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Evolution of Rotator Cuff Repair Techniques: Are Our Patients Really Benefiting?

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Abstract

The repair integrity of rotator cuff tears, which are a common disorder, is influenced by many biologic, environmental, and surgical factors. Surgery for rotator cuff repairs has evolved significantly over the past decade. The technical goals of rotator cuff repair include achieving high initial fixation strength, minimizing gap formation, and maintaining mechanical stability until biologic healing occurs. A variety of surgical techniques have been established to capitalize on certain aspects of these tenets and have been shown to provide biomechanical and biologic benefits; however, overall clinical outcomes may be dependent on certain tear characteristics. It is important for orthopaedic surgeons to be familiar with the natural history of rotator cuff disease to understand the various repair strategies and techniques and the outcomes associated with these procedures.

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Rotator cuff repair is one of the most common orthopaedic shoulder procedures. The primary goal of rotator cuff repair is to successfully reconstitute glenohumeral joint function by restoring normal rotator cuff kinematics. It is well known that rotator cuff repairs are at risk for failure, with 20% to 40% of primary repairs resulting in failure. Even higher rates of failure have been reported in revision cases.[1-6] Outcome studies following rotator cuff repair have shown that patients report high satisfaction ratings,[5,7,8] often despite the failure of complete anatomic healing. Recent data have shown that healing and the anatomic integrity of the rotator cuff repair site correlates with improved outcomes, particularly with regard to strength and functional recovery.[1-4,8,9] Repair methods have significantly evolved over the past decade to allow improvement in

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postoperative cuff integrity, strength, and overall outcomes.

Recent biomechanical and clinical research has focused on the numerous variables that are known to influence repair integrity and clinical outcomes. The natural history of rotator cuff disease, with a focus on the important examination and presentation findings that have a known association with repair success, are discussed in this chapter. Various rotator cuff repair strategies are also reviewed, including the evolving repair constructs, guidelines for using repair techniques, and an overview of the outcomes associated with the evolving repair techniques.

Tendon Healing and the Natural History of the Disease

The incidence of rotator cuff disease increases naturally with age.[10] Yamaguchi et al[10] examined bilateral shoulders using ultrasound in a large group of patients with unilateral shoulder pain. Contralateral asymptomatic tears were present in a large percentage of patients and occurred in an age-dependent fashion. The mean age of the patients with no tear on the contralateral side was 49 years, with unilateral tears, 59 years, and with bilateral tears, 68 years. These results strongly suggest that rotator cuff disease is a progressive, age-related, degenerative process.

Full-thickness tears of the rotator cuff initiate a cascade of alterations that compromise the muscle-tendon unit. These include atrophy, degeneration, retraction, fibrosis, and decreased collagen expression,[11-14] which play significant roles in the success of repairs. Outcomes following rotator cuff repair are primarily dependent on factors such as patient age, tear size, muscle atrophy, fatty change, and chronicity.[1,2,4,7,8,11,12,15] In one of the first studies to identify age as a significant factor affecting healing, Boileau et al[1] evaluated cuff integrity after arthroscopic repair of the supraspinatus tendon. The authors reported a 70% healing rate, although healing occurred in only 45% of patients older than 65 years. Similar results were reported by Lichtenberg et al[16] in a study of 53 patients in whom the overall healing rate was 75%. The average age of the patients with healed repairs was 59 years compared with an average age of 65 years for patients in whom healing did not occur. Age as an independent variable related to retearing following rotator cuff repair has recently been challenged by Oh et al.[17] Based on a multivariate analysis, the authors determined that advanced age did not act independently of tendon retraction and the degree of fatty degeneration as a factor in retearing after repair.

The classification system defining fatty degeneration of the rotator cuff was first described by Goutallier et al;[18] it was subsequently determined that degenerative changes are indicative of the size and chronicity of the tear.[19-22] The amount of fatty degeneration is an important factor relating to outcomes after repair.[23-25] Using MRI to correlate muscle atrophy and fatty degeneration to patient outcomes, Gladstone et al[26] evaluated 38 patients 1 year after rotator cuff repair. It was found that muscle atrophy and fatty degeneration of the rotator cuff were independent predictors of American Shoulder and Elbow Surgeons and Constant scores.[26]

In addition to biologic factors, environmental factors such as smoking or other chemical exposure may have significant affects on healing. In an evaluation of a population of patients with shoulder pain, a highly statistically significant association, which demonstrated a time- and dose-dependent response, was reported between smoking and the presence of a rotator cuff tear.[27] More recent smoking and heavier smoking were also associated with the presence of a tear.[27] Smoking also has been shown to be detrimental to rotator cuff healing.[10] In an animal model, the administration of nicotine resulted in decreased cell proliferation and extracellular matrix production in the healing tendon.[28] Biomechanical testing showed inferior material properties of the repair tissue exposed to nicotine when compared with a control group.[10]

Basic science research on tendon biology and healing has proliferated in the past several years. In general, a tendon heals by scar formation rather than by tendon regeneration. The healing process is largely (but not independently) modulated by transforming growth factor beta-1 rather than by transforming growth factor beta-3, which leads to scar-free healing in skin and tendon in fetal models of soft-tissue injury. In animal models of rotator cuff healing, most repairs attain only 50% of the structural properties and 10% of the material properties compared with normal tendon.[29,30] The challenge going forward is to integrate the use of growth factor and tissue engineering strategies to enhance healing in a cost-effective and reliable manner.

Biomechanical Rationale

The technical goals of rotator cuff repair include achieving high initial fixation strength, minimizing gap formation, and maintaining mechanical stability until biologic healing. The important characteristics of rotator cuff repair at time zero are shown in **Table 1**. It is well documented that healing of the rotator cuff repair site correlates with superior outcomes, particularly regarding the recovery of function and strength.[1-4,8,9]

Bone-to-tendon healing begins with the formation of a fibrovascular tissue interface between the tendon and bone.[29,30] Early on, bone will grow into the interface tissue,[31] which is followed by a gradual increase in collagen fiber continuity created between the tendon and bone.[29] The fibrovascular tissue interface is an important consideration regarding the improved surface area for healing afforded by restoration of the anatomic footprint.[32-34] Traditional single-row repairs result in persistent tear rates ranging from 29% to 90%.[1,7,8,35] These tears may be caused in part by the prolonged and complex biologic process of rotator cuff tendon healing, the lack of footprint restoration, and biomechanical considerations. Typically, after a rotator cuff tear, the tissue is relatively avascular for several months. To incite a vascular response, biologic factors necessary for healing must originate from bone; however, these factors are impeded by the synovial environment because the synovial fluid and other factors are believed to be an impediment to healing at the tendon-bone interface. The repaired tendon must remain relatively still for long periods of time over as large an area of the healing zone as possible to maintain the healing response; this is difficult to achieve because of tendon-bone interface motion and is the reason why increasing tissue compression on bone potentially enhances the healing process.[36] An ideal rotator cuff repair should be strong and gap-resistant with compression forces that protect the endosteal healing factors. In an attempt to address these considerations, rotator cuff repair configurations have evolved considerably over the past decade.

Technical failures related to technique, implants, and suture selection are becoming less commonplace because of recent technologic advancements in implant materials. More concerning is the concept of anatomic failure, which takes into consideration the rotator cuff tendon footprint, biomechanics, and resting tension on the repair. The footprint of the supraspinatus rotator cuff tendon is two-dimensional and measures approximately 12 to 14 mm medial to lateral and 25 mm anterior to posterior.[37,38] Pressure on the rotator cuff tendon should be considered as a third dimension, taking into account compression on the tendon and contact area. Many biomechanical studies have established that double-row configurations significantly increase the amount of native footprint covered with the repaired tendon.[33,39,40] In a cadaver study, Meier and Meier[34] reported that a double-row repair restores the supraspinatus tendon footprint more closely than a single-row technique. Brady et al[33] reported on a clinical intraoperative study of patients treated with repair of full-thickness rotator cuff tears using double-row fixation. The authors compared the footprint coverage of repairs after an initial lateral-row repair and after the double-row repair and determined that single-row repairs left an average of 52.7% of the rotator cuff footprint uncovered. After a double-row repair in which the medial-row sutures were secured, there was complete (100%) footprint coverage in all patients, representing a mean increase in footprint coverage of 119%.

Table 1
Ideal Rotator Cuff Repair Construct Characteristics at Time Zero

Restoration of anatomic footprint
Resistance to gap formation
Ultimate tensile strength
Resistance to cyclic elongation
Number of cycles to failure

Double-row repairs also have shown improved strength, less gap formation, and significantly increased resistance to cyclic displacement.[41-46] A meta-analysis[47] compared the biomechanical properties of single-row and double-row constructs in 15 studies using animal and human models. Nine studies demonstrated a statistically significant advantage to a double-row repair with regard to biomechanical strength, repair failure, and gap formation. Additionally, five of the studies demonstrated the double-row repair was superior to single-row repairs with respect to anatomic restoration.[47]

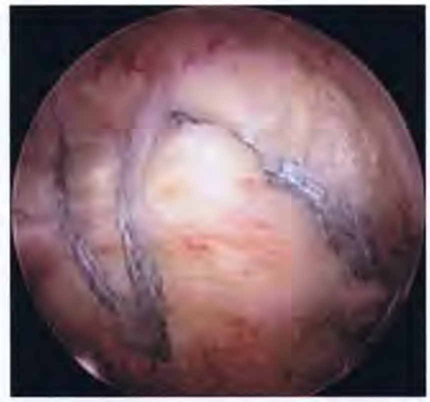

Figure 1 Arthroscopic image of a transosseous equivalent (TOE) rotator cuff repair.

Transosseous Equivalent Repairs

When discussing double-row rotator cuff repairs, a differentiation must be made between first-generation constructs and newer constructs containing bridging sutures between the medial and lateral rows, known as the modified double-row or transosseous equivalent (TOE) repair[48-50] (**Figure 1**). First-generation, double-row repair constructs consist of a medial row of mattress-type sutures with simple sutures placed at the lateral edge of the cuff without linkage between the two rows.[51] This configuration has been shown to mechanically outperform single-row suture anchor techniques in the laboratory in terms of footprint restoration and construct strength.[34,44] However, anchor crowding can occur on the tuberosity, and biomechanical testing also has shown that first-generation, double-row configurations fail to prevent repair site gapping during humeral rotation, especially at the anterior anchor point.[41] TOE repairs perform better than single-row repairs under cyclic loading and ultimate failure testing while providing biologic containment and tissue-to-bone compression.[33,34,44,49,50,52] Anatomic anchor crowding is diminished because the lateral fixation is placed more distally on the lateral wall of the greater tuberosity rather than proximally on the lateral crest of the tuberosity. Biomechanical testing that emphasized internal and external rotation during high loading conditions showed the TOE construct was superior because of self-reinforcing properties, allowing for solid tendon fixation during rotational testing.[53]

Bisson and Manohar[54] compared open transosseous repair (considered the gold standard) with the bridging TOE construct for supraspinatus tears in paired cadaver shoulders. The authors reported no significant difference between the two techniques with respect to elongation, load to failure, or stiffness. In addition, these repair methods demonstrated failure loads of approximately 400 to 450 N, which is approximately 50% of the strength of an intact supraspinatus tendon.[55] However, failure loads were higher than those previously reported for earlier-generation techniques.[39,44,45,56-58] Gerber et al[57] reported that the single-row configuration produces an ultimate tensile strength of 208 N, which is barely sufficient to resist the physiologic rotator cuff load of the supraspinatus. The repair strength at time zero was reported to be 336 N for double-row[59] and 443 N for TOE repairs.[50]

Mini-Open and Arthroscopic Repairs: Making the Transition

Advancements in arthroscopy have dramatically changed rotator cuff surgery and have facilitated the evolution from open to mini-open to complete arthroscopic repairs. Arthroscopically assisted rotator cuff repair is a hybrid technique, which combines the benefits of mini-open and arthroscopic techniques and is useful for certain repairs and by surgeons transitioning to complete arthroscopic procedures. The mini-open technique, first described by Levy et al[60] in 1990, uses arthroscopy to treat intra-articular pathology and subacromial decompression and is followed by rotator cuff repair through a limited deltoid-splitting approach. The approach, which is an extension of the anterior portal, allows the deltoid fibers to be split in line for access to the repair and avoids deltoid takedown from its origin. The addition of arthroscopic inspection permits a detailed examination of the glenohumeral joint for possible concomitant disorders such as degenerative biceps lesions, labral pathology, cartilage defects, and glenohumeral arthritis. Several studies have documented the high incidence of intra-articular pathology found during arthroscopy; knowledge of this pathology provides important prognostic details.[61-64]

The main advantages of the arthroscopically assisted mini-open technique over traditional open surgery are lower perioperative morbidity, improved cosmesis, accelerated rehabilitation, improved identification of intra-articular pathology, and preservation of the deltoid. The open repair allows the use of transosseous repair sutures, which are considered the gold standard;[8] however, the results of this technique have not been fully elucidated. A disadvantage of the mini-open technique is increased subdeltoid scarring, which leads to higher rates of stiffness. There are also a variety of tears that are difficult to treat using this technique, including massive tears with a posterior-to-anterior and U-shape orientation, as well as retracted tears.

The indications for mini-open and arthroscopic rotator cuff repairs are the same as those for open repairs and include persistent pain or weakness and a documented tear of the rotator cuff. Specific indications for the mini-open repair include tears with minimal retraction and those that are primarily limited to the supraspinatus tendon. Relative contraindications to arthroscopic repair include active or recent infection, medical comorbidities making anesthesia unsafe, massive tears with fixed tendon retraction, and those with superior escape.

Arthroscopic Rotator Cuff Repair

Arthroscopic rotator cuff repair represents a notable improvement with regard to morbidity associated with deltoid takedown and postoperative rehabilitation. In comparison to the open or mini-open methods, the complete arthroscopic procedure is more technically demanding and requires a steep learning curve before it can be done proficiently. The arthroscopic rotator cuff repair technique has unique complications, including fluid extravasation, device failure, thermal injury, longer surgical times, and concerns about higher cost.[65] The advantages of the arthroscopic technique include a marked improvement in cuff tear visualization, an expedited postoperative phase, the ability to identify and treat all concomitant pathologies, and the ability to repair the rotator cuff with minimal surgical insult to the deltoid. Most notably, the arthroscopic technique offers greater versatility in recognizing and anatomically reducing a va-

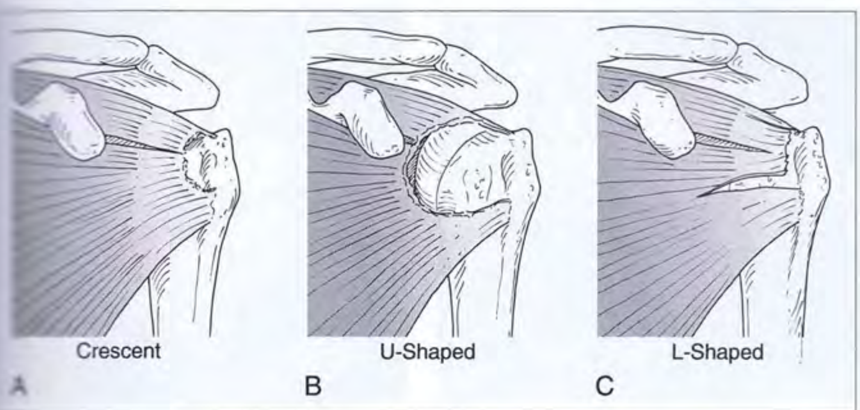

Figure 2 Illustration of the basic rotator cuff tear patterns. **A,** The crescent tear is the most basic pattern and may be approached with a variety of techniques. **B,** The U-shaped tear is usually more chronic and degenerative in nature and can require margin before footprint. **C,** The L-shaped tear consists of an anterior-to-posterior component at the footprint in conjunction with a medial-to-lateral component, which can be either anterior or posterior at the supraspinatus-infraspinatus junction.

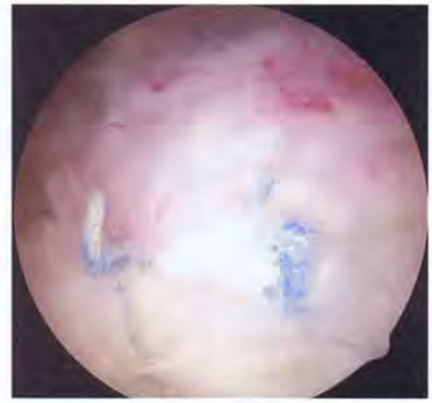

Figure 3 Arthroscopic image showing an intact single-row rotator cuff repair.

Figure 4 Arthroscopic image showing margin convergence of a large U-shaped rotator cuff tear before footprint repair. These tears are typically chronic and/or degenerative in nature.

variety of partial- and full-thickness tear patterns. Patients should be advised that a more minimally invasive approach to repair does not equate with improved tendon healing and faster recovery from a functional standpoint, and differences at 1 year postoperatively, except the incision size, are indistinguishable.

Arthroscopic Strategy

Successful arthroscopic rotator cuff repair begins by determining the tear pattern. Although several classification systems exist, the most valuable is a straightforward description of the tear pattern as crescent, U-shaped, or L-shaped (**Figure 2**).[66,67] The crescent tear is typically an avulsion injury and is the most basic pattern. The crescent tear is unique because it is typically acute and has excellent biologic healing potential. This pattern may be treated with a variety of techniques; however, an acceptable result may be achieved using a single-row configuration with multiple anchors as needed[67] (**Figure 3**). To assist with reducing the tear, it may be helpful to repair the posterior margin first, followed by the anterior portion and then the central portion of the tear. The U-shaped tear is usually more chronic and degenerative in nature. In general, this type of repair may require margin convergence or side-to-side repair (**Figure 4**) before the footprint repair and begins at the apex of the tear progressing medially to laterally. Using this technique will help reduce tension and repair length at the repair site. The repair is completed using a single- or double-row technique, depending on the surgeon's preference.

One of the most common configurations is the L-shaped tear, which consists of an anterior-to-posterior component at the footprint in conjunction with a medial-to-lateral component. The medial-to-lateral component is almost always one of the limbs of the L and extends upward into the weaker tissue of the rotator interval; however, the L (or reverse L) may extend into the junction between the supraspinatus and infraspinatus. The lateral limb of the L-shaped tear is usually located along the rotator cuff cable or where the infraspinatus comes around laterally to envelop the supraspinatus (**Figure 5**). The apex of the L-shaped tear should be anatomically reduced to the exact area in which it was torn to reduce the risk of postoperative failure (**Figure 5, C**). Arthroscopic visualization of these tear patterns greatly facilitates anatomic reduction and a tension-minimized repair construct.

Surgical Technique: Critical Steps

Complete arthroscopic repair begins in the same manner as that previously de-

Figure 5 Arthroscopic images showing the pathology and repair of an L-shaped tear consisting of an anterior-to-posterior component at the footprint in conjunction with a medial-to-lateral component. **A,** L-shaped tear. **B,** Anatomic reduction of the tear. **C,** Final intact repair.

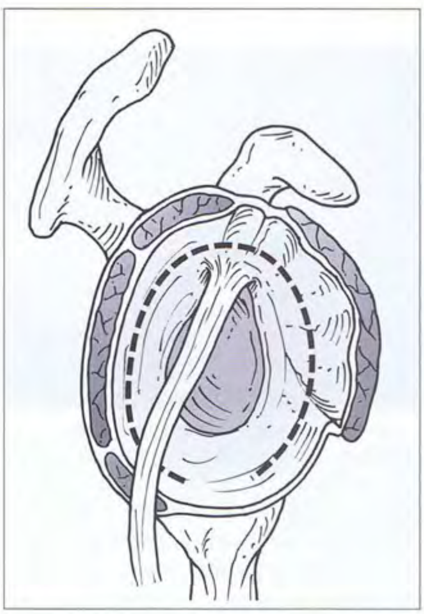

Figure 6 Mobilization of the rotator cuff with pericapsular release. In chronic rotator cuff tears, the tendon may be adherent to the glenoid neck, and releasing the capsule above the superior labrum and around the glenoid is helpful. The dotted line represents the plane of the release.

Figure 7 Arthroscopic image showing visualization of rotator cuff pathology through the lateral portal.

scribed for mini-open repairs; however, there are a few key steps that are critical to success. Tendon releases are crucial and can be performed with arthroscopic hand instruments, an electrothermal device, or an arthroscopic elevator to obtain mobilization of the rotator cuff tissue and prevent undue tension on the repair. Initially, releases should be performed between the rotator cuff tendon and the undersurface of the acromion. Anteriorly, releases are performed to separate adhesions in the rotator interval (interval slide) region between the supraspinatus and subscapularis, with releases performed to the base of the coracoid. A posterior release or slide will separate the supraspinatus and the infraspinatus, although this is rarely required. In chronic rotator cuff tears, the tendon may adhere to the glenoid neck; releasing the capsule above the superior labrum and around the glenoid is helpful (**Figure 6**).

Tendon footprint reconstruction can be performed using a variety of configurations; however, the surgeon must be aware of appropriate portals and the benefits of each in facilitating suture passing. Although viewing from the posterior portal and working through the lateral portal is possible, viewing through the lateral portal and working through the posterior, anterior, and accessory anterolateral portals improves suture passing capabilities and direct visualization (**Figure 7**). To establish the accessory anterolateral portal, an 18-gauge spinal needle is used to determine the proper trajectory for anchor placement and suture passing (**Figure 8**). Footprint preparation also is performed through this portal. When preparing the footprint, it is important to create a bleeding surface by removing only minimal cortical bone to improve suture anchor pull-out strength. However, with TOE fixation constructs, more cortical bone may be removed with the burr during preparation to obtain a viable bleeding bony surface of the greater tuberosity.

The anchor position is dependent on the suture repair configuration. When performing a single-row repair,

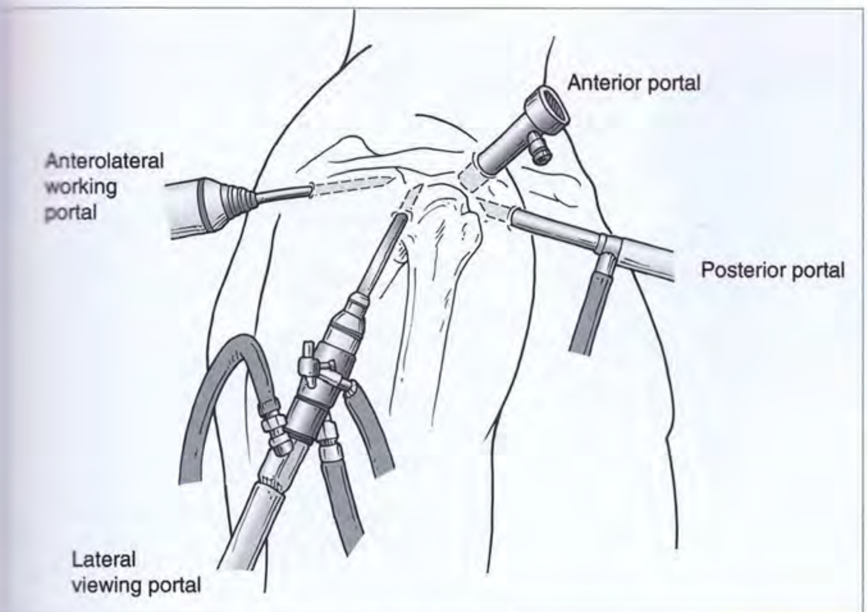

Figure 8 Illustration showing standard portal placement for an arthroscopic rotator cuff repair.

Figure 9 Arthroscopic image showing the placement of medial row anchors just off the articular margin of the footprint in a double-row rotator cuff repair.

the anchor is placed at or near the lateral edge of the greater tuberosity. In a double-row repair, the medial row of anchors (**Figure 9**) is placed just off the articular margin of the footprint. Lateral row anchors are placed after medial knots are tied and are positioned lateral to the footprint just off the greater tuberosity. Following anchor placement, sutures are passed through the rotator cuff tendon using a variety of suture passing devices, tissue penetrators, or suture shuttle devices. Arthroscopic knot tying is crucial to a successful repair. Although many sliding and nonsliding knots have been described (including the Roeder, the midshipman, the Revo, and the western), using simple half-hitch knots passed on alternating posts tied from posterior to anterior is a reliable and simple technique. There are now numerous devices, anchors, and suture configurations to replicate the TOE, both with and without knots.

Several authors have reported the clinical outcomes of complete arthroscopic repairs that are comparable to the results achieved with open and arthroscopically assisted techniques.[68-75] A brief summary of the results comparing mini-open to all-arthroscopic rotator cuff repairs is found in **Table 2**.

Evolution of Techniques: Clinical Outcomes

The clinical outcomes of the newer suture repair constructs have yet to be fully defined. It is important to note that not all of the reported data can be generalized to a particular repair construct. When evaluating the literature on repair techniques and outcomes, there are numerous contributing factors to consider, such as the number of anchors used, the chronicity of the tear, and patient age. Although reports will typically describe the basic repair configuration (single-row, double-row, or TOE), it is important to note the total number of anchors involved in the repair, the number of anchors that are used for the medial and lateral rows in double-row repairs, and the configuration of the sutures as they bridge the tissue from medial to lateral (such as straight medial to lateral, sutures crossed over one another to create interconnectivity, or knotless or knotted medial row). The number of anchors represents the number of fixation points; therefore, it may be possible that, regardless of how the repair is configured, more fixation points may ultimately result in a stronger repair.[44] This may also be true in studies involving larger rotator cuff repairs because more anchors are used in large repairs, and outcomes may be dependent on this factor. Chronicity and the number of tendons involved should also be considered. In certain situations, chronic tears can be less amenable to double-row constructs because the tissue may not allow full reapproximation to re-create the anatomic footprint. Patient age should be noted because younger patients may place higher loads on the repair site despite the fact that their tissue quality is often superior.

Currently, prospective results have suggested that rotator cuff repair tendon healing occurs more frequently in patients treated with double-row repairs compared with single-row repairs.[6,76-78] Sugaya et al[79] compared

Table 2

Summary of Results Comparing All-Arthroscopic to Mini-Open Rotator Cuff Repairs

Authors (Year)	Number of Patients	Mean Follow-up	Reported Outcomes
Kose et al[68] (2008)	25 all-arthroscopic, 25 mini-open	26 months	Preoperative and postoperative Constant-Murley and University of California at Los Angeles scores and satisfaction not significantly different between groups
Pearsall et al[69] (2007)	27 all-arthroscopic, 25 mini-open	50.6 months	No statistical difference in outcome between the two groups
Verma et al[70] (2006)	38 all-arthroscopic, 33 mini-open	minimum 2 years	No difference in clinical outcomes between the two techniques
Sauerbrey et al[71] (2005)	28 all-arthroscopic, 26 mini-open	33 months	All improved; the difference in scores between the two techniques not statistically significant
Warner et al[72] (2005)	9 all-arthroscopic, 12 mini-open	minimum 27 months	No differences in outcomes
Youm et al[73] (2005)	42 all-arthroscopic, 42 mini-open	minimum 2 years	Arthroscopic and mini-open rotator cuff repairs produced similar results for small, medium, and large rotator cuff tears with equivalent patient satisfaction rates
Severud et al[74] (2003)	35 all-arthroscopic, 29 mini-open	44.6 months	Shoulders in the all-arthroscopic group showed better motion at 6 and 12 weeks
Kim et al[75] (2003)	42 all-arthroscopic, 34 mini-open	39 months	No difference in shoulder scores, pain, and return to activity between the groups

39 patients treated with a single-row repair to 41 patients treated with standard double-row suture anchor repair at an average follow-up of 35 months. Using MRI, the authors found a 25.6% retear rate in the single-row constructs compared with a 9.8% retear rate in the double-row repairs. Similarly, Charousset et al[76] used CT to assess healing at 6 months in both single- and standard double-row repairs. Double-row fixation resulted in a significantly greater healing rate (19 of 31 repairs; 61%) compared with single-row fixation (14 of 35 repairs; 40%). Duquin et al[77] performed a systematic review of more than 1,100 rotator cuff repairs described in studies that compared single-row to double-row constructs. A statistically significant decrease in anatomic retear rates was found for true double-row repairs when compared with single-row repairs for all tears larger than 1 cm.

Although double-row repairs appear to be superior in the laboratory and on imaging exhibit improved healing rates over single-row repairs, similar clinical outcomes between the two techniques have been reported in most studies. Franceschi et al[80] performed a randomized controlled trial comparing 30 patients with single-row repairs and 30 patients with standard double-row fixation. Although the authors believed that the double-row technique produced a mechanically superior construct as evidenced by better cuff integrity on postoperative MRI, they found no significant difference in postoperative clinical scores or range of motion between the two groups at 2-year follow-up.[80] Similarly, in a randomized clinical trial comparing 40 patients (20 single-row and 20 double-row constructs), Burks et al[81] reported no significant differences in clinical outcomes or physical examination results. There were no significant differences in MRI measurements of footprint coverage, tendon thickness, and tendon signal between the groups.[81] Many of these studies may be underpowered, which presents a significant challenge in interpreting the data and applying the information clinically. Researchers at Rush University in Chicago recently determined that to detect a 10% difference in healing rates based on an estimated 30% failure rate for single-row repairs and a 20% failure rate for double-row repairs, 219 patients in each group would be needed for the study to be considered appropriately powered. A summary of the studies comparing single- to double-row repairs and the results of double-row outcome studies are found in **Tables 3** and **4**, respectively.[6,76,79-86]

The TOE bridging construct was developed to provide increased contact and compression on the footprint to enhance healing potential. The medial row of anchors theoretically may provide a barrier between the synovial environment and the healing zone to contain healing factors. Although there are limited clinical data on TOE constructs, early results have been promising. To evaluate the healing rate of TOE repairs, Frank et al[78] examined a cohort of 25 patients with a minimum 1-year follow-up. Postoperative

Table 3
Summary of Results Comparing Single-Row to Double-Row Rotator Cuff Repairs

Authors (Year)	Number of Patients	Mean Age (years)	Mean Anchors	Reported Outcomes
Burks et al[81] (2009)	20 SR, 20 DR	56.5	SR: 2.2 DR: 3.2	No clinical or MRI differences between SR or DR repairs
Park et al[84] (2008)	40 SR, 38 DR	56	Not given	No difference between SR and DR for all, but DR had better outcome scores and Shoulder Strength Index for tears > 3 cm
Franceschi et al[80] (2007)	30 SR, 30 DR	61	SR: 1.9 DR: 2.3	Both had comparable clinical outcome at 2 years; DR repairs produced mechanically superior construct compared with SR repairs
Charousset et al[76] (2007)	35 SR, 31 DR	59	Not given	No significant difference in clinical results, but tendon healing rates were better with DR repairs
Sugaya et al[79] (2005)	39 SR, 41 DR	57.9	SR: 2.4 DR: 3.2	No statistical difference between the groups in the postoperative scores; DR repairs had improved structural outcomes

SR = single row, DR = double row

Table 4
Summary of Results Following Arthroscopic Double-Row Rotator Cuff Repairs

Authors (Year)	Number of Patients	Mean Follow-up	Reported Outcomes
Vaishnav and Millet[85] (2010)	17 with knotless self-reinforcing DR system	1.5 years	Average pain scores decreased; average SANE scores increased; satisfaction 9.8 of 10
Lafosse et al[83] (2008)	105 with DR of SS or SS + IS	Prospective (minimum 2 years)	12 failed repairs (11%); intact RCR associated with significantly increased strength and ROM; postoperative Constant score 80.1 ± 11.1
Sugaya et al[6] (2007)	86 with full-thickness RCT using suture anchors	Prospective, average 31 months (14 months for MRI)	All clinical outcomes scores significantly improved ($P < 0.05$); retear rate higher for larger/massive tears
Huijsmans et al[82] (2007)	242 with DR suture anchor technique	22 months (minimum 12 months)	VAS improved from 7.4 to 0.7; good to excellent outcome in 220 (91%); intact RCR in 174 (83%) via US; improved strength and ROM in intact repairs
Anderson et al[86] (2006)	52 with DR suture anchor technique	30 months (minimum 24 months)	L'Insalata shoulder ratings improved from 42 to 93 ($P < 0.001$); active ROM improved in all planes ($P < 0.001$); strength increased in ER and FE ($P < 0.001$) and IR ($P = 0.033$); failure rate of 17%

DR = double row, SANE = single assessment numeric evaluation, SS = supraspinatus, IS = infraspinatus, RCR = rotator cuff repair, ROM = range of motion, US = ultrasound, ER = external rotation, FE = forward elevation, IR = internal rotation, VAS = visual analog scale

MRIs showed intact rotator cuff repairs in 22 of 25 patients (88%). In tears that were limited to the supraspinatus tendon, 16 of 18 patients (89%) had intact repairs. Healing was noted in three tears that were considered massive.[78]

With the development of these second-generation double-row repair constructs, a new failure mode has been reported. Historically, recognized failure modes for arthroscopic rotator cuff repairs included failure at the bone-anchor interface, the anchor-suture interface, and the suture-tendon interface.[87-89] However, repair failure at the musculotendinous junction following double-row and TOE repairs are now being reported. Trantalis et al[90] identified a subset of five patients who showed an atypical mechanism of tendon failure after a double-row repair. The tendon footprint appeared well fixed in these patients; however, medial to the intact footprint, the tendon was torn through the rotator cuff. Other investigators have reported similar failure modes.[91,92] Cho et al[91] reported on 46 retears following either single-row or TOE repairs. Most of the TOE repairs (74.1%) had a retear pattern that had remnant cuff tissue at the rotator cuff footprint, with the tear occurring more medially. The authors concluded that the TOE technique tended to better preserve the footprint, but retear occurred mainly in the musculotendinous junction. This information may have significant implications in revision surgery following failed bridging repairs. There are several considerations related to this failure mode. If healing rates are superior in double-row or TOE repairs, advocating the implementation of these techniques should be weighed against the potential mechanism of failure. This finding has not been appreciated by most studies that used MRI or ultrasound to evaluate retear rates following double-row or TOE repairs.[1,6,78,80-83] Certainly, there are technical precautions that will minimize this failure mode, and it should be assumed that this failure mode could occur with either standard double-row or TOE repairs. Preventive measures, such as avoiding overtensioning of the medial row by performing an anatomic cuff tear reduction, will reduce stress at the musculotendinous junction. Placing the medial suture lateral to the musculotendinous junction and closer to the rotator cuff cable entirely within the tendon may also minimize this type of failure.

Clinical Decision Making: Single-Row Versus Double-Row Techniques

With such a large amount of data available in the literature and the similarities of the various results, it is prudent to consider patients individually before generalizing the use of a certain construct to all patients. Factors such as patient characteristics, length of the procedure, surgical cost, and technical demands are important when weighing the benefits of the different techniques. Churchill and Ghorai[65] examined the total cost and operating room time of mini-open compared with all-arthroscopic rotator cuff repair techniques at low-, intermediate-, and high-volume centers using the 2006 New York State Ambulatory Surgery Database. The authors reported that the surgical time was significantly shorter in the mini-open group (103 minutes) compared with the all-arthroscopic group (113 minutes). Surgical costs were also significantly less in the mini-open group ($7,841) compared with the all-arthroscopic group ($8,985), resulting in an additional cost of $1,144 more per patient when an arthroscopic repair was performed.[65] Although a breakdown in cost was not reported between the different arthroscopic techniques, it can be assumed that the cost would be higher when a double-row construct is used rather than a single-row repair. Similar surgical time differences were found by Franceschi et al[80] in a study comparing single-row to double-row outcomes. It was reported that the average surgical time for single-row procedures was 42 ± 18.9 minutes and that double-row repair averaged 65 ± 23.4 minutes. These studies did not consider the financial burden associated with anatomic failure following rotator cuff repair (such as time off work or the cost of revision surgery).

Decision making must also take into account certain clinical factors. Probably the most important of these is the size of the rotator cuff tear. Most studies to date examining outcomes from single- and double-row repairs typically have enrolled most patients with tears that are less than 3 cm.[6,41,76,81,93] Park et al[84] compared 40 patients with single-row fixation to 38 patients treated with double-row fixation. The mean age of the patients was 56 years, and outcomes were measured at 2 years postoperatively using the American Shoulder and Elbow Surgeons and Constant scoring systems and the Shoulder Strength Index. The authors reported improvement in functional outcome in both groups, but there was no significant difference between the groups. When patient results were stratified by tear size, no difference was found between the repair techniques in patients with small to medium (< 3 cm) tears; however, in patients with large to massive tears (> 3 cm), all outcome measures were significantly improved in the group that had been treated with a double-row repair.[84] This may be evidence to support the use of single-row fixation in small to medium rotator cuff tears while reserving double-row techniques for large and massive tears.

Summary

Many factors play a vital role in obtaining a successful result after a rotator cuff repair. Patient factors such as age, biology, and environmental influences are beyond the control of the treating surgeon; however, the surgeon does influence the technique of cuff reduction and the repair construct. Recently, many advances have been made in rotator cuff repair. Despite these improvements, it is important to keep in mind the basic tenets of achieving a strong repair, including minimizing motion, achieving an anatomic repair, and preventing gaps. Although second-generation techniques appear to be biomechanically superior to single-row repairs, additional research is needed to define the patient characteristics and type of rotator cuff tear that would benefit from a double-row or TOE repair construct.

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