iannotti showed data on a small group of patients who had suprascapular neuropathy secondary to a ganglion cyst. At 1-year follow-up, complete resolution of symptoms was reported without recurrence of the ganglion on repeat MR imaging [42]. The arthroscopic technique below and other methods have opened the door for treatment of ganglion cysts in an atraumatic way. Avoiding musculature

detachment offers a huge benefit to the patient [23, 42]. Much debate though exists whether cyst decompression alone is sufficient or if it is more appropriate to perform cyst decompression and labral debridement or labral repair [43]. Recently, some authors write that they do not decompress the cyst but instead treat the labrum with a repair [44]. No literature, including our technique, has a randomized study to show the efficacy of any of these four treatment modalities.

Advocates for treating intra-articular lesions such as the labral tear believe that if you correct the one-way valve mechanism, the cyst will never return [45]. These authors at times just treat the SLAP tear and ignore the cyst as they believe it will decompress itself after correction of all intra-articular pathology. The last group of labral repair alone without decompression of the cyst is discussed above with the study of Schroder [44]. Curiously, there is a case report of a debridement of a labrum tear with radiographic evidence of resolution of a spinoglenoid notch cyst and reinnervation shown by EMG after this procedure [46].

Other authors investigate the type of labral tear present and have arthroscopically decompressed the cyst, debrided the frayed labrum, and repaired the type 2 SLAP in this young population [47]. Fehrman also reported in a small series after nonoperative treatment great success with complete pain relief with intervention both in the intra-articular lesion and an open resection of the ganglion [48]. Chen in one report and Lichtenberg in another both reported on a small series with repair of a SLAP and excision of the ganglia in an arthroscopic approach [49, 50]. All patients in both series had complete pain relief and improvement in strength and excellent function at their reported follow-up. If the labrum is intact, these authors have in the past incised the capsule above the labrum just posterior to the biceps to decompress the ganglion cyst. Other authors who used the subacromial method to decompress the ganglion cyst find the raphe between the supraspinatus and infraspinatus which is lateral to the spinoglenoid notch and incise the capsule in this spot and place and now proceed with a decompression of the ganglion cyst with an accessory posterolateral portal [42]. It appears from the literature that debridement or repair of the glenoid labrum in most patients with a spinoglenoid ganglion cyst had the best outcome with the lowest recurrence rate [46, 48, 51].

We have though maintained a position of decompressing the ganglion from the posterior aspect of the shoulder and not repairing the labrum unlike others with excellent results [51, 52]. We have performed this method in over 30 patients with follow-up and have had only one patient where the pain did not resolve in a multiply-operated worker's compensation case. No recurrence of any cyst occurred in this group. It is acknowledged that every patient in this group has an investigation of any intra-articular pathology but no one with an intact labrum receives a capsulotomy posterior and superior to the glenoid rim to decompress the stalk of the ganglion cyst. Those authors who proceed with this type of decompression understand that no dissection should proceed beyond 1 cm medial to the superior capsule attachment to the glenoid to avoid the nerve as it courses through the spinoglenoid notch. We caution surgeons who attempt to decompress a ganglion cyst at the spinoglenoid notch to be wary of this technique to avoid its complications and consider a more direct approach. Complications to the suprascapular nerve can occur and the average distance to the suprascapular nerve from the posterior glenoid rim is 1.8 cm and the motor branches we have found it to be approximately 2.0 cm. We have encouraged patients with a complication of a suprascapular nerve injury and profound external rotation weakness to consider a latissimus dorsi transfer.

The last controversy that exists is the patient treated with labral repair and no cyst decompression. These authors believe that spinoglenoid cyst excision is unnecessary and avoids undue risk of injury to the suprascapular nerve during surgery. Although good results were reported with patients without pain, we cannot agree since many patients had a cyst still present on repeat MRI. The presence of a cyst for us will continue to erode nerve conduction and

ultimately irreversible muscular atrophy in the infraspinatus fossa with permanent external rotation weakness.

Recurrence of ganglion cysts with other approaches other than a posterior approach to the spinoglenoid notch has been reported. Hawkins has shown non-operative techniques with aspiration lead to an unacceptable recurrence rate with continued compression of the suprascapular nerve [23]. Recurrence as reported by others of the cyst due to failure of the SLAP repair to heal or inadequate initial resection of the cyst all give credence in our minds for a different approach [51]. Debridement may not be adequate off the glenoid neck for fear, and appropriately so, of injury to the suprascapular nerve as visualization is so difficult. Understanding the appropriate depth of resection when working with such an oblique angle and tight space seems difficult even for the most skilled surgeon. While the cyst when working to decompress with an intra-articular method is known to be located adjacent to the posterior and superior quadrant of the glenoid at the 10:30–11:00 position on a right shoulder and at 2:00–2:30 position on the left shoulder, identification of its exact location by this method is not as simple as it may appear. Blame on the lack of healing power of the patient is also avoided with our posterior approach as described below although identification of the recurrence and understanding how to proceed with a road map are essential with the aid of a new MRI if the labrum is found to not heal after repair has been performed.

Rehabilitation is affected with the intra-articular technique as opposed to a posterior approach with no labrum repair. If a concomitant SLAP repair is performed, then the patient must remain in a sling for 3–4 weeks. If no SLAP repair is performed, then 7 days of a sling is utilized with the patient commencing progressive range of motion exercises and strengthening with return to full overhead activities by 6 weeks. While understanding if labral repair is necessary or if isolated cyst decompression will resolve all symptoms for the patient with suprascapular nerve compression, only time will tell with future studies and meticulous follow-up.

53.13 Summary

Compression of the suprascapular nerve both at the transverse scapular ligament and the spinoglenoid ligament is a disease of a young overhead laborer or avid athlete. While many patients present with a long, protracted history, early diagnosis and intervention help to alleviate symptoms and promote a rapid return to activities with improved muscle strength.

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54 Postoperative Rehabilitation Following Rotator Cuff Repair: General Principles

Tyler Spiering, Corey Snyder, and Michael T. Freehill

Rotator cuff tendon tears represent a major clinical challenge for shoulder care in the orthopedic sports medicine field. With >4.5 million annual physician visits and >450,000 rotator cuff repairs performed each year, rotator cuff disease is the most common condition affecting the shoulder and is responsible for significant amount of pain and functional impairment in the adult population [1, 2]. As a result, these injuries account for a vast amount of disability and financial hardship throughout the world. It is for these reasons that there is continuous need for further advancement and refining of treatment algorithms both from a surgical standpoint and from a rehabilitation approach.

Most shoulder surgeons would agree that postoperative rehabilitation following rotator cuff repairs is equally, if not more, important than the surgical repair itself. A good surgical outcome is not possible without a well-programmed rehab protocol. For this reason, it would seem paramount that there be an optimal protocol to allow patients achieve their goal functional outcome. Still, there remains a fair amount of variation in postoperative protocols and controversy over the optimal timing, intensity, and progression of rehabilitation as well as the modalities used. Part of this variability stems from the fact that rotator cuff repairs have a reported retear incidence of up to 20–94% in large tears and there is no clear explanation for this finding [3–5]. There are, however, certain risk factors that seem to be associated with increased retear rates including age >60, osteoporosis, presence of stage 1–2 fatty infiltration and atrophy, obesity (BMI > 30), large to massive tears, smoking history, significant cuff retraction, and poor tendon quality [6–8]. Ahmad et al. [8] reviewed 127 cases of arthroscopic repair with a 29.1% retear rate and reported patient compliance as a significant independent prognostic risk factor for retear, in addition to large primary tear size, poor tendon quality, high repair tension, large cuff retraction, and poor footprint coverage. When it comes to rehabilitation protocols, there are several things that need to be taken into consideration including the aforementioned risk factors, surgeon preference, tear characteristics, repair type, individual progress, postoperative complications, and functional goals (i.e., competitive athlete versus elderly homemaker) [9]. It often becomes a balancing act between protecting the repair, preventing or improving stiffness [10], and restoring pre-injury function and strength in an appropriate time frame. In general, most reha-

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bilitation protocols follow a similar overarching philosophy and rehabilitation timeline, but there can still be a significant amount of variability. In this chapter, we hope to start by reviewing our basic understanding of healing phases in rotator cuff pathology, lay out the general principles of postoperative rotator cuff rehab incorporating the most evidence-based treatment interventions, and account for surgical and rehabilitation considerations. Finally, we will present some of the supporting literature for current practices and theories surrounding postoperative rehabilitation.

54.1 Phases of Healing

Postoperative rehabilitation and tendon healing are intimately related, and therefore no discussion of rehab would be complete without reviewing the various stages of rotator cuff healing following surgical repair. After all, much of what we know and implement through rehab programs is based on the stability of repair constructs and the progression through phases of healing. Rotator cuff tendon healing for both non-operatively managed tears and surgically repaired tears is believed to progress through three primary phases of healing. It's important to review these healing phases in this chapter as they lay the foundation for much of the underlying time frames and progression of rehabilitation protocols. Millett et al. [11] nicely describe these phases as follows.

The initial phase of the healing process is the inflammatory phase which typically occurs during the first 5–7 days. During this period, vascular permeability increases, and platelets from blood plasma localize to the tear and initiate a clot formation with bonds of fibrin and fibronectin cross-links. Additional inflammatory cells such as polymorphonuclear leukocytes and monocytes are attracted to the site via chemotactic mediators where they then remove tissue debris and begin forming a "callus" of type I and III collagen [12]. The influx of these cells is further increased by the release of histamine and bradykinin which lead to an increased vascular permeability [11].

The second healing phase is the proliferative phase which is thought to take place between the second and third weeks but may extend for up to 6 weeks. The proliferative phase is marked by a transition from acute inflammatory cells to fibroblasts, myofibroblasts, and endothelial cells which convert the soft fibrin clot to a stronger scaffold of granulation tissue and extracellular matrix [12]. Collagen is initially produced by fibroblasts as type III fibers with haphazard arrangement and lack of cross-linking.

The third and final phase of healing is that of maturation and remodeling which ensues beyond the third to sixth week mark and continues until complete healing, often lasting more than a year. It is during this period that the disordered scaffold of type III collagen becomes organized and replaced by type I collagen. This remodeling is dependent on appropriate stress and strain which guides alignment of the collagen fibers in parallel. The duration for complete healing to permanent repair tissue and maximum tensile strength is not known, but some studies have suggested a period of about 12–16 weeks [13] or even up to 26 weeks in a sheep model [14]. While it is important to understand these general phases of healing when discussing rotator cuff rehabilitation after surgical repair, it is still not fully understood how immobilization and active versus passive exercises are best incorporated into our postoperative protocols.

54.2 Glenohumeral Biomechanical Considerations

In addition to the phases of tendon healing, a fundamental understanding of shoulder biomechanics and force couples is critical to formulating and optimizing a rehabilitation program. The rotator cuff, consisting of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles, works in concert with the glenohumeral joint capsule and ligaments, as well as the scapulothoracic musculature, to stabilize the joint, keep the humeral head reduced, and provide dynamic control throughout shoulder motion. The soft tissue structures are critical as the bony structures do not provide significant stability. Shoulder sta-

bilization relies on the delicate balance of force couples and kinematic control of scapulohumeral rhythm with an approximate contribution of 2:1 for glenohumeral motion (120°) and scapular motion (60°), respectively [15]. Specific force couples between the subscapularis and infraspinatus/teres minor, as well as the supraspinatus and deltoid, are critical for providing balanced kinematics about the shoulder and rely on effective co-contractions. When injury affects components of these force couples, motion becomes compromised and inefficient and can lead to subacromial impingement or inflammation of the subacromial bursa leading to pain. Studies have shown that pain associated with rotator cuff tears and tear size itself both significantly affect the scapulohumeral motion in these patients, leading to increased scapular motion with elevation in sagittal and scapular planes [16, 17]. The alteration in normal scapular kinematics termed scapular dyskinesia affects rotator cuff function as a compensatory mechanism to overcome certain deficits. This information may be useful in guiding patients through rehabilitation protocols as accentuating the scapular contribution to exercise motion may allow for more efficient use [17].

54.3 Early Versus Delayed Passive ROM

Perhaps the main distinction between postoperative rotator cuff protocols is the contrast between a more aggressive approach with early passive motion (EPM) and a more conservative, delayed passive motion (DPM) protocol. With EPM, passive motion usually begins immediately on postoperative day 1 with a goal to avoid stiffness and atrophy [10, 18], whereas DPM protocols emphasize immobilization until about 4–6 weeks to minimize micromotion which could overload and cause failure at the repair site [19, 20]. This delayed approach is based on the willingness to tolerate increased stiffness out of concern for detrimental tendon healing and fear of retearing which has been demonstrated in animal models from tissue overloading [21, 22] occurring most often within the first 3 months after surgery [23, 24]. Several studies and meta-analysis have looked at the various effects of these contrasting protocols, yet no consensus has been established.

Four studies comparing these protocols showed that patients in the EPM group tended to have quicker recovery of functional range of motion; however, there was not a statistical difference beyond the later time points of 6 and 12 months [25–28]. Based on a recent meta-analysis by Li et al. [23], patients in EPM protocols demonstrated significantly better FF and ER at both short- and midterm follow-up, but only FF was improved at long-term follow-up which was typically 1 year postoperatively. A randomized prospective study by Arndt et al. [29] found that patients in the EPM group had improved motion and functional scores, decreased stiffness, and no difference in retear rates. Chang et al. [30] similarly noted improved FF and less stiffness in EPM groups, but no difference in overall shoulder function and also a trend toward increased retear rates for the EPM patients. Another meta-analysis by Chen et al. [31] demonstrated improved motion in the EPM groups with increased retear rates, compared to higher healing rates and functional scores in the DPM groups.

Furthermore, several meta-analyses have found no significant differences in range of motion, functional outcomes, or retear rates between the two protocols [21, 25, 32–34]. Regarding the concern for stiffness in DPM protocols, a retrospective review by Parsons et al. [35] evaluated 43 patients who were immobilized in a sling full time for 6 weeks after repair and found that only 23% were considered stiff at 6–8 weeks (<100° forward flexion and <30° external rotation) and there was no difference between the stiff and non-stiff groups for motion at 1 year. In addition, functional scores were similar, and MRI evaluation revealed a trend toward lower retear rates in the stiff patients. Similarly, Mazzocca et al. [32] performed a randomized prospective trial for 73 patients and found no difference in functional scores at 6 months. Other studies that have specifically analyzed tendon healing either with ultrasound [25], CT [29, 34], or MRI [26, 32] have reported healing of 76.6% in the EPM groups compared to 85.9% in the DPM groups.

When looking at results of various functional scores (i.e., Constant, ASES, SST), patients in the EPM and DPM protocols have comparable results although the ASES was slightly higher in DPM groups at the long-term follow-up [26, 29, 32, 34, 36]. These outcomes, as a whole, suggest that it is probably safe to begin EPM exercises for small or medium tear sizes, but it may not change the overall functional outcome beyond 1 year and may lead to slightly decreased functional outcome and increased retear rates for larger tears.

In summary, surgeons need to weigh the individual risks and benefits when deciding on a rotator cuff repair rehab protocol for each patient in the context of their known risk factors for failure. In patients with small- or medium-sized tears with an adequate repair construct and risk factors for stiffness, it is potentially beneficial to get them in an EPM protocol especially for short-term functional outcomes [30, 37]. In contrast, larger tears (>5 cm) [37] and those at risk for structural failure, such as patients older than 60–65 years of age with atraumatic tears, would likely benefit from a longer period of immobilization to reduce retear rates without significantly affecting long-term outcomes.

54.4 Early Passive Versus Active ROM

In general, both the early and delayed protocols compared above vary based on introduction of passive range of motion alone. This brings up the idea of what about active exercises. A recent review by Kluczynski et al. [38] suggested that early active motion was harmful and should not be introduced until at least 6 weeks post-op as they reported increased structural defects in the early active motion groups for small and large tears. The argument for earlier active motion is the positive influence that it has on organizing fibers in a healing tendon and promoting tensile strength [12]. Raschhofer et al. [39] specifically compared primary passive motion with early isometric loading in a randomized trial. The main difference between treatment groups was that the early active group utilized the isometric testing procedure or dynamic relocation test as the primary exercise from 2 to 6 weeks post-op. After the initial 6 weeks, both groups carried out a similar rehabilitation protocol. Results from this study revealed a greater reduction in pain scores in the active group for the first 6 weeks, as well as slightly improved functional scores at most time points. External rotation strength and range of motion in flexion, abduction, and external rotation were all the same between treatment groups, but the active group had increased internal rotation at 12 weeks. This study, while limited, supports the idea that introducing low-resistance, high-repetition active exercises earlier in post-op rehabilitation may be a reasonable strategy to improve pain scores and achieve improved function earlier on. In another study by Düzgün et al. [27], they found patients with early active motion experienced less pain and improved functional outcomes at 16 weeks. Certainly more literature is required to support this theory in practice, but it should not be ignored.

54.5 Phases of Rehabilitation

As we have described previously, many factors must be taken into consideration when planning a patient-specific rehabilitation program, but the phases of tendon healing described above certainly help provide a rough framework for clinical practice. There are a spectrum of methodologies and variations in the specific time points used, but there is a fair amount of agreement and consistency in the general phases of shoulder rehabilitation which stem from our understanding of the healing process. The rehabilitation phases that will be discussed in this section are generalizations but provide some underlying structure to the art of postoperative rehabilitation (Table 54.1).

54.5.1 Phase I: Protective Phase

The immediate postsurgical phase usually takes place during the first 6 weeks after repair and involves mostly passive exercises coupled with manual therapy techniques with the goal of mini-

Table 54.1 Sample of a common rotator cuff rehabilitation protocol

	Range of motion	Immobilizer	Therapeutic exercises
Phase I 0–4 weeks	Passive ROM only Advance as tolerated Goals: Flexion—140° Abduction—60–80° Ext. rotation—40° at side	Worn at all times except for hygiene and therapeutic exercise	Elbow/wrist hand ROM, grip strength, pendulums, isometric scapular stabilizers exercises
Phase II 4–6 weeks	Continue PROM stretch to goals above	Discontinue sling at 4–6 weeks	Begin gentle active-assistive exercises without resistance. Pulleys
	Add A/AROM as tolerated		Joint mobilizations (grades I and II)
6–12 weeks	Full P/AROM as tolerated	None	Begin active exercise
Phase III 12– 16 weeks	Progress to full active motion. No restrictions. Begin posterior capsular stretching	None	Active exercises with light resistance. Therabands. Continue scapular strengthening. Add IR/ER isometrics
Phase IV 12– 24 weeks	Full painless motion	None	Advance therabands strengthening. May begin light weights. Begin functional sport/work specifics. Return to previous activity level

If a biceps tenodesis was performed, no resisted biceps strengthening until 8 weeks post-op
If a distal clavicle excision was performed, no horizontal adduction until 8 weeks post-op

mizing loads across the repair site. When we look at the phases of healing described previously, this rehab phase largely corresponds to the healing phases of inflammation and proliferation during which the repair tissue lacks organization and tensile strength. Thus, the focus during the first 6 weeks is to maintain and protect the integrity of the repair, while the tissue eventually begins to mature as an organized tendon. It is during this phase that the most variability exists between different rehabilitation protocols.

It is important to keep in mind the first phase of rehab, especially the first week, also involves general postoperative care such as incision care, analgesia considerations, and reducing inflammation, though one could argue that some amount of inflammation is vital to the healing potential at the repair site. Furthermore, during this period, the patient is adapting to activities of daily living with the new functional limitations of not using the operative side, and thus they require a fair amount of education and support. For analgesic purposes, cryotherapy has become an important modality during this phase, and our protocols, like many others, advise patients to apply it as much as possible for the first few days and then as needed for breakthrough pain or post-activity periods thereafter. The analgesic effect of cryotherapy is said to occur between 50 and 60 °F [40], and studies have shown that cryotherapy results in less pain which often translates into better tolerance of rehab and decreased narcotic needs [41]. In addition, manual therapy techniques such as soft tissue mobilization (i.e., effleurage, friction, kneading) and low-grade joint mobilization have been shown to reduce pain in patients postoperatively and relieve impingement syndrome by maintaining a central location of the humeral head in the glenoid fossa [42, 43]. Our practice utilizes these techniques to assist in patient comfort prior to passive range of motion with the techniques directed to areas away from the surgical incision such as the periscapular muscles, cervical spine, and distal arm. These techniques have also been shown to reduce edema and improve circulation for the patient. A randomized controlled trial comparing manual therapy and home exercise with placebo treatment demonstrated that while the manual therapy did not result in any significant differences in the short term, it seemed to lead to greater improvements at long-term follow-up, especially for shoulder function and strength [44].

In general, most surgeons will maintain patients in an abduction brace/sling for these first 6 weeks which is thought to enhance the regional

blood flow and limit passive tension at the repair site [13, 20, 45–48]. For example, Hatakeyama et al. [48] demonstrated less tension on the superior cuff with 30° and 45° abduction. Many even suggest brace wear during sleep for the initial week; however, much of these recommendations are reliant on patient compliance which must be considered. Patient compliance, in general, is a major limiting factor, and poor compliance throughout the rehab protocol has been linked to poor outcomes and recurrence [8]. The downside of immobilization is the somewhat obvious consequence of increased shoulder stiffness reported in up to 15% after rotator cuff repair, [10, 49, 50] as well as muscle mass loss [24]. However, there is certainly evidence that suggests immobilization is beneficial for tendon healing and strength of repairs [20, 47, 51, 52], and a recent study by Parsons et al. further suggests similar long-term outcomes even in those patients who are initially stiff [35]. Additionally, avoiding early motion and cyclical loading theoretically decreases gapping at the repair site which may lead to retears. On the contrary, cadaver studies have demonstrated that strength of tendon repairs at time zero can exceed 250–350 N which theoretically could withstand the majority of in vivo forces across intact rotator cuff tendons which has been measured as 43–900 N for the supraspinatus and infraspinatus during daily activities [53–57]. As for the duration of immobilization, Koh et al. [58] randomized patients to either 4 or 8 weeks and found no difference in range of motion or functional scores and similar retear rates. Of note, for patients with risk factors for stiffness including calcific tendonitis, adhesive capsulitis, PASTA, concomitant labral repair, or single-tendon cuff repair, Koo et al. [59] demonstrated that a modified program incorporating early closed-chain overhead stretching prevented the occurrence of stiffness.

Typical precautions during this phase are avoiding all active range of motion at the shoulder, no stretching, no lifting or reaching behind the back, and avoiding any sudden movements that may jeopardize a more tenuous repair. With regard to passive motion and exercises during this phase, most protocols begin by incorporating gentle shoulder pendulums (Codman's exercise) [60], scapular motion isometric exercises, and possibly supine passive motion to tolerance after the initial week. It's important to note that poor form for passive pendulum exercises and drinking a bottled water have been shown to elicit EMG activity greater than 15% of the maximum voluntary isometric contraction in the rotator cuff muscles, so education and clear instructions are critical [61]. The argument for early supine passive motion comes from EMG studies demonstrating the lowest EMG activity during passive supine exercises [62]. When passive shoulder motion is allowed, it is generally limited to forward flexion of 90°, external rotation to 35° in scapular plane, and internal rotation to chest only. Lee et al. [26] compared an aggressive early range of motion to a limited early range of motion program and found no difference for function, range of motion, or pain scores, but a trend toward more retears in the aggressive group.

One modality which comes into question on occasion is the use of a continuous passive motion (CPM) machine. There have been a few studies comparing CPM machine use with basic passive, self-assisted ROM exercises. Short-term improvement in ROM and pain levels with use of CPM for 2 h per day was demonstrated by Garofalo et al. [63]; however, there were no differences at 1 year. Additional studies have also suggested the benefits of CPM seem to be short lived and may not be associated with any long-term benefits. Raab et al. [64] found the use of a CPM may lead to improved pain relief in certain subsets of patients including females and those over 60 years of age, but no difference in shoulder scores at 3 months. In a prospective randomized trial, Lastayo et al. [65] similarly found no significant difference for patients assigned a CPM for the first 4 weeks and suggested that the use of manual passive ROM exercises was a more cost-effective way to achieve similar results. These findings demonstrate no clear benefit for the use of CPM in postoperative rotator cuff rehab, but there may be a role in early post-op pain relief in small subsets of patients. Additionally, aquatherapy has been incorporated by some authors during this period after the incision is healed or

during the second phase. The buoyancy is used for assistance and support with certain studies demonstrating movements like forward flexion in the water results in less rotator cuff activation and can lead to motion goals earlier [66]. Some surgeons have established specific motion criteria to progress to the next phase of rehab, but this can be difficult to generalize across all patients and is not routinely used.

Our preference is to limit patients to scapular passive motion and then gentle pendulum exercises beginning at 2 weeks. Scapular muscle activation is important for restoring the force couples and scapulohumeral rhythm as previously mentioned. The use of other modalities such as pulleys or self-assisted motion is not recommended during this phase as EMG studies have shown significantly more muscle activity, especially in the supraspinatus, with these modalities compared to more passive exercises [67]. It is encouraged to start active motion at the fingers, wrist, and elbow during this period, although patients with a tenodesis are initially restricted to passive range of motion at the elbow so as to not overstress the repair.

54.5.2 Phase II: Mobility Phase

Weeks 6–12 make up the second phase of rehab and mark the gradual introduction of protected active exercises and increasing loads. The tendons healing to bone ought to be sufficiently strong to withstand some applied forces at this time frame, but they are still remodeling and maturing so it is important not to overstress the repair site leading to suture cutout or failure. Gradually increasing loads with movements during this phase of healing is important for optimal tendon healing and mechanical function [65, 68, 69]. Full active range of motion is the ultimate goal during this phase, but patients are also expected to have full painless passive range of motion early on in this phase. If they lack full passive motion by the sixth or seventh week, there must be a focus on scapular/glenohumeral joint mobilization by incorporating techniques such as soft tissue mobilization, contract/relax techniques, and long-duration stretching of the posterior shoulder, latissimus dorsi, and pectoralis muscles. At this point, most patients are no longer using a brace/sling, but they are still generally restricted from any lifting, holding their body weight, sudden movements, and excessive behind-the-back activities during this phase.

In addition to continuing pendulum and scapular motion exercises from the first phase, this phase marks the introduction of active assisted (AAROM) flexion in the supine position as well as prone rowing to neutral arm position. Exercises with AAROM in general have been shown to result in moderate EMG levels, but certain exercises such as a wall walk or the ball roll exercise (Fig. 54.1) can generate marked supraspinatus activity [62, 70]. A randomized controlled trial by Baumgarten et al. [71] compared 27 patients in a rehabilitation program that utilized pulleys after 6 weeks and 26 patients in a program without pul-

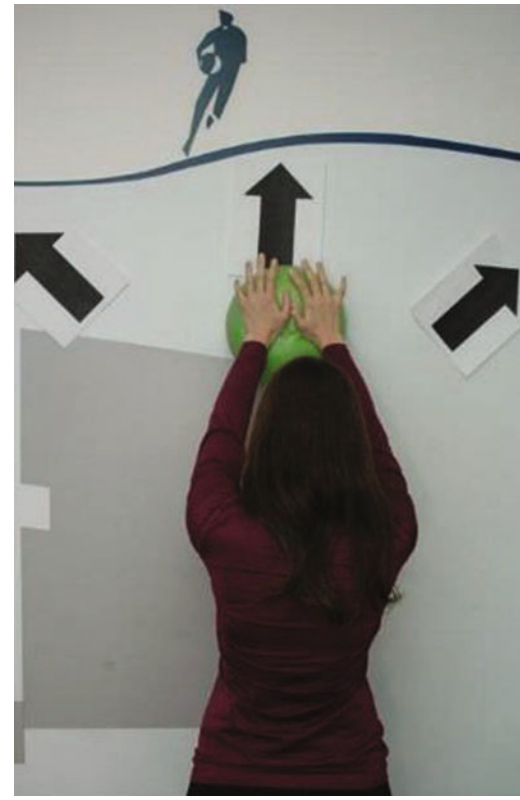

Fig. 54.1 Ball roll on wall diagonals. Exercise utilized during phase II of rotator cuff rehabilitation

leys and found no differences in functional scores or range of motion. They concluded that initiating pulley exercises during this phase did not result in inferior outcomes and therefore likely safe to utilize. As noted previously, aquatic exercises are often utilized during this phase as another active assisted environment. Around the eighth week mark, many providers will also begin rotator cuff submaximal isometric exercises and active motion exercises for shoulder abduction and flexion in the scapular plane focusing on slow, purposeful movements. Active range of motion (AROM) without resistance is generally acceptable as long as AAROM is progressing and pain free. Again, it is difficult to generalize a specific criterion for moving on to the next phase, but most authors propose that patients ought to have full functional range of motion before graduating from phase II. This has been described as 120° forward flexion, 45° extension, 130° abduction, 115° adduction, 60° external rotation, and 100° internal rotation [72].

54.5.3 Phase III: Progressive Resistive Phase

After obtaining full active shoulder range of motion, patients progress to the third phase of rehabilitation which generally takes place around weeks 12 through 16. The focus of this phase is to maintain full and painless active and passive range of motion at the shoulder while working toward dynamic shoulder stability, gradual restoration of strength and endurance, optimizing neuromuscular control, and returning to functional activities. Patients should still avoid sudden motions and activities, as well as lifting anything heavier than 5 lb. Dynamic shoulder stability is the ultimate goal during this period, and this is typically achieved by introducing dynamic stabilization exercise and a strengthening program, as long as the patient has regained sufficient kinematic and soft tissue compliance so as not to stress the repair site.

Strengthening typically begins with isometric exercises of the periscapular muscles, deltoid, and trapezius and then progresses to more elastic resistance exercises with high repetitions and low to moderate resistance. This is usually initiated with light resistance bands or light dumbbells. It is important to understand the specific shoulder positions that isolate the various muscles when planning the strengthening portion of rehabilitation programs as maintaining normal kinematics is important to restore the native force couples and biomechanics of the glenohumeral joint. Several studies have looked at this and have guided exercise selection. Based on MRI studies that looked at muscle signal intensity with different exercises, side-lying abduction showed greatest signal in supraspinatus, subscapularis, infraspinatus, and deltoid muscles [73]. They also showed that abduction in the plane of scapula with internal rotation had the second highest signal for supraspinatus, subscapularis, and infraspinatus and the greatest increased signal in the trapezius, but there was more subacromial impingement noted [73].

As a result of these studies and empirical evidence, a general rehabilitation program will incorporate various exercises at this phase including external and internal rotation with therabands or sport tubing, external rotation while lying on their side, and lateral raises. Some authors will add closed-chain exercises for proprioception and strengthening [74]. Prone full can exercises (thumb up) in the scapular plane which target the lower trapezius are begun in addition to prone rowing [75], prone horizontal abduction, prone extension, and resisted elbow flexion/extension. A few of the common exercises we use at our

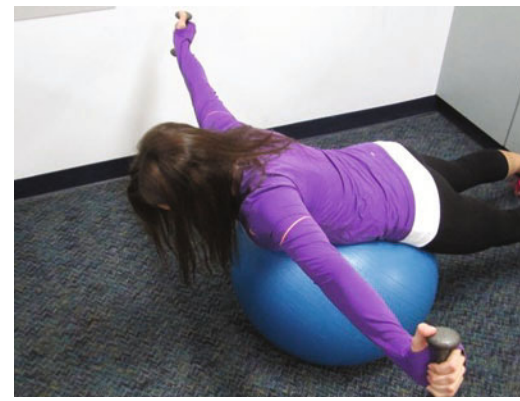

Fig. 54.2 Prone over Swiss ball with upper extremity T lifts. Exercise utilized during phases III and IV of rotator cuff rehabilitation

Fig. 54.3 Prone over Swiss ball with upper extremity Y lifts. Exercise utilized during phases III and IV of rotator cuff rehabilitation

institution beginning in phase III include prone over Swiss ball exercises with upper extremity T and Y lifts demonstrated in Figs. 54.2 and 54.3, respectively. Most rehab programs will avoid any exercise with arm above the level of the shoulder due to impingement [11]. Around week 12, patients may initiate light functional activities and then fundamental shoulder exercises around the 14th week.

54.5.4 Phase IV: Return to Sport/ Function Phase

Postoperative weeks 16 through 26 and beyond typically mark the fourth and final phase of rotator cuff rehabilitation. This period is characterized by advanced strengthening and gradual return to work, recreational, and sporting activities depending on the patient characteristics and goals. Progression of closed-chain exercises such as push-up advancement is often emphasized, as well as plyometric activities which further strengthen the scapulothoracic musculature [76]. If shoulder motion is tight at this point, self-capsular stretching becomes an important modality in addition to further strengthening and advanced proprioceptive activities. Many programs will begin to incorporate sport-specific exercises during this period. These are typically light activities, such as golf chipping or putting, which act to simulate the activity in what is sometimes referred to as an interval sport program. The criteria often used to determine return to sport or full activity are fully functional range of motion, no pain or tenderness, and satisfactory strength on examination.

54.6 Conclusion

This chapter serves as a general overview for the current best practice in postoperative rehabilitation protocol following rotator cuff repair. While there are still some discrepancies on the introduction of certain modalities and exercises, the protocol laid out in this chapter represents the general underlying progression of therapy based on the current literature and our knowledge of rotator cuff tendon healing. With consistently elevated retear rates, more prospective studies are needed to further tailor these protocols and optimize postoperative outcomes. In the end, postoperative rehabilitation will always be a dynamic process with balancing of patient and surgical risk factors, functional goals, and constant communication between surgeon, patient, and therapist.

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55 Postoperative Rehabilitation: Return to Sport in the Noncompetitive Athlete

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Rotator cuff disease is frequently tied to tissue degeneration related to advancing age, with a higher prevalence in individuals between 40 and 60 years [1].

The cause of rotator cuff tear is usually degenerative in elderly subjects and traumatic in younger patients [2]. Athletes are especially at risk, in particular those who practice overhead or forced overhead sports (tennis, golf, baseball, basketball) and contact sports (rugby, American football, ice hockey) [3].

When lesions are symptomatic, conservative treatment is typically recommended. In some cases, it is not possible to reduce symptoms and regain function without surgical treatment. The main goals of surgical procedures for rotator cuff repair (RCR) are to restore function and reduce pain.

The healing process of collagen tissues usually occurs between 1 and 60 days after injury, with final fiber maturation occurring up to 360 days. The initial phase is inflammation (1–3 days postoperatively), followed by proliferative or tissue repair phase (3–20 days). Fibroblasts initiate collagen synthesis in the repaired tissue, and this healing tissue begins to strengthen the sutured site. The healing tissue is remodeled through gentle stress. In the first 3 weeks after surgery, the suture performed can only withstand minimal stress due to the weakness of the healing tissue. The rehabilitation program in this initial stage of healing should be focused on pain relief, minimize inflammation, increase scapular control, and prevent postoperative complications. Between 21 and 60 days, the healing tissue becomes progressively stronger and more responsive to remodeling. Therefore, moderate stress should be applied to the joint. Peak remodeling should occur between 1 and 8 weeks [4, 5].

Physiotherapy after RCR plays a fundamental role, as it facilitates the recovery of strength and function. The great question regarding rehabilitation refers to the ideal moment to start rehabilitation that should initiate and develop the ROM (range of motion) gain and muscular strengthening of the cuff rotator, without disturbing the healing process. Re-tearing and stiffness are troubling complications and may be related to when the ROM gain begins [6–10]. The current literature suggests that early movement improves ROM after RCR but with a higher risk of re-tearing the rotator cuff [10, 11].

Patients with calcific tendonitis, adhesive capsulitis, partial articular supraspinatus tendon avulsion (PASTA)-type repair, concomitant labral repair, and single-tendon RCR are at the greatest risk for stiffness development [6].

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Parsons et al. evaluated 43 patients in these conditions and hypothesized that a later start to rehabilitation after RCR can contribute to stiffness of the shoulder. The sling was used for 6 weeks, and passive ROM exercises were performed between 6 and 12 weeks and active ROM exercises after 12 weeks. Patients who presented <100° of flexion and <30° of external rotation up to 8 weeks postoperative (PO) were considered at risk of stiffness (23% of total). However, after 1 year of surgery, there were no differences in ROM between the stiff and nonstiff groups. The authors believed that slowing ROM gain in the first few weeks after the operation does not encourage stiffness, even in those who exhibit some initial ROM resistance [12].

Restoring motion, strength, and function requires a proper rehabilitation program to maintain the integrity of the rotator cuff. A very slow physiotherapy program tends to promote stiffness, but an overly aggressive approach can result in recurrent rupture [13].

We believe that the best indicator for the initiation of ROM gain and strengthening of RCR is related partly to the size of the lesion, the tissue healing time, and mainly the stability of the tendons after surgery. The conditions of preexisting tissue and the stability reached after surgical repair are the main factors that guide physiotherapy. Lesions can eventually grow large, but when they reach satisfactory stability in surgery, early mobility can be achieved.

Some informations, which a physiotherapist should know before starting rehabilitation, can help during the onset and progression of physical therapy. One of the factors that guides the immobilization time is *the surgical approach*; in some cases, the sling is needed for a greater length of time, resulting in cicatrization of the subscapular tendon or the deltoid muscle (in open surgeries). Other examples include the *size of the tears*, *fixation method utilized* (more or less stable), *location of the lesion* (whether each tendinous region involved in the repair allows certain movements, as in the case of subscapular repair that requires caution in the gain of external rotation), the *timing of surgery* (related to the risk of joint stiffness), *surrounding tissue quality* (which will guide the volume and intensity of the exercises), and *individual characteristics* (age, health habits, lifestyle, activity level, type of professional activity, and type of recreational and/or sports activity because exercises should be customized to the personal function and activities of each patient) [14].

With this information in hand, the physiotherapist can start the treatment without risk of re-tearing. Close communication between the surgeon, the patient, and the physiotherapy team is important and should be maintained throughout the recovery process.

In Brazil, a variation of post-RCR physical therapy programs exist due to the immense size of the country, which sometimes hinders the exchange of information among professionals. Access to information and the personal experiences of surgeons and physiotherapists is not uniform in all states.

Tables 55.1 and 55.2 contain detailed information on our guidelines, which were developed based on scientific evidence, tissue healing time, and the professional experiences of surgeons and physiotherapists. Table 55.1 describes the guidelines for small and/or medium lesions with stable repair, and Table 55.2 describes guidelines for large and/or medium lesions with unstable repair.

These guidelines serve as a basis for conducting physiotherapy, but the individual characteristics of each patient should be respected, and the program should be personalized. Each phase covers patient guidance, period of initiation and progression of ROM gain, initiation of strengthening, and functional exercise activities for daily living and sports.

55.1 Specific Concepts of Rehabilitation

55.1.1 Guidance

Like other authors [15, 16] we believe patient orientation and adherence to treatment are the most important points in rehabilitation. Patients

Table 55.1 Rehabilitation guideline RCR for small or medium lesions (stable repair)

Phase	ROM	Active exercises	Strengthening	Functional exercises
Phase I (3–6 weeks)	Passive elevation 90° ER 45° (0° ABD)	Active exercises elbow, wrist (avoid elbow flexion, supination strength if biceps repair or tenodesis until 8 weeks) Scapulothoracic mobility Trigger points relief Hydrotherapy if available	NO	Functional activities/ ADL guidance
Phase II (7–10 weeks)	Elevação, flexion 130° (PROM, AAROM) Flexion AROM (8 weeks) ER (0° ABD) progressive ER 45° (45° ABD) IR abduction (8 weeks) IR hand on back (8 weeks)	Slide table ER with cane Flexion supine position (8 weeks) Scapular punched supine position (8 weeks)	Isometric, isotonic scapular for stability Isotonic biceps Isometric light RC, deltoids (0° ABD) 8 weeks Flexion side position (if possible) 8 weeks Extension prone position ER side position (if possible) 8 weeks	Proprioception at ranges below 60° if possible (8 weeks)
Phase III (11–14 weeks)	Progressive flexion, elevation ER progressive (45° de ABD) ER (90° de ABD) Extension progressive	Slide wall Flexion, elevation, ER active progressive	Isotonic light for all muscles (below 90°) Flexion standing light weight (below 90°) Scapular exercises progressive Press up wall	OKC, CKC (especially athletes) Functional activities emphasize on elderly
Phase IV (15–20 weeks or more)	ROM without restriction	Without restriction	Isotonic progressive all muscles Flexion standing progressive weight Push up, push up plus, hug dynamic (if necessary) Standing scapular punched ABD horizontal (if necessary)	OKC, OKC progressive Plyometric if necessary (16 weeks) Training motion sport (16 weeks) Return sport without throwing (20 weeks) Return sport (24 weeks)

ER external rotation, *ADL* activity of daily living, *PROM* passive range of motion, *AAROM* active-assisted range of motion, *AROM* active range of motion, *ABD* abduction, *IR* internal rotation, *OKC* open kinetic chain, *CKC* closed kinetic chain, *ROM* range of motion

must respect the use of the sling, perform home exercises and follow the guidelines for daily activities as prescribed by the multiprofessional team.

The patient's expectations are often unmet because he or she has not understood the information about the surgery and the postoperative plan. Poor patient satisfaction after RCR is related to persistence of pain and dysfunction, among other complaints [16]. These clarifications can easily be made before and after the procedure.

55.1.2 Pendulum Exercises

Pendulum exercises can be potentially dangerous after RCR if performed incorrectly. Poor performance of this exercise can cause more than

Table 55.2 Rehabilitation guideline RCR for large or medium lesions (unstable repair)

Phase	ROM	Active exercises	Strengthening	Functional exercises
Phase I (6–10 weeks)	Flexion, elevation PROM, AAROM 130° ER (0° ABD) progressive	Active exercises elbow, wrist (avoid elbow flexion, supination strength if biceps repair or tenodesis until 8 weeks) Trigger points relief Scapulothoracic mobility Slide table ER with cane Hydrotherapy if available	*No*	Functional activities/ADL guidance
Phase II (11–14 weeks)	ER (45° ABD) IR abduction IR hand on back Extension (12 weeks)	Slide table ER with cane Flexion active supine position Scapular punched supine position	Isometric scapular for stability Isotonic biceps Isometric light RC, deltoids (0° ABD) Flexion side position (if possible) ER side position (if possible) Extension prone position (if possible)	Proprioception at ranges below 60° (if possible) emphasize functional activities
Phase III (15–20 weeks)	ER progressive (45° ABD) ER (90° ABD) Progression of other movements	Slide wall Active ER, flexion, IR progressives	Isotonic progressive for all muscles Scapular exercises progressive Press up wall and floor (if necessary) Horizontal abduction (if necessary)	CKC, OKC progressive Functional activities emphasize on elderly
Phase IV (20–24 weeks)	ROM without restriction	Without restriction	Isotonic progressive all muscles Flexion standing progressive weight Push up, push up plus, hug dynamic (if necessary) Standing scapular punched ABD horizontal (if necessary)	OKC, OKC progressive Plyometric if necessary Training motion sport Return sport without throwing (24 weeks) Return sport with throwing (28 weeks)

AAROM active-assisted range of motion, *ER* external rotation, *ABD* abduction, *ADL* activity of daily living, *IR* internal rotation, *CKC* closed kinetic chain, *OKC* open kinetic chain

15% of maximal voluntary isometric contraction (MVIC) of the supraspinatus and infraspinatus muscles. Significant activation of these muscles occurs even when performed correctly [17]. Therefore, we do not recommend this exercise in our RCR guidelines.

55.1.3 Sling

The surgeon, who is knowledgeable of the tissue conditions during surgery and the level of stability during repair, should determine how long the patient should wear a sling. Vieira et al. asked

78 shoulder surgeon specialists in the Brazilian Congress of Shoulder and Elbow Surgery the following question: What is the recommended time of immobilization after arthroscopic shoulder surgery? 4.3% of participants indicated early mobilization, 8.7% indicated less than 3 weeks, 67.4% indicated between 3 and 6 weeks, and 19.6% answered that the onset of mobilization depends on the lesion found. We agree that the ideal immobilization time is approximately 3 weeks for small to medium lesions with stable repairs and 4–6 weeks for large to medium lesions with unstable repairs [1].

55.1.4 Modalities

We used cryotherapy three to four times a day in the first 2 weeks postoperation [18] and two to three times in the subsequent period until pain decreased. The application of neuromuscular electrical stimulation was used in cases of acute pain.

55.1.5 ROM and Strengthening

We based ROM gain on Edwards et al. study, which conducted a systematic review on the identification of which passive, active-assisted, active, and strengthening exercises required more or less involvement of the supraspinatus and infraspinatus muscles. Forty-three exercises were analyzed with EMG, which determined the MVIC of each of them. Exercises with a maximum MVIC of 15% were considered low demand; MVICs between 15% and 20% were low-moderate; MVICs between 21% and 40% were moderate; MVICs between 41% and 60% were high demand; and an MVIC of 60% or higher was very high demand. The studies included in the review were conducted with healthy individuals; we should not extrapolate the results to individuals with RCR, because details such as lesion size, quality and integrity of the tendon, type of surgery, repaired tissue conditions, stability achieved in repair, age, and health habits directly interfere with tendon resistance to muscle contractions [8]. However, we have not identified studies evaluating rotator cuff MVIC in RCR subjects. We believe that studies of this nature can serve as a guide in the establishment of these standards. Figures 55.1, 55.2, and 55.3 illustrate MVIC exercises below 15% and above 50% for the supraspinatus, infraspinatus, and subscapular muscles, respectively.

We orient the recovery of ROM in the abduction position with extension and especially with internal rotation (Fig. 55.4), after

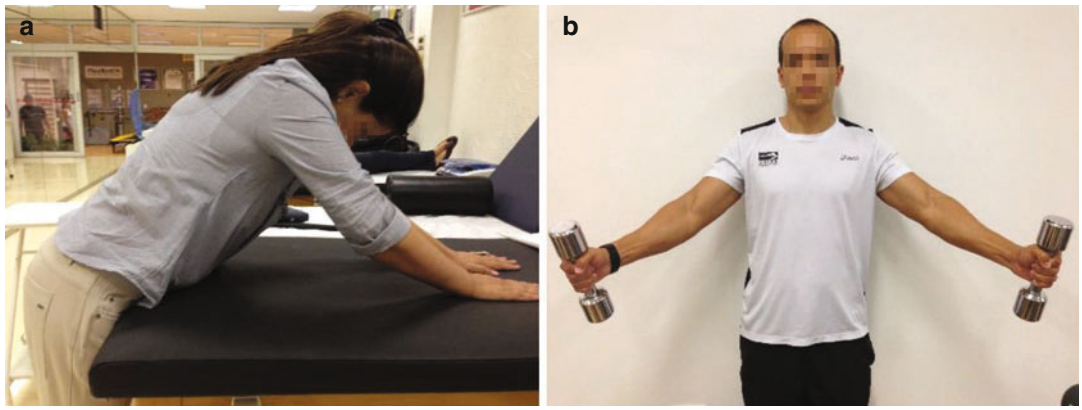

Fig. 55.1 (**a**) Slide table (MVIC <15% supraspinatus). (**b**) Full cam shoulder ABD (MVIC >50% supraspinatus)

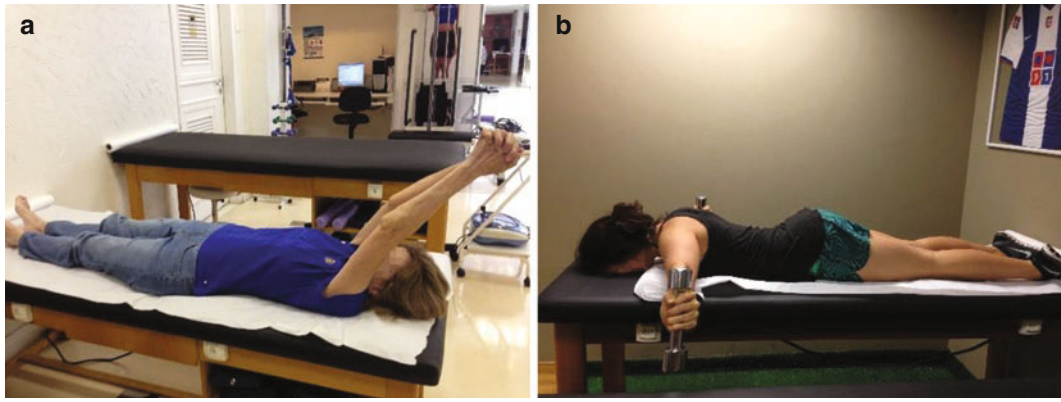

Fig. 55.2 (**a**) Supine self-assisted elevation (MVIC <15% infraspinatus). (**b**) Prone horizontal ABD 90° (MVIC >50% infraspinatus)

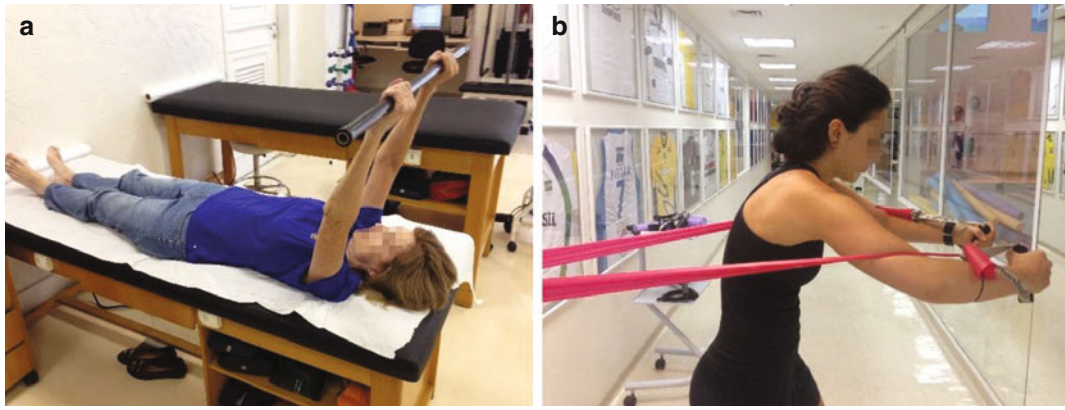

Fig. 55.3 (**a**) Pulley-assisted elevation (MVIC <15% subscapular). (**b**) Dynamic hug (>50% MVIC subscapular)

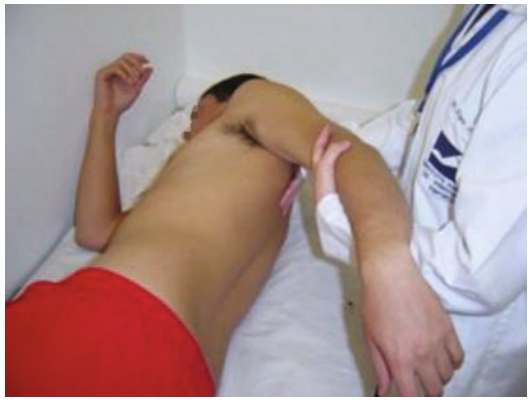

Fig. 55.4 Extension with abduction that promotes tension in the supraspinatus muscle

10–12 weeks of PO, because this position causes a significant increase in tension in the rotator cuff [9, 19].

55.1.6 Activation and Strengthening of the Scapular Muscles

The rotator cuff functions to promote co-contraction, to lower the humeral head, and to promote shoulder movements. These movements cannot occur if the scapula does not maintain the axis of rotation in the glenohumeral, allowing for optimal performance of

the rotator cuff. When the scapula does not perform the support role for the movements of the humerus, the result is a condition defined as scapular dyskinesis [20]. In the presence of dyskinesis, the combination of anterior tilt, internal rotation, and upward rotation of the scapula is common during arm elevation, as opposed to the expected movement of posterior tilt, external rotation, and upward rotation [21]. The three-dimensional scapular movement is necessary to maintain the subacromial space throughout the movements.

Dyskinesis is a common condition observed in individuals with or without injury [22–24]. In postoperative situations, the shoulder is expected to present scapular activation deficits; these should be minimized until the treatment is completed. In our experience, even after 6 months of physical therapy, scapular dyskinesis is common even in patients who have performed well in the exercises. We argue that these individuals may have had some altered scapular patterns for chronic lesions or individual biomechanics, prior to the procedure.

Scapular performance is predictive of rotator cuff activity at various shoulder positions. For this reason, scapular training is considered one of the pillars of shoulder rehabilitation.

Activating the scapular muscles requires multiplane exercises, following an ascending order of difficulty and performance. Once the patient performs an exercise satisfactorily, the difficulty of training can progress. Strengthening the rotator cuff muscles requires good posture of the body and, consequently, of the scapula. This demonstrates that muscle groups are trained together rather than in isolation, even though some of them may be activated more easily in certain positions.

The important muscles that should be focused on are the anterior serratus and lower and medium trapezium to prevent the scapular dyskinesis (Figs. 55.5 and 55.6). The power of these muscles and superior trapezium keeps the correct scapulohumeral rhythm [25–28].

Fig. 55.5 Strengthening of the anterior serratus in closed kinetic chain

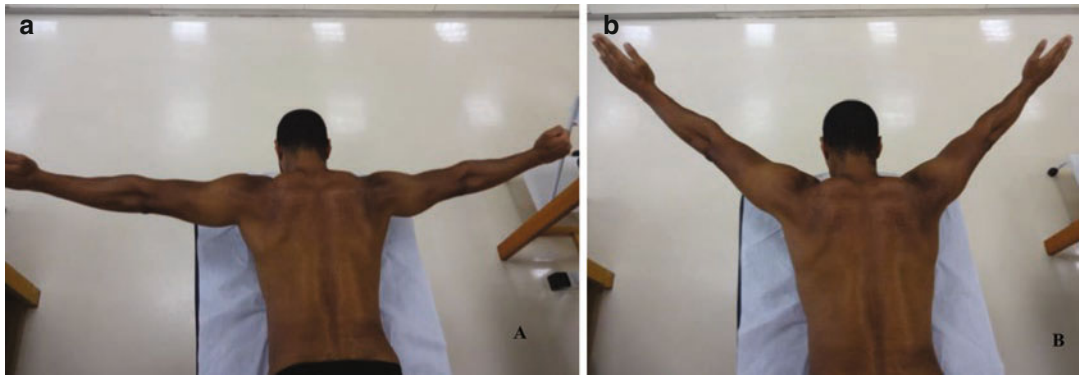

Fig. 55.6 Trapezium strengthening medium fibers (**a**) and lower fibers (**b**)

55.2 Sensory-Motor Training, Advanced Strength, and Return to Activity

After surgical intervention, the functional rehabilitation program is vital for the return of normal shoulder function. Regaining a joint's sense of position and neuromuscular control requires training. Functional rehabilitation is believed to increase sensitivity and facilitate the coactivation of the afferent responses of the capsuloligamentous and musculotendinous receptors, and reactive muscular contractions [29]. Functional exercises include open kinetic chain (OKC) and closed kinetic chain (CKC), allowing the reproduction of movements and postures from daily life as well as sports activities.

The final phase of rehabilitation consists of overhead strengthening, progressing endurance, advanced closed chain, proprioceptive, and plyometric exercises. Based on the functional status and strength achieved at this point postoperatively, patients may or may not be appropriate for this phase of rehabilitation. The physical therapist should focus on specific functional requirements based on strength deficits [30].

OKC exercises with ball-throwing movements are included, in addition to CKC exercises that simulate falls and movements on the ground. In both cases, the CORE activation is needed to maintain the correct muscular activation sequence and transfer and dissipate energy in the kinetic chain [31, 32].

The diagonal exercises are used to strengthen the muscles (Fig. 55.7). The diagonal D1 in the flexor pattern (acceleration) and extension (deceleration) activates the rotator cuff, scapular waist, and deltoid muscles, which is important to improve the coactivation of the intra-articular power couples [33, 34].

The sensory-motor training is an important part of the program. The lack of shoulder stability increases the need of the sensory-motor system for neuromuscular control. The feed forward and feedback mechanisms are considered as critical points of the kinetic chain, making their training extremely important for the prevention of lesions [35].

Fig. 55.7 Diagonal exercise (D1)

Plyometric training is also included, which facilitates the increase of excitability of the neural system and the reactive capacity of the neuromuscular system of healthy athletes shoulders (Figs. 55.8 and 55.9). This training includes the eccentric movement that produces elastic energy and transforms this accumulated energy into kinetic energy, which is transferred to the concentric phase using the shortening-strengthening cycle [36–38].

The return to the sport should be done gradually. The Advanced Throwers Ten Exercise Program [39] can be included. This program consists of exercises that restore muscle balance and symmetry in the overhead-throwing athlete, which is necessary for the symptom-free return to sports after lesion. Specific exercises for the sport of each patient can be used [40], as in the figures. The Brazilian shoulder surgeons agreed in relation to the time taken to return to sports (>6 months) [1].

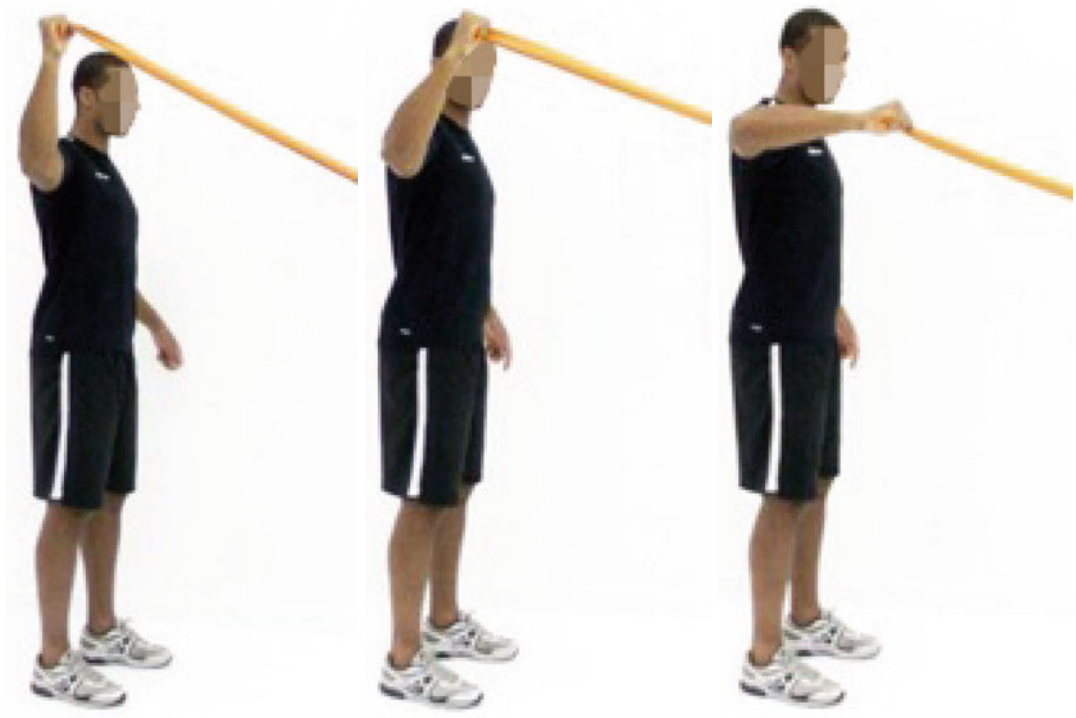

Fig. 55.8 Plyometric exercise in external rotation

Fig. 55.9 Plyometric exercise in internal rotation

55.3 Criteria to Return to Sports

Clinical decision-making for determining the successful completion of a rehabilitation program and thus safe return to activity can be challenging. There is no consensus on treatment or timing to return to play. Is a general practice, concurrent with most studies, athletes are allowed to return to play when they can demonstrate symmetric range of motion and strength and perform sport-specific exercises without pain and limitations.

Measures of strength, mobility, resistance, or pain do not necessarily translate into the patient's ability to perform a specific movement, such as the sporting gesture. However, these measures are used to as criteria of return to sport.

Clinicians have some instruments to assist them in making discharge and return to activity decisions, with most clinicians opting to use

some variation of a strength measure as a means of determining cessation of treatment or activity readiness [41]. The strength test identifies possible deficiencies and assesses safe progress in rehabilitation.

Routinely, the manual muscle testing is applied during the rehabilitation to identify strength deficits and strength imbalances. In conditions where neurological integrity is compromised, manual muscle testing may have clinical value. However, manual muscle testing may not have robust value as an individual evaluation tool for musculoskeletal injury with an absence of nerve injury or neurological dysfunction [41].

Isokinetic evaluation of IR and ER strength can help determine a functional-strength profile in patients suffering from shoulder disorders to guide diagnosis, therapy, and rehabilitation [42].

Due to the absence of a gold standard of assessment for upper extremity physical performance [41], clinicians will often utilize some variation of strength testing because force is a basic component for the execution of fundamental physical tasks. Furthermore, strength testing is for identifying potential impairments and assessing progress in the secure rehabilitation setting; it has been recognized that single-component physiological measurements of strength, mobility, endurance, or pain do not necessarily translate to a patient's ability to perform a highly skilled dynamics task [43].

Evaluation tests of the upper limb are used in clinical and sports practices to provide important information about functional performance. Specifically, dynamic tests, whether in an OKC (pull-up, throwing test, and shot putting) or CKC (one-arm hop test, upper quarter Y-balance test, and the closed kinetic chain upper extremity stability test), enable not only the identification of possible deficits in strength and muscular power but also to evaluate proprioception and motor control [44–47].

These instruments have a low cost of application; are portable, easy, and quick to administer; and provide an immediate result which contributes to the use in clinical practice. However, the clinical measurement properties of these tests should be better evaluated for individuals with rotator cuff lesions.

55.4 Considerations

One of the main expectations of athletes, whatever their age or level of play, is to return to sports after treatment, if possible at the same level as before injury. This is especially true of professional and competitive athletes [48].

In their systematic literature review, Plate et al. [3] found 83.3% of the patients returning to competitive sports with a mean of 8.6 months after the intervention out of 124 recreational athletes (sports using the upper limb above the head) who underwent arthroscopic debridement or either arthroscopic or open cuff repair.

Klouche et al. [48] in their meta-analysis included 25 studies, with 859 patients (683 athletes) all treated surgically (arthroscopic debridements, arthroscopic repairs, repairs by minimally invasive approach, and open surgery). Although their results do not differentiate the type of treatment performed, it showed that the overall rate of return to sports was 84.7% with 65.9% of participants returning to play at the same level after between 4 and 17 months. However, if considering only professional and competitive athletes, the returned to play at the same level as before their injury was 49.9%.

Vives et al. [49] found 89.7% of patients who underwent open acromioplasty and rotator cuff repair and arthroscopic acromioplasty and mini-open repair returning to nonprofessional golf at the same level as their pre-lesion level, but with a weekly intensity significantly reduced.

Sonnery-Cottet et al. [50] evaluated 51 amateur tennis players with rotator cuff repair (open repair and arthroscopic debridement), found 78.4% of the patients returning to sport at a mean 9.8 months after surgery at an identical or better level at the last follow-up in 77.5% of the cases, and not found difference in the ability to return to tennis between types of surgery.

Studies evaluated patients with arthroscopic rotator cuff repair who participating in a recreational sport soliciting the shoulder showed better results. Antoni et al. [51] found 88.6% of the returned to the same sport: 91.7% of the golfers, 88.9% of the tennis players, and 76.9% of the swimmers. Liem et al. [52] found better results in their study when they evaluated recreational

athletes who undergone arthroscopic repair with 100% of the patients returning to sports at a weekly frequency and duration identical to their preoperative activity.

Bathia et al. [53] assessed a series of 31 recreational sports patients over 70 years of age operated for arthroscopic rotator cuff repair, and they noted that 77% of these patients returned to their sport at the same level. However, older individuals have characteristics that can make rotator cuff repair more challenging and contribute to the worst outcomes after surgery: higher prevalence to massive rotator cuff tears compared with younger patients [54], decreased bone quality, lamellar dissection, and fatty infiltration are more common [55], and healing may be impaired by poor blood supply, as histologic examination of rotator cuff tendon tissue has shown decreased vascularity in older patients [56].

There is a contrast between the recreational and the professional athlete in the literature regarding treatment of complete rotator cuff tears. Return to sports has been far more difficult for professional overhead-throwing athletes. High-level athletes who experience rotator cuff tear have a dramatically inferior prognosis for returning to sports compared with recreational athletes.

This is an important information because it shows that a professional player cannot rely on surgical repair of the rotator cuff to return him to a sports career at the same level. Although many patients do not return to play at the same level, the results of the studies in terms of pain relief or range of motion are almost all very good [48].

One of the hypotheses to explain this is that psychological factors, such as fear of another injury or loss of confidence in the shoulder, are usually not evaluated even though they may influence the return to sports [48].

Analyzing failures of the rotator cuff repairs, studies have suggested risk factors for a poor functional outcome: degenerative origin [57], work-related injuries [58], full-thickness tears [49, 58–60], associated labral injuries [57, 61, 62], and late surgery [63]. According to the literature, the risk factors of returning to sports at a lower level of play are professional athletic status [60, 63] and a delayed return [50].

According to a systematic review published by Ejnisman et al. [64], no studies with a high level of evidence have demonstrated what the best approach should be, in dealing with rotator cuff injuries.

Several limitations can be observed in the studies related of the return to sport. The first is the low level of evidence of the studies. We were unable to look for risk factors of not returning to sports, because most of the authors proposed a hypothesis [48]. Most of the studies do not mention the postoperative treatment performed or cite poorly. There is little information about how the return to the sport was made and what criteria were used.

55.5 Conclusion

Our objective was to provide guidelines and instructions for rehabilitation teams to administer efficient treatments after RCR. These guidelines are not intended to replace decision-making with regard to clinical treatment or the progression of a patient's postoperative course. The rehabilitation program must be adapted to the particulars of the case and the reality of the service. We base our protocol on tissue healing time, surrounding tissue quality conditions, and repair stability at the same time that movement, strength, and function are reestablished.

The return to sports in the postoperative of the rotator cuff is still a challenge for clinicians. Decision-making involves several factors, from the type and extent of the injury, the type of surgery, and the rehabilitation process performed.

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Outcome Measurement Tools for Rotator Cuff Disease

56

Guillermo Arce, Juan Pablo Previgliano, Enrique Salas, and Francisco Arcuri

56.1 Introduction. Why Do We Need Them?

Peter Drucker, known as the father of management, coined the statement "If you can't measure it, you can't manage it, if you can't manage it, you can't improve it."

There are many reasons why orthopedic surgeons need well-designed outcome measurement tools. The first motivation is scientific. Levels of evidence have been formulated, allowing publications to be ranked or given a certain grade of recommendation. The highest level of evidence is assigned to randomized clinical trials, while systematic reviews of high-quality trials are also quite valuable. Proper studies require good design and use of validated outcome scores. The use of these measures allows comparisons between studies. If the scores are either modified or used on inappropriate groups of individuals, such comparisons are flawed.

The second reason for using optimal outcome tools is to determine the clinical value of any given medical treatment or surgical procedure. Such role is typically related to results and cost. In many countries, outcome data represents an essential factor to obtain coverage. Hence, we are encouraged to implement evidence-based strategies for achieving the best care for our patients.

One of ISAKOS missions is to promote education and research around the world. The goal of this chapter is to describe the currently available scoring systems for characterization of rotator cuff disease. We hope this chapter will help readers select the most suitable scoring tools for their current or future research projects.

56.2 Types of Scores

Objective physician assessment often weights into subjective patient-reported outcome evaluations. The latter is usually due to an inherent bias during clinical evaluation, in which the physician disregards the patients' perception of their result. The scores can be either patient-based, physician-based, or a combination of both, while the latter are most often used. There are condition-specific scores such as the Western Ontario Rotator Cuff Index (WORC) [1] or the Rotator Cuff Quality of Life (RC-QOL) [2] and non-condition-specific scores like the Simple Shoulder Test (SST) [3]. Additionally, there are diverse score types depending on the weight of each section or domain.

According to Harvie et al. [4] who reviewed 610 articles relating to shoulder surgery, a total of 44 different outcome scores were found. Twenty-two of them were physician-based (50%),

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21 patient-based (47.7%), and only 1 combined both types (2.3%). Of note, in only 8 (2.7%) occasions, the authors explained the score rationale.

In recent years, there has been a proliferation of patient-based outcome scores, recognizing the benefits of such tools compared to physician-oriented ones. As previously mentioned, physician-based outcomes tools are prone to bias and error and may not represent the patient's view, whereas patient-based scores can be used in clinical trials and may be valid for comparing and aggregating cohort studies. The use of patient-based outcome tools will directly improve levels of evidence, but many of them have not been properly tested for reliability, validity, repeatability, and sensitivity to change. The minimal important clinical difference (MCID) is one of the main features of each scoring system. Investigators planning clinical trials should select instruments that have been developed with appropriate patient input for item generation.

56.3 Published Scoring Systems for Rotator Cuff Disease

In 1992, Christian Gerber was one of the first to integrate scoring systems for the functional assessment of shoulder girdle [5]. Four years later, Romeo et al. [6] reported a scoring system for shoulder conditions.

On behalf of the ISAKOS Scientific Committee, Kirkley et al. [7, 8] reviewed the most commonly used shoulder scoring systems. Then, the authors developed and validated various Western Ontario measurement tools including the WOSI (for instability), the WOOS (for osteoarthritis), and the WORC (for rotator cuff disease).

More recently, Schmidt et al. [9] reported a systematic review of specific shoulder reported outcome measures. The authors concluded that the American Shoulder and Elbow Surgeons Score (ASES), the SST, the WORC, and the Oxford Shoulder Scores (OSS) bear high reliability, validity, responsiveness, and interpretability while having low administrative burden. The American Academy of Orthopedic Surgeons (AAOS) also recommends the ASES and the OSS for the evaluation of rotator cuff pathology.

Table 56.1 Guidelines for language translations and cross-cultural adaptations

1. Translation	Translation from English by two independent persons (informed and uninformed). Native language # 2
2. Synthesis	Fusion of the two translated versions resolving any discrepancies
3. Back translation	Back translation into English. Two native English. Language # 2 as a second language. Third person clarify concepts
4. Expert committee review	Pre-final version reviewed by an expert committee
5. Pre-testing	Pre-final version tested by 30 patients

Appropriate phrasing is essential to fully grasp the meaning of each questionnaire. Therefore, it is usually best to translate scores and validate them in each native language. The process of score translation to a certain language and to perform the transcultural adaptation needs five steps (see Table 56.1). We described below the commonly used scoring systems for rotator cuff disease.

56.3.1 The UCLA Shoulder Score

The University of California at Los Angeles Rating Scale was first published in 1981 by Amstutz et al. [10] for patients undergoing shoulder arthroplasty due to osteoarthritis. This system assigns a score to patients based on five separate domains: pain, function, active forward flexion, strength of forward flexion, and overall satisfaction. The weighting is such that pain accounts for 10 points, function for 10 points, forward flexion for 5 points, strength for 5 points, and overall satisfaction for 5 points, giving a total of 35 points. Items in this score were selected by the authors without direct patient input. Even though it has been widely used to report rotator cuff surgery outcomes, this tool has not been validated for either shoulder instability or rotator cuff treatment.

56.3.2 The Shoulder Pain and Disability Index (SPADI)

In 1991, Roach et al. [11] published the SPADI, a score with 13 items divided into two sub-scales: pain (five items) and disability (eight items). The response format selected for this tool was a 10 cm VAS anchored verbally at each end. The total score for this score is determined by averaging the scores for both domains: pain and disability. This score had limited validation and no responsiveness formally tested nor MCID data.

56.3.3 The ASES

In 1993, the Society of the American Shoulder and Elbow Surgeons developed a standardized form for the assessment of the shoulder function, including shoulder instability and rotator cuff disease [12]. This score combines both patient and physician-oriented assessment. Interestingly, only the patient-driven part of the questionnaire counts for the final score result.

The patient-oriented section has 11 items and it is divided into two areas: pain (one item) and function (ten items). The response to the pain item is marked on a 10 cm VAS, which is further divided into 1 cm increments and anchored with verbal description at 0 and 10 cm. The remaining ten items of the functional area include activities of daily living like putting a coat, lifting 10 lb above the shoulder height and throwing a ball overhand. Finally, there are two general items: doing everyday work and performing conventional sports. There are four categories for response options ranging from zero (unable to do) to three (not difficult). The final score is calculated by multiplying the pain score (maximum 10 points) by 5 (total possible 50) and the cumulative activity score (maximum 30) by 5/3 (therefore a total possible 50) for a total of 100.

The physician section, which does not count for the former result, includes physical examination and documentation of range of motion, rotator cuff signs, strength, and instability. No scores are derived from this section of this instrument. ASES is not disease specific, and its use in clinical trials may lead to poor responsiveness and validity. The MCID was determined to be 12/17 (100). The ASES score has been translated to many languages including Arabic, German, Italian, and Portuguese, among others [13–15]. After the validation of these translations, the instrument became more valuable as patients could answer in their native language.

56.3.4 The Constant Score

It is the most widely used in Europe for all shoulder conditions [16]. It combines physical examination tests with subjective evaluations reported by the patients. The subjective assessment consists of 35 points, and the remaining 65 points are assigned for the physical examination assessment.

Subjective assessment includes a single item for pain (15 points) and four items for activities of daily living (work, 4 points; sport, 4 points; sleep, 2 points; and positioning the hand in space, 10 points).

Objective assessment includes range of motion (forward elevation, 10 points; lateral elevation, 10 points; internal rotation, 10 points; external rotation, 10 points) and power (scoring based on the number of pounds of pull the patient can resist in abduction to a maximum of 25 points). The total possible score is therefore 100 points. The MCID is 10.4 (100).

This score system bears specific weight for each item (pain 15%, function 20%, range of motion 40%, and strength 25%), weighting more heavily on range of motion and strength. This tool may be useful for discriminating between patients with rotator cuff disease and osteoarthritis, but it is not useful for instability.

Katolik et al. [7] described a normalization of the constant score according to gender and age. The proposed formula is Raw Score/Normal Score × 100.

56.3.5 The Disabilities of the Arm, Shoulder, and Hand (DASH)

This tool was created by the AAOS [17]. The DASH is a 30-item questionnaire designed to

evaluate upper extremity-related symptoms and measure functional status at the level of disability. A major limitation of this tool is that the item-generation phase did not include interviews with patients with the conditions of interest. It has been well documented that physicians are poor judges of what is important for the patients and this tool is intended for patients with any condition of any joint of the upper extremity. Unfortunately, the broader scope of this tool makes it less attractive for use in clinical trials for rotator cuff disease.

56.3.6 The Shoulder Rating Questionnaire

In 1997, L'Insalata et al. [18] published this questionnaire that includes six separately sored domains with different weight: global assessment 15%, pain 40%, daily activities 20%, recreational and athletic 15%, and work 10%. The total maximum score is 100. Construct validation through correlations between this instrument and other measures of the shoulder function has not been determined.

56.3.7 The SST

In 1992, Lippitt, Harryman, and Matsen reported the SST (development and testing) [19], a 12-item questionnaire (yes/no responses). This tool combines subjective items and items that require patients' collaboration to perform active movements. Due to the dichotomous response options, the SST is unlikely to be sensitive enough for the detection of small but clinically meaningful changes in patient functions. In 2015, Arcuri et al. [20] published a validated Spanish version of this score that remains quite useful in Latin America and Spain.

56.3.8 The Oxford Shoulder Score

The Oxford Shoulder Score (OSS) [21] evaluates outcomes following shoulder surgery (excluding shoulder stabilization procedures), while a second iteration specifically focused on shoulder stability. Both scores have 12 items completed by the patients, rating the answers on a 1–5 scale. The best score is 12 and the worst is 60. Both scoring systems have been shown to be sensitive to changes in patient conditions and should provide reliable and valid information [7, 8].

56.3.9 The Western Ontario Shoulder Tools

In 1998, Kirkley [5, 6] published three disease-specific quality of life measure tools for the shoulder: the WOSI (in 1996) [8], the WOOS (2001) [22], and the WORC (2003) [1].

The WORC is a 21-item survey covering five domains in which the patient rates responses on a 100 mm line VAS-type response with 0 being the worst and 100 being the best. The domains are (1) pain and physical symptoms (six questions), (2) sports and recreation (four questions), (3) work function (four questions), (4) social function (four questions), and (5) emotional functions (three questions). Response to each question is measured in mm and totaled to a raw score. The WORC score is then calculated with the following formula:

$$\frac{2100 - \text{raw score}}{2100 \times 100} = \%\text{score}$$

The WORC has been validated in many languages and in patients with both surgical and nonsurgical treatments of rotator cuff tendinitis, tendinosis, partial-thickness tears, and cuff tear arthropathy [11]. Its MCID is 245.26 [11]. Thus, pre- and posttreatment scores must differ by at least 246 points to be derived a clinically meaningful difference. Measures of statistical significance must also be met. The WORC is easily administered in an office setting, or through post mailing or electronic emailing. Score data can easily be collected for later use.

56.4 Committee Consensus and Recommendations

Computer-based testing will inevitably play an essential role in the arsenal of tools used to evaluate patients with rotator cuff disorders. There are

currently a few Web sites for shoulder scores, and they do the automated cumulative sum formula. Two of them (www.orthopaedicscore.com and www.orthotoolkit.com) are mainly for printing, but the researcher can save the scores and data. These tools are extremely useful to record the consecutive preoperative and postoperative assessments of the surgically or not surgically treated shoulder conditions. Consequently, patients can be requested to fill these forms the best they can, and then the physician can print and save the final scores with all the patient data (baseline characteristics and clinical outcome).

Another excellent Web tool is the Surgical Outcomes System or SOS, a comprehensive network where the system sums the questionnaires of the several scores. In addition, SOS performed digital storage of patients' replies, enabling physicians to save their cases, while the system sends emails with questionnaires to patients every predetermined time. Then, the software can analyze the data and keep the surgeon informed about the patients' outcome with graphics and pies. As imagine, there are certain legal issues related to patient data privacy. Currently, the tool is only available in North America and some Europeans countries.

The Committee has evaluated all of the abovementioned scoring systems to measure outcomes based on the following criteria: (1) The system should be disease-specific to allow direct comparisons between patient pre-treatment and post-treatment states, (2) be primarily patient-completed, or at least divided into physician- and patient-completed responses, (3) include both general health and disease-specific outcome measures, and (4) be validated for reliability and responsiveness.

For clinical outcome assessment of rotator cuff disease treatment, the consensus recommends using the WORC, the ASES score, and the OSS. For a secondary measure of motion or strength, we recommend the Constant Score, as it has been reliably used in many studies following rotator cuff surgery.

This project was undertaken as a step of a worldwide organization, ISAKOS, to standardize outcome reporting of treatments in patients with rotator cuff disease. In this fashion, we should be able to directly analyze and compare more research and outcome reports and provide better treatments for our patients. These recommendations are not definitive and will likely need future modifications. However, thus far, the herein scoring systems are recommended as the best tools for research reporting.

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Part VII

Complication

Failed RC Surgery

57

Leland C. McCluskey Jr. and Felix H. Savoie III

57.1 Introduction

As primary rotator cuff repairs (RCR) are being performed more often, the prevalence of failed primary repairs within the population is increasing and will continue to increase, leading to a subsequent increase in the necessity for revision repairs [1, 2]. Revision rotator cuff repair presents a challenge to the surgeon due to both paucity and inadequacy of current literature as well as the technically challenging nature of the revision repair. The goal of this chapter is not only to present the current literature but to provide the reader with a conceptual basis with which to approach the re-torn rotator cuff.

A review of the literature for outcomes of both open and arthroscopic revision rotator cuff repair is presented in Tables 57.1 and 57.2. The articles reviewed encompass experience from 1984 through 2018 and include over 685 patients. There is a wide spectrum of outcome measures presented, including the ASES, UCLA score, healing rate, complications, VAS pain scale, SANE score, and range of motion (most commonly measured as forward flexion), but unfortunately there is not a single outcome measure which is used uniformly across the literature. Most of the literature reports improvement in these measures when measured both pre- and postoperatively, supporting the conclusion that revision rotator cuff surgery is a safe and worthy endeavor for patients with recurrent tears [6–8]. Postoperative imaging, a more objective measure, to determine the presence of re-tear or to assess healing was not uniformly performed in all studies. In a study by Sears et al., 25% of asymptomatic patients after revision were found to have a re-tear, while all eight patients who were clinically symptomatic had recurrence of a tear [9]. Kowalsky and Keener imaged 100% of their patients with ultrasound postoperatively, finding that only 52% had healed. Patients with involvement of greater than one tendon only healed in 27% of cases, while single-tendon recurrences healed 70% of the time [10]. Lädermann et al. found no difference in clinical outcomes when comparing massive vs. sub-massive tears, which is in contrast to the literature for primary repairs which has shown that massive tears are associated with poorer outcomes [7]. These findings confirm that more data is needed in order to improve operative technique and patient selection and to validate promising new technologies in the treatment of recurrent rotator cuff pathology.

57.2 Causes of Repair Failure

Symptomatic improvement after primary RCR can occur even in the absence of healing [11]; however, biologic *healing* of the repair is associated with

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Table 57.1 Comparison of demographic data from current literature

Study	Year of publication	Repair technique	Patients	Mean age in years	Massive tears (% of total)	Follow-up in months (range)
DeOrio [3]	1984	Open	27	52	29.6	46 (26–118)
Bigliani [29]	1992	Open	31	60	38.7	61 (25–180)
Nevaiser	1992	Open	50	54	42	30 (24–84)
Djurasovic	2001	Open	80	59	30	49 (25–110)
Lo	2004	Arthroscopic	14	58	79	23.4 (12–NA)
Keener	2010	Arthroscopic	21	56	NA	36 (24–50)
Piasecki	2010	Arthroscopic	54	54.9	7	31.1 (12–78)
Ladermann	2011	Arthroscopic	74	60.8	72	59 (24–120)
Hartzler	2013	Open	37	58 (41–80)	16	7 (1–49)
Parnes [4]	2013	Arthroscopic	94	52 (44–72)	54	NA (NA–12)
Chuang	2014	Arthroscopic	32	69.3	59	70.3 (13–165)
Sears	2015	Open	24	50.5 (37–70)	NA	50 (30–112)
Shamsudin	2015	Arthroscopic	50	63 (43–80)	NA	35 (19–45)
Skoff [5]	2015	Open	10	58 (47–65)	0	24 (12–44)
Petri	2016	Open	13	57 (26–68)	100	30 (24–48)
Mora	2017	Arthroscopic	51	60 (36–77)	23.5	25 (12–58)
Hohn	2018	Arthroscopic	23	60.1 (43–79)	NA	48 (25–71)

better overall outcomes [12]. A better understanding of how and why these repairs fail guides our treatment in the revision setting and improves our technique and strategy in the setting of primary repair.

Although most failures are multifactorial, George and Khazzam categorized failures into five categories: (1) surgical complications, (2) diagnostic errors, (3) technical errors, (4) failure to heal, and (5) traumatic failure [13].

57.2.1 Complications

Primary arthroscopic RCR has a complication rate of approximately 10% [14]. Complications associated with RCR include infection, stiffness, foreign body reaction, disruption of deltoid origin, and neurologic injury [13, 15]. These complications can cause continued postoperative pain and dissatisfaction but also may contribute to failure of the repair itself by increasing the tension and force across the repair site.

57.2.2 Diagnostic Errors

Undiagnosed concurrent pathology can lead to incomplete resolution of the patient's symptoms or in some cases worsening of symptoms. Concurrent pathologies such as biceps tendinopathy, suprascapular neuropathy, adhesive capsulitis, undiagnosed os acromiale, and cervical spine pathology are common reasons for shoulder pain which should have been addressed at or prior to primary repair. Overdiagnosis can also contribute to failure. A 2017 study by Erickson et al. reviewed an insurance database finding that of 29,827 patients who underwent primary RCR, those who had biceps tenodesis had a higher reoperation rate than those who did not [16].

57.2.3 Technical Errors

Improper tissue mobilizations, resulting in high-tension repairs and suture cutout, are common mistakes leading to failure. Improper anchor placement, or too many anchors that block access of tendon to the bone, including improper positioning, angulation, and protruding anchors can cause ineffective soft tissue fixation, anchor pull-out, and tissue abrasion. Anchors that pull out become loose bodies in the shoulder, causing additional pain and damage. Cummins et al. reviewed a series of 342 primary cuff repairs performed by a single surgeon and found that 6% ($n = 22$) subsequently underwent a revision repair

Table 57.2 Comparison of outcomes from current literature

	DeOrio	Bigliani	Nevaiser	Djurasovic	Lo	Keener	Piasecki	Lödermann	Hartzler	Parnes	Chuang	Sears	Shamsudin	Skoff	Petri	Mora	Hohn
Forward elevation, mean ± SD (gain)	Abduction 85° ± 59° (NA)	128° ± 42.73° (36°)	137°+/- NA (NA)	130°+/-NA (25°)	153° ± 33° (32°)	146° ± 29° (NA)	136° ± 11.8° (15°)	152° ± 42° (16°)	Median 110° (−20°)	NA	156° ± 17° (9°)	NA	NA (2)	NA	NA	135.6° ± 40.9° (30°)	NA
ASES, mean ± SD (gain)	NA	NA	NA	NA	NA	74 ± 24 (NA)	68 ± 7 (24)	77 ± 25 (26)	NA	NA	87 ± 13 (NA)	67.2 ± 27.9 (NA)	NA	75 (57)	86 ± 10.3 (NA)	NA	77 ± 16 (29)
UCLA, mean ± SD (gain)	NA	NA	NA	NA	28 ± 7 (15)	NA	NA	27 ± 7 (9)	NA	NA	30 ± 5 (14)	NA	NA	28 (24)	NA	NA	NA
VAS pain score, mean ± SD (gain)	NA	NA	NA	3 (4.4)	NA	2.7 ± 2.6 (NA)	2.7 ± 0.8 (2.4)	2.0 ± 2.3 (3.0)	Median 5.0 (3)	NA	0.9 (3.7)	NA	NA	NA	NA	6.49 ± 2.9 (NA)	NA
Patient satisfaction (%)	NA	52%	90%	70%	93%	NA	NA	78%	NA	NA	NA	37%	NA	NA	NA	73%	NA
SANE score, mean ± SD	NA	NA	NA	NA	NA	NA	68.1 ± 8.3	74.7 ± 20.9	NA	NA	NA	66.9 ± 26	NA	NA	74.8 ± 17.5	NA	69 ± 21
Non-healing or re-tear (%)	NA	NA	NA	NA	NA	52%	NA	NA	NA	10.6%	NA	NA	40%	0%	NA	5.8%	17%
Complications/ revision (%)	14.8%	NA	NA	NA	0%	0%	11.1%	8.1%	2.7%	9.6%	NA	NA	12%	0%	0%	15.9%	NA

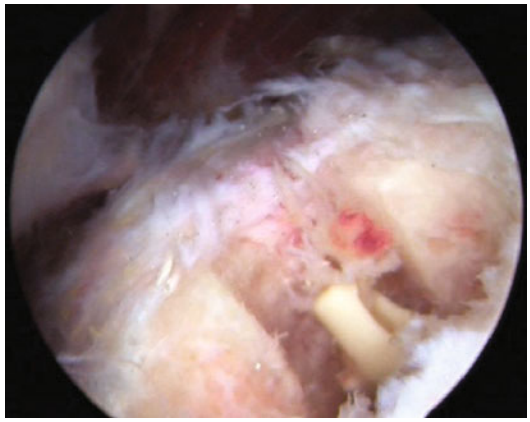

Fig. 57.1 Loose, prominent anchor with cyst formation

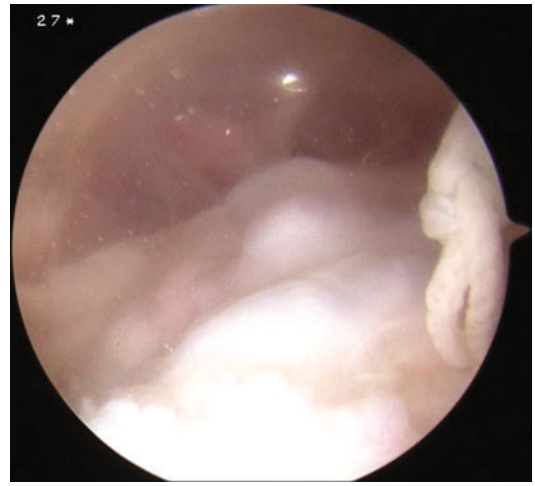

Fig. 57.2 Failed RCR with essentially no vasculature

[17]. At the time of revision surgery, they discovered that the primary mode of failure was tendon pulling through the sutures ($n = 19$), followed by new adjacent tears ($n = 2$), and finally pull out of anchors ($n = 1$) (Fig. 57.1).

57.2.4 Failure to Heal

Rate of healing for RCR is variable in the literature, from 19% to 94% [12, 18, 19]. The general area of the rotator cuff attachment has poor healing capacity in the best of circumstances. Poor vascularity to the rotator cuff and greater tuberosity, poor bone quality, and poor tissue quality of the rotator cuff are all possible causes of failure to heal. Additionally, medically comorbid conditions such as diabetes mellitus [20, 21] and smoking [22] have been shown to increase RCR failure and clinical results (Fig. 57.2).

57.2.5 Traumatic Failure

Traumatic failure of a RCR can occur early or late in the postoperative course. Early failure is generally due to an acute traumatic event such as a fall or overly aggressive physical therapy. Early failure most commonly occurs at the suture-tissue interface as described by Cummins et al. [17]. Late traumatic failure typically occurs after complete healing and, similar to primary cuff tears, results from overuse (repetitive trauma) or acute injury. Iannotti's study on the timing of failure clearly showed that most occur within the first 12 weeks, suggesting that any type of trauma should be avoided during the first 3 months after repair [23].

57.3 Diagnosis of Failed Rotator Cuff Repair

Failure of a primary rotator cuff repair can occur early or late in the postoperative course. Early failure should be suspected in patients with unexpected pain or weakness that does not improve with the typical course of postoperative physical therapy. Murrell has shown that early recovery of full range of motion is a negative predictor of successful healing [24]. Patients with medical comorbidities such as diabetes or nicotine use are also at elevated risk for *early* failure [20–22]. At any stage after RCR, new-onset pain, weakness, nighttime symptoms, wound problems, or fevers should prompt evaluation [13]. Additionally, a detailed timeline should be established. After the index procedure, did the patient's pain get better and then get worse? Was the onset of pain associated with a traumatic incident?

It is imperative that the treating surgeon obtain detailed information on the index procedure to

include repair technique, size and orientation of original tear, and additional procedures performed during the index procedure. If pre-op and/or intraoperative images are available, these should be reviewed as well. New imaging studies such as MRI or ultrasound should be obtained in addition to plain film radiographs of the affected shoulder. The sensitivity of MRI in detecting recurrent rotator cuff tears is lower than for primary tears secondary to artifact from implanted material and postsurgical changes [25]. Ultrasound has become increasingly popular in orthopedic surgery but is well-known to be very user-dependent. A study by Pricket et al. compared ultrasound with subsequent findings at subsequent arthroscopy, finding that ultrasound was 91% sensitive, 86% specific, and 89% accurate for identifying *recurrent* rotator cuff tears [26]. If questions remain after MRI or ultrasound, more advanced imaging studies may be used such as MR arthrography or CT arthrography, which increase the sensitivity for discovering a recurrent tear [27]. Lastly, second look arthroscopy may be used for both diagnostic and therapeutic purposes after thorough work-up as described above [28].

Surgeons must also consider other possible causes of shoulder pain or concurrent shoulder pathology in the differential diagnosis. Many can be addressed at the time of revision surgery, while others necessitate a different treatment algorithm. Arthritis of the glenohumeral joint or acromioclavicular joint, adhesive capsulitis, biceps pathology, os acromiale, suprascapular nerve pathology, scapulothoracic dysfunction, infection, deltoid rupture, and even cervical spine pathology are all possible causes of shoulder pain after RCR [28].

57.4 Indications for Surgical Intervention

After the diagnosis of a re-tear has been confirmed, the appropriate treatment modality must be decided upon by the surgeon and the patient. A discussion with the patient should include analysis of the cause of failure and a frank conversation about the patient's postoperative expectations. Options at this point may be a basic rehabilitation [13], revision rotator cuff repair, muscle tendon transfer, reverse shoulder replacement, or arthrodesis.

Revision rotator cuff repair surgery is generally recommended in the setting of a physiologically young and active patient with a repairable re-tear. It is up to the operative surgeon to adequately assess his or her ability to perform a revision repair. In some cases referral to a more experienced surgeon may allow a revision repair with excellent outcome rather than select other options.

In patient with severe atrophy of just the supraspinatus and minimal arthritis, a superior capsular reconstruction along with partial repair may be the best option. Similarly a failed repair with intact subscapularis and severe atrophy of the infraspinatus would do better with a tendon transfer. Those age-appropriate patients with arthritis and failed rotator cuff surgery may be best managed with arthroplasty. Several studies have described negative prognostic factors in series of patients who underwent revision RCR. Poor tissue quality [6, 29], deltoid detachment [6, 15, 29, 30], pre-op ROM <90° [6, 7, 31, 32], increasing patient age [10], tear size [10, 31], and female gender [7, 32], none of these are contraindications to undertaking a revision RCR; however, these factors should temper the surgeon and patient expectations for postoperative results.

57.5 Operative Technique

Surgical technique for revision RCR should be tailored to the individual patient and surgeon. We do not aim to describe step-by-step technical aspects of the repair; rather, we present general principles, some based on scientific literature and others the opinion of the author(s). The primary goal of the revision rotator cuff repair should be *healing* of the tissues, which is associated with better overall outcomes for the patient [12]. The basic principles of revision repair are:

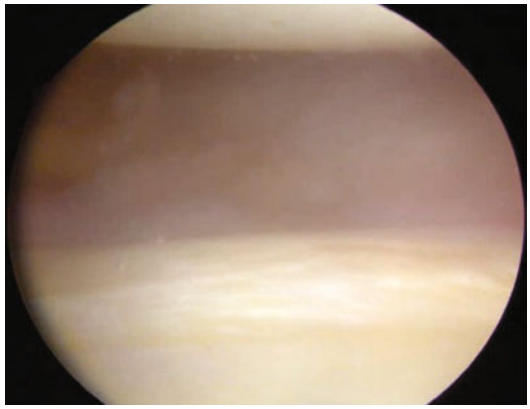

Fig. 57.3 Tight inferior capsule requiring release

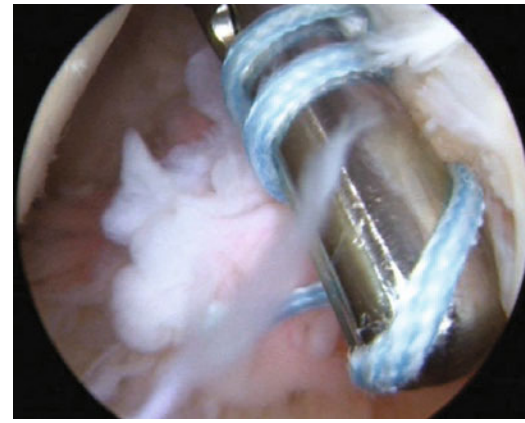

Fig. 57.4 "Alligator roll" removing sutures from failed RCR

1. Release and remove all adhesions, contractures, and foreign materials.
2. Preserve any residual rotator cuff muscle and tendon, including the biceps—if available—for use in the repair.
3. Complete all associated bone and soft tissue work before beginning the repair.
4. Think biology: preserve medial bursal tissue to attach to the rotator cuff, prepare a vascular healing bed with microfracture and trephination holes into the marrow, and use vented anchors when possible.
5. Complete a tension-free, biomechanically sound repair while maximizing available healing area (Fig. 57.3).

57.5.1 General

Arthroscopic, mini-open, or open repair can be performed for revision repair. This decision should be based on comfort level of the surgeon, as current literature does not indicate that one method is superior. In most cases arthroscopy provides superior access to the entire shoulder, and even if deltoid repair is required, an arthroscopic repair can still be performed, followed by a mini-open deltoid repair [6, 13]. A thorough diagnostic arthroscopy should be performed at the outset, including the assessment of the long head of the biceps tendon, glenoid labrum, and subscapularis tendon. Careful attention should be paid to the quality of the tissue, as re-torn rotator cuff tissue is often retracted and atrophied with fatty infiltration [33].

57.5.2 Releases

Soft tissue release is vital to achieve a tension-free repair. The joint capsule and coracohumeral ligament are usually completely released in all revision cases to allow proper mobilization of the tissue. The humeral head often rides high due to tissue retraction in this setting. Releasing sufficient tissue to allow the humeral head to sit in an anatomic position can be viewed as a measure of sufficient release. Additionally, the residual tendon must be released from the overlying bony structures and undersurface of the deltoid muscle. We strongly recommend release between the bursal layer and the overlying structures in order to preserve the vascular supply and cells contained within the bursal layer. One must exercise caution to avoid resecting normal tendon (Fig. 57.4).

The suprascapular nerve may come under tension during the repair of a rotator cuff repair as the tissues which have been retracted are manually pulled to length [34]. Though not correlated with improved healing, suprascapular nerve release at the time of revision RCR has been described by Savoie et al. to improve pain relief,

active forward flexion, and strength when compared to a similar group without suprascapular nerve release. Zunkerman and Savoie open J Sports Med-Dove Press [35].

57.5.3 Debridement

Attention should also be placed on debridement of scar tissue, loose suture and anchors, and intra-articular adhesions. Old suture anchors should be removed if possible, especially if prominent; however routine removal is controversial, as some authors feel that the risk of greater tuberosity fracture is not worth the reward. Anchor stacking and replacement with larger anchors are both viable options; however we believe that anchors should be removed and that stacking one anchor next to another decreases available healing area. Grafting and various bone filler are preferable to anchor stacking.

57.5.4 Bone Work

The revision situation differs from the primary in that all bone issues should be corrected, even minor ones. The subacromial space should be visualized and decompressed both anteriorly and laterally. The residual acromion should be smooth, without any irregularity or protrusions. Distal clavicle excision is generally warranted based on preoperative clinical exam findings, imaging studies, and intraoperative findings. We have found distal clavicle excision to be beneficial in freeing the supraspinatus tendon and in improving access for suture placement in these revision situations.

The greater tuberosity should be prepared to a bleeding surface using microfracture techniques, which creates bone marrow vents that serve as a conduit of access for growth factors and stem cells, the so-called Crimson Duvet [36]. However, it is important to preserve bone surfaces for anchor placement, leaving an 8–10 mm "circle" available for each anchor. In the revision setting, the posterior wall of the bicipital groove is often an undisturbed area for anchor placement.

57.5.5 Repair

The basics of repair of the tendons are not unlike repair of primary rotator cuff tears but with an increased emphasis on tension-free repairs. Oblique convergence sutures are used, as they convert a large tear to a smaller one and improve the biomechanical fulcrum for rotator cuff function. Vented anchors should also be used, as they carry the theoretic advantage of allowing bone marrow contents which promote healing to infiltrate the area most in need of healing, rather than acting as a plug, preventing these biologic factors from reaching the area of repair.

Once the entire "prep" has been completed, which may take some time, the surgeon can move into revision repair.

57.6 Steps in Revision Repair

1. Release the inferior capsule as well as the capsule adjacent to the torn tendons.
2. Remove old anchors and sutures.
3. Bone work: trephinate or microfracture the greater tuberosity, lateral decompression of the acromion; remove distal clavicle if necessary.
4. Complete the releases: release both bands of the coracohumeral ligament, and continue an anterior interval slide to the suprascapular nerve. Decompress the nerve if there is grade 3 or 4 atrophy.
5. Move into the specifics of revision repair (Fig. 57.5).

We often use one or two oblique convergence stitches to both help close the defect and act as "rip-stop "stitches. One or two triple loaded anchors are inserted into the most medial aspect of the greater tuberosity footprint. If the subscapularis is involved, it will require its own medial anchor. The supraspinatus and upper infraspinatus can be repaired with a single triple loaded anchor, but if the lower half of the infraspinatus tendon is involved, then an additional anchor is required for this tendon and the teres minor.

In cases with deficient tendon, the lateral 5–8 mm of articular cartilage can be removed to

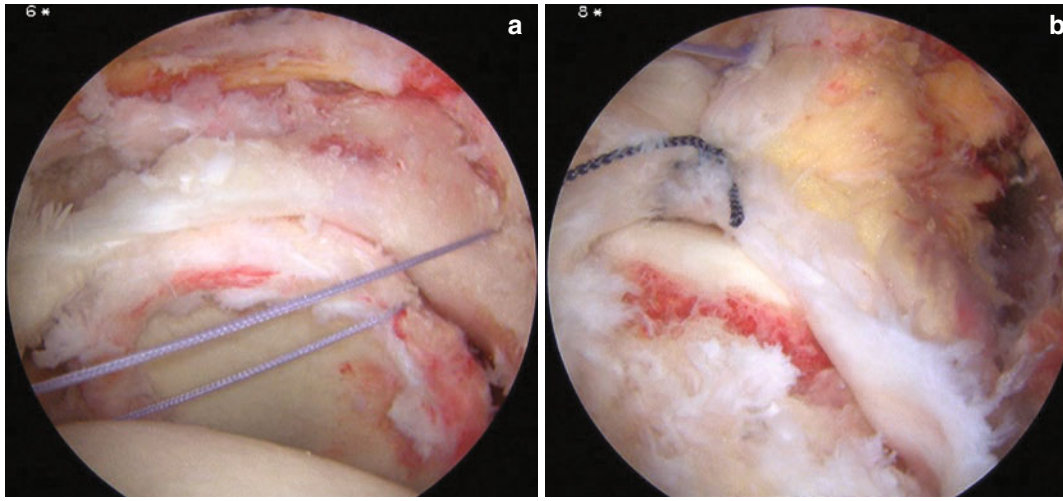

Fig. 57.5 (**a**) Oblique convergence stich before tightening. (**b**) Once convergence stitch tied

obtain better anchor placement and minimize tension on the repair.

Once the medial anchors are placed, sutures are retrieved through the tendon about 3–5 mm lateral to the muscle tendon junction, with each passage about 1 cm apart. These may be retrieved between the convergence sutures to increase suture hold on the tendon.

We prefer to tie each of these mattress sutures individually and then utilize the sutures to compress the footprint by placing them into knotless lateral row anchors, but knotless constructs also provide sound biomechanical fixation (Fig. 57.6).

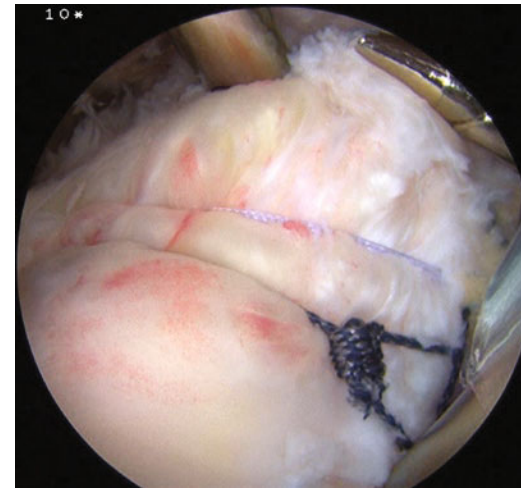

Fig. 57.6 Final view of revision rotator cuff repair using two margin convergence stitches, one rip stop and a single lateral anchor

57.6.1 Mechanical and Chemical Augments

Augmentation of rotator cuff repairs is an exciting area of research. Several studies have demonstrated that mechanical augmentation with biologic or synthetic scaffolds is safe and effective in primary rotator cuff repairs [37–41], but long-term data and data for revision rotator cuff repairs are lacking. Additionally, there is a lack of consensus as to the most appropriate materials to be used for augmentation. Chemical augments such as PRP or PRFM have been studied in primary rotator cuff repairs, but data is scant on revision repairs, and the current consensus is that the data do not support the use of PRP to improve healing or outcomes [28, 42–45].

Examples of mechanical biologic augments include autologous fascia lata [37], porcine dermal collagen [46, 47], and acellular human dermal matrix (AHDM) (Wong) [40, 48, 49]. Synthetic grafts have also been studied, including polypropylene [50], polyester [51], poly-L-lactic

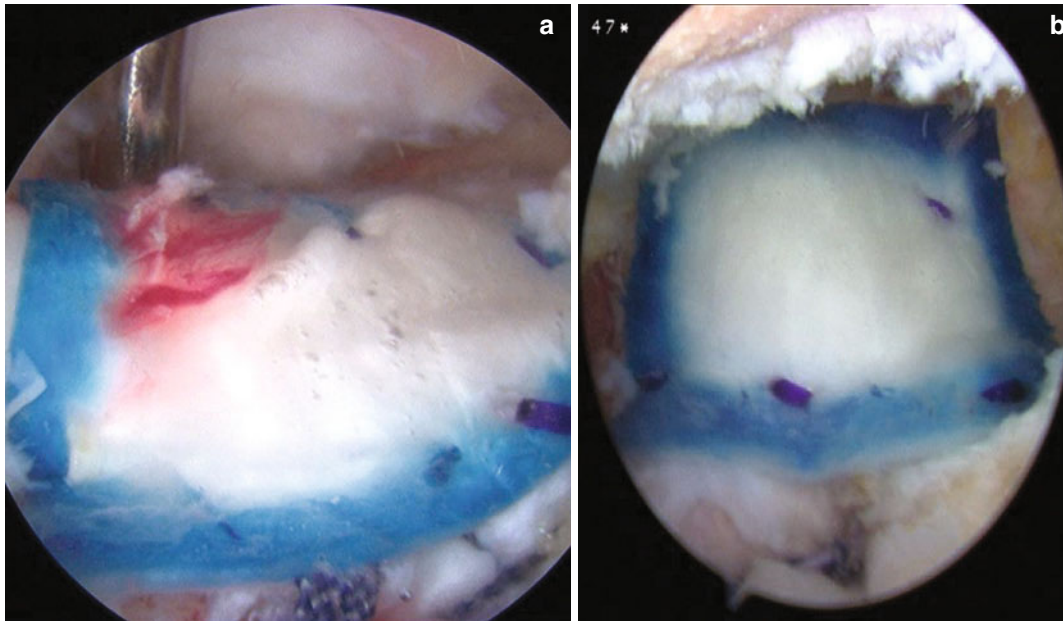

Fig. 57.7 (**a**, **b**) The addition of a collagen patch is useful in revision rotator cuff surgery

acid [52], polytetrafluoroethylene [53], and polyurethane [54].

Recently, acellular human dermal matrix (AHDM) has been studied in the setting of revision RCR. A 2015 study by Sears et al., a 2016 study by Petri et al. [49], and a 2018 study by Hohn et al. [48] all show improvements in patient outcomes, but the outcomes do not show improvement superior to the current data for non-augmented revision [9]. Additionally, the hypothesis that augmentation with AHDM improves healing in the setting of revision cuff repairs cannot be proven without larger cohorts of patients who receive postoperative imaging to confirm healing of the rotator cuff. These studies do, however, illustrate that the use of AHDM in the revision setting is safe and its efficacy should be further investigated (Fig. 57.7).

Recent work on the use of porous vascular patches holds promise in improving the healing rate in these difficult cases. A study of 13 cases with MRI follow-up at regular intervals showed that all of the grafts induced healing by 3 months and was eventually radiographically indistinguishable from native tissue. Twelve of 13 reported improvement from preoperative measures [55].

57.7 Postoperative Course

Physical therapy protocols after rotator cuff revision are similar to those after primary repair but should proceed much more slowly. Physical therapy should be delayed allowing for adequate healing time. We recommend 8 weeks of immobilization in a pillow sling, although most of the protocols described in the current literature remove the pillow sling at 6 weeks [13], followed by aquatic and supine pain-free rehab. When passive range of motion is allowed, passive flexion, scapular plane abduction, and external rotation are emphasized, while internal rotation is avoided [10]. The patient then graduates to active motion, followed by strengthening exercises at 3 [6, 30, 32, 56] to 4 [7, 28, 33] months postoperatively. Full return to normal activities was not allowed until 4 [33], 6 [8], or even 12 [7, 30, 57] months postoperatively.

Additionally, the author(s) of this study advocates for routine ultrasound examination every 6 weeks to evaluate for healing, which can help guide physical therapy and ensure that the patient is ready to graduate to the next stage of therapy.

57.8 Summary

Revision rotator cuff repair can be effective in managing most failed primary repairs. Aggressive release and debridement, preservation of bursa structures for blood and cell supply, and marrow venting of the greater tuberosity along with a biomechanically and biologically sound repair construct are essential.

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