Biomechanical and Biologic Augmentation for the Treatment of Massive Rotator Cuff Tears

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Recent studies have reported that massive rotator cuff tears do not heal as predictably as, and may have diminished clinical outcomes compared with, smaller rotator cuff tears. An improved understanding of the biologic degeneration and the biomechanical alterations of massive rotator cuff tears should provide better strategies to optimize outcomes. The approach to patients with massive rotator cuff tears requires careful assessment of the patient and the extent of rotator cuff degeneration to determine the appropriate treatment. For a rotator cuff tear that is repairable, the goal is to produce a tension-free, anatomical repair that restores the footprint using soft tissue releases and various suturing techniques, including double-row, transosseous-equivalent suture bridges or the rip-stop stitch. For irreparable cuff tears, the surgeon may elect to proceed with 1 of 2 approaches: (1) palliative surgical treatment—that is, rotator cuff debridement, synovectomy, biceps tenotomy, tuberoplasty and/or nonanatomical repair with partial repair; or (2) salvage treatment with various tendon transfers. Even though the biomechanical constructs for rotator cuff repairs have been improved, the integrity of the repair still depends on biologic healing at the tendon-to-bone junction. There has been much interest in the development of a scaffold to bridge massive rotator cuff tears and adjuvant biologic modalities including growth factors and tenocyte-seeded scaffolds to augment tendon-to-bone healing. The treatment of rotator cuff disease has improved considerably, but massive rotator cuff tears continue to pose a challenging problem for orthopaedic surgeons.

Keywords: rotator cuff; massive; tear; repair; biologics

DeOrio and Cofield[25] defined massive rotator cuff tears as those in which the length of the greatest diameter of the tear measured more than 5 cm; other authors have defined massive cuff tears as those that involve at least 2 tendons.[38] The literature on both open and arthroscopic approaches reports improved results in shoulder function and pain relief with rotator cuff repair, although the size of the tear has a direct effect on clinical outcome and tendon healing.[4,6,16,17,25] Galatz et al[32] published one of the early series of arthroscopic rotator cuff repair for massive tears and determined that 17 of 18 (94%) resulted in repeated tears. Recent series of arthroscopic rotator cuff repair have demonstrated that postoperative healing occurs between 71% and 89% for the entire cohort, but tendon healing drops considerably to 47% to 50% for the subset of massive rotator cuff tears.[1,6,31,40,41,67,73] In addition, other studies report that rotator cuff tears may progress in size over time and become associated with muscle atrophy and fatty infiltration.[27,85] The purpose of the present article was to examine the biologic and biomechanical alterations associated with rotator cuff degeneration, to review the clinical results of the treatment of rotator cuff repair for massive tears, to discuss surgical techniques and methods of fixation, and to explore possible methods to augment the healing of degenerative rotator cuff tendon.

Alterations in Tendons in Massive Rotator Cuff Tears

Biopsy samples obtained from spontaneously ruptured tendons demonstrate that 97% have evidence of a characteristic histopathologic pattern consistent with degenerative changes

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in the cuff tissue.[59] Although macroscopic changes may not be visible, rotator cuff tendinopathy has been associated with reduced cellularity, decreased vascularity, increased disorganization, and lower collagen concentrations than normal tendon tissue.[2,33,40] After a massive cuff tear, a process of atrophy, fibrosis, and fatty infiltration occurs within the torn tendon as well as the associated muscle belly.[38] Massive cuff tears are also often characterized by less compliant and more stiff tissue, sometimes leading to severely retracted tendon margins, especially where tissue has atrophied or has fatty infiltration.[40,62] The wide-tear margin coupled with poor-quality tissue makes surgical mobilization difficult and sometimes impossible.[85]

Alterations of Shoulder Mechanics With Massive Cuff Tears

Massive rotator cuff tears typically involve the supraspinatus superiorly and the infraspinatus (and rarely the teres minor) posteriorly. It is much less common for rotator cuff tears to extend anteriorly and involve the subscapularis tendon. In the axial plane, the deltoid moment is no longer balanced by the subscapularis, infraspinatus, and teres minor muscles, leading to loss of the subacromial space. However, Hansen et al[45] demonstrated that in the presence of a massive rotator cuff tear, stable glenohumeral abduction can be maintained without excessive superior translation, provided that the remaining intact cuff generates sufficient force to counteract the deltoid. For 6- and 7-cm tears with equal extension into the anterior and posterior cuff, the increased force requirements in the remaining intact cuff portions were less than 50% of the intact condition. However, for 8-cm tears, the necessary force requirements were found to be greater than 80% of the forces generated in the normal state. Furthermore, the increased compensatory forces must act through a smaller cross-sectional area, potentially leading to further tear extension and perhaps warranting early repair of such defects, or leading to failure of repairs already performed.[45]

The loss of shoulder stability resulting from large rotator cuff tears can result in other shoulder structures becoming increasingly important for structural integrity. For example, the coracoacromial arch, normally implicated as an extrinsic etiologic factor in cuff tearing, often acts as a stabilizer against anterosuperior dislocation of the humeral head in this condition.[81] Consequently, subacromial decompression with release of the coracoacromial ligament is not advocated in these patients.[30] There is yet no clear consensus regarding the function of the long head of the biceps muscle with regard to active superior humeral stability.[55,114,115,119,125] In massive cuff tears with subscapularis tendon involvement, the long head of the biceps often subluxates medially, thereby necessitating tenodesis or tenotomy during the repair.[68]

ROTATOR CUFF REPAIR

The goal of rotator cuff surgery is an anatomical, tension-free repair of the rotator cuff tendons to the footprint.[2,109,117] Long-term data show successful results with open repair,[28,34,48,95,128] but with improved techniques, arthroscopic methods are showing similar results,[14,35,108,122] although long-term data with objective validated assessment tools are still limited.

The initial approach to patients with rotator cuff tears requires careful assessment of a number of factors. These include age, comorbidities such as diabetes, history of smoking, use of nonsteroidal anti-inflammatory drugs, the extent of rotator cuff degeneration, size and chronicity, and overall fitness. Patients over the age of 65 have been shown to have a higher frequency of larger tears and fewer excellent results than younger patients, although satisfaction rates in studies of patients 62 years of age and older are high.[44,47,65,124] In a recent prospective analysis of the prognostic factors affecting clinical and ultrasound outcome, age and tear size were the most significant independent factors affecting ultrasound outcome.[84] Diabetes has been shown to lead to higher rates of infection and rotator cuff repair failure,[19] and a study evaluating the effects of smoking found that the nonsmokers had greater postoperative pain relief and higher clinical scores than smokers.[74] Nonsteroidal anti-inflammatory drugs have been shown to inhibit tendon-to-bone healing in a rat model,[22] and their use should be reconsidered after rotator cuff repair.

The initial treatment should begin with nonoperative management, which includes activity modification, anti-inflammatory medications, physical therapy, and possibly steroid injections.[43] Nonoperative treatment of impingement syndrome and rotator cuff tears with physical therapy that attempts to restore shoulder function and strengthen the intact portions of the rotator cuff, periscapular muscles, and deltoid has been shown to be effective.[56,79] More recent data on structured deltoid rehabilitation programs, including Levy exercises, have demonstrated significant improvements in Constant scores and forward elevation in medically unfit elderly patients with massive rotator cuff tears.[67] Corticosteroid use, however, is controversial. In a recent systematic review, the authors found little reproducible evidence to support the use of subacromial injections in rotator cuff disease,[62] although 2 studies showed improved range of motion[1,91] and 1 study showed greater pain relief with the injections.[1]

Surgical management may be necessary for patients with failed nonoperative therapy, and the most appropriate treatment should be determined on a case-by-case basis. The orthopaedic surgeon should first determine if the massive rotator cuff tear is amendable to repair. The history and physical examination may provide clues to the duration of symptoms, and thus the chronicity of disease. On physical examination, patients may demonstrate the external rotation lag sign, or the hornblower's sign, which has been shown to be highly sensitive and specific for irreparable massive cuff tears involving the teres minor.[113] An external rotation lag with the arm adducted is usually consistent with an infraspinatus tear. Both the "lift-off" sign and the "belly press" sign, as well as internal rotation lag, are indicative of subscapularis tear.[39,40,49] Severe limitations in active motion may indicate a suprascapular neuropathy, and an EMG scan should be obtained before surgical treatment.[75] Plain radiographs should be obtained to determine the acromiohumeral distance and evidence of glenohumeral joint degeneration. Acromiohumeral distance (<7 mm) on an anteroposterior radiograph has a significant negative correlation with size of rotator cuff tear and fatty degeneration of the infraspinatus tendon, and may indicate an irreparable tear; however, other studies have reported poor intraobserver and interobserver reliability.[5,12,28,97] The MRI findings associated with irreparable tears include tear size greater than 40 mm in both length and width, supraspinatus width of less than 5 mm at the superior margin of the glenoid, as well as high signal in the infraspinatus tendon.[105] Magnetic resonance imaging can also be used to determine the degree of atrophy and fatty infiltration, which have been positively correlated with poor outcomes and irreparability.[38,42] It should be emphasized, however, that although MRI is useful in better understanding the pathologic abnormalities, it cannot necessarily determine the ability to repair a defect, as laxity or stiffness can vary greatly depending on the patient.

Open Rotator Cuff Repair

Long-term studies have shown that open rotator cuff repair can provide pain relief, with improvements in function and strength.[21,34,95,110,128] However, the results for large or massive cuff tears have been less predictable. Cofield et al,[21] in their prospective study of 105 shoulders (average 13.4 years of follow-up), 49 of which had large (38) or massive (11) tears, found that massive tears demonstrated no significant difference in terms of postoperative active abduction or external rotation compared with baseline. According to the Neer classification, only 2 of the 11 shoulders (18%) with massive tears had excellent results, compared with 21 of the 38 shoulders (55%) with large tears. However, 6 of the 11 patients with massive tears (55%) stated they were "much better" postoperatively.[21] In another study, however, Rokito et al[95] reported satisfactory long-term outcomes on patients treated with open repair of large or massive cuff tears. They noted a significant decrease in pain along with a significant improvement in function and range of motion.[95] Some limitations of these 2 studies include subjective outcomes assessment tools and small sample sizes, respectively.

Harryman et al[46] were among the first to show that the integrity of the cuff at follow-up rather than the size of the tear at time of surgery may be a major predictor of postoperative outcome. They found that 68 of 105 (65%) of repaired rotator cuffs remained intact at an average of 5 years.[46] Intact rotator cuffs at follow-up had better function and range of motion compared with recurrent defects. Of those patients whose shoulders had with intact tendons, 92% reported being free of pain and 96% were satisfied. Despite having worse functional outcomes, 87% of those with recurrent defects were satisfied as well. Other groups have also reported a correlation between the integrity of the repair and functional outcomes.[36,58] Because the true relationship between repair site integrity and outcomes is not fully elucidated at this point, future studies that address this topic are needed.

Although open repairs showed evidence of successful outcomes, surgeons found they could better visualize the pattern of the tear with the use of an arthroscope, as well as mobilize and repair the rotator cuff, all the while eliminating the need for deltoid detachment, which was necessary in open repairs and can lead to residual weakness. This led to an increase in the popularity of arthroscopic repairs.

Arthroscopic Rotator Cuff Repair

In a series of 59 patients treated arthroscopically with an average of 3.5 years of follow-up, Burkhart et al[14] reported significant improvement in pain, function, strength, and motion for patients with all tear sizes, including massive tears. Jones and Savoie[57] reported on 50 patients, 13 with massive tears, with an average follow-up of 32 months. In their study, 98% were satisfied and 88% had a good or excellent University of California at Los Angeles (UCLA) score. The authors did not report any difference between massive and smaller rotator cuff tears. Bennett[4] reported significant improvement in Constant and American Shoulder and Elbow Surgeons (ASES) scores, significant decrease in pain, and a 95% satisfaction rate in 37 patients with massive tears treated arthroscopically at a mean follow-up of 3.2 years.

Nevertheless, these positive results must be viewed critically, as the rate of recurrence of defects has been shown in some studies to be greater than that of open rotator cuff repairs.[32] One should also be wary of the fact that the rate of recurrence may be confounded by repaired defects that never healed. Galatz et al[32] reported the results of a series of large rotator cuff tears (>2 cm) repaired arthroscopically and noted recurrent tears were observed in 17 of 18 (94%) patients by ultrasound at 1 year. Verma et al[111] reported retear rates of 50% in repaired massive cuff tears by ultrasound, but the retear rate was only 19% for tears smaller than 3 cm. Galatz et al[32] also reported in their series that the ASES score had increased from an average of 48.3 preoperatively to 84.6 points at 1 year but decreased to 79.9 points at 2 years after surgery, leading many to believe that the integrity of the repair plays a significant role in postoperative outcomes.[32] Indeed, other authors have noted superior clinical outcomes with intact repairs. Huijsmans et al[51] reported a 53% retear rate by ultrasound in arthroscopically repaired massive rotator cuffs; intact repairs exhibited significantly better strength and active forward elevation results. In a prospective study of arthroscopic rotator cuff repair of full-thickness tears, Lafosse et al[64] noted a retear rate of 17% for large or massive cuff in their series, with significantly lower pain scores in patients with intact repairs. Boileau et al[9] also noted significantly greater strength in patients whose tendons had healed, and Charousset et al[18] noted that functional recovery was poorer for retears in their series. Cole et al[23] found a 22% recurrent tear rate as well as an inverse correlation between recurrent tear and functional outcomes. In a prospective study of arthroscopic double-row repairs, Sugaya et al[104] noted a 5% retear rate for small-to-medium tears and a 40% retear rate for large and massive tears, with inferior overall scores and strength for failed repairs.

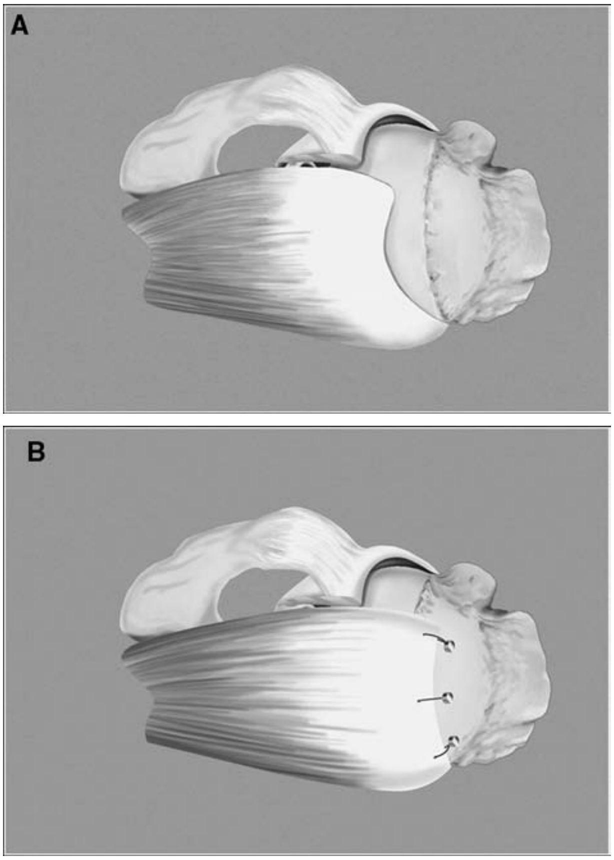

Figure 1. Interval slide techniques. A, use an interval slide to release the coracohumeral ligament between the supraspinatus and subscapularis tendons. B, once mobilized, the supraspinatus tendon can be fixed at its anatomical footprint with minimal tension Reproduced with permission from Tauro JC. Arthroscopic repair of large rotator cuff tears using the interval slide technique. *Arthroscopy.* 2004;20(1):13-21.[71,72]

The anterior arthroscopic interval slide is a method to mobilize massive, contracted, immobile rotator cuff tears by releasing the rotator interval past the medial border of the capsule, as described by Tauro[107] (Figure 1). A posterior interval slide involves release of the interval between the supraspinatus and infraspinatus but should not extend medial to the scapular spine to avoid inadvertent injury to the suprascapular artery. In their study of arthroscopically repaired massive cuff tears using single- and double-interval slides, Lo and Burkhart[69] reported 8 of 9 (89%) patients were satisfied, along with a 10.0 increase in the postoperative UCLA score, at a mean follow-up of 17.9 months.[69,70]

Optimizing Biomechanical Construct With Arthroscopic Rotator Cuff Repair

The method of fixation in arthroscopic repairs has been implicated as an important source of repair failure.[16,24,127] The various arthroscopic fixation techniques currently available include single-row repairs, double-row repairs, and transosseous equivalent repairs (Figure 2). In biomechanical studies comparing single- versus double-row repairs, double-row repairs exhibited less gap formation, more stiffness, and higher ultimate load to failure[61]; double-row configurations were also better adept at restoring the anatomical footprint.[76] In a cadaveric model, Park et al[89] showed that the transosseous equivalent rotator cuff repair with 4 suture bridges had significantly greater tendon-insertion contact area than both the double-row and 2-suture bridge techniques. In a second article, the same group showed that the transosseous equivalent repair had higher ultimate load to failure than the double-row technique in cadaveric specimens.[90] In a cadaveric model of massive rotator cuff repairs, Tashjian et al[106] reported no significant difference in cyclic loading of transosseous and single-row suture anchor techniques. Clinical studies on double-row versus single-row repairs are limited, but a recent cohort study showed significantly greater ASES and Constant scores, as well as Shoulder Strength Index scores in patients with large to massive tears (>3 cm) treated with double-row repair compared with single-row repair.[88] There were no significant differences between the 2 repairs for small to medium tears. Charousset et al[17] reported better tendon healing rates with double-row repairs as compared with single row, but no significant difference in clinical results. Sugaya et al[103] also found no significant difference in outcome between double-row and single-row repair in their series. A recent, randomized controlled trial of single-row versus double-row fixation found no significant difference in UCLA scores or range of motion between the 2 groups at 2 years between the 2 constructs, although more of the patients had intact tendons in the double-row fixation group.[31] Although sample sizes and duration of follow-up are limited, and only 1 study is a randomized controlled trial, these reports do show that evidence to support the superiority of double-row fixation, in terms of clinical functional outcomes, is currently limited.

Suture configurations also play an important role in arthroscopic fixation as the suture-tendon interface has been recognized as a weak link. The modified Mason-Allen stitch, the preferred stitch in open repairs, is challenging to perform arthroscopically; consequently, there is the recent search for a biomechanical equivalent. The massive cuff stitch[73] is a combination of simple and horizontal stitches that has an ultimate tensile load similar to that of a modified Mason-Allen suture (Figure 3). This is attractive not only because of its relative simplicity but also its fundamental structural similarity to the modified Mason-Allen stitch. In a biomechanical study of sheep infraspinatus tendons by Ma et al,[73] the massive cuff stitch demonstrated significantly greater ultimate tensile load compared with the simple and horizontal stitches. There was no significant difference in ultimate load between the massive cuff stitch and the modified Mason-Allen stitch.[73] A more recent in vitro study comparing the modified Mason-Allen stitch and massive cuff stitch when suture-anchored into bone also found no significant biomechanical difference between these 2, and the authors concluded that the massive cuff stitch may be a simpler and biomechanically equivalent alternative to the modified Mason-Allen stitch.[100]

A number of advanced techniques have been also used in arthroscopic rotator cuff repairs to help mobilize retracted, difficult, massive cuff tears, such as margin convergence and

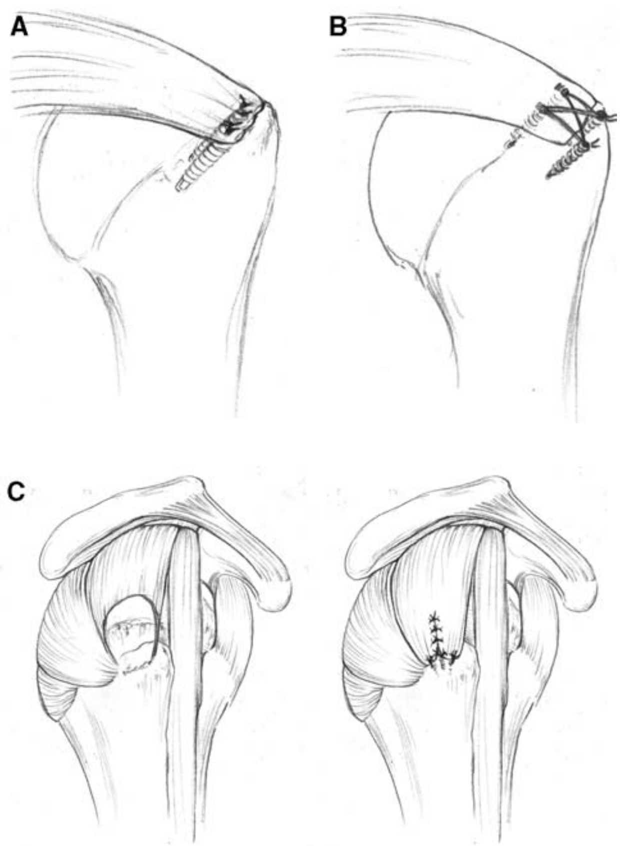

Figure 2. Arthroscopic rotator cuff repair suture anchor fixation. A, single-row configuration. B, double-row with suture bridge configuration. C, margin convergence with single-row configuration.

partial repairs. Biceps procedures are often used to treat pain and symptoms associated with biceps tendinopathy.

Margin Convergence

Margin convergence aims to decrease strain at the tendon-bone interface of the rotator cuff repair by apposing the anterior and posterior cuff tear margins at the apex (Figure 2C).[13] In their case series of 59 patients with average follow-up of 3.5 years, Burkhart et al[14] reported no significant difference in U-shaped tears treated with margin convergence versus crescent-shaped tears treated by direct tendon-to-bone repair.

Partial Repairs

The technique of partial repair for massive rotator cuff tears attempts to restore normal shoulder mechanics despite incomplete defect coverage. As described by Burkhart et al,[15] the goal is to convert the tear to a "functional cuff tear" by repairing the tear margins and restoring anteroposterior force couples. In the original article, the authors reported 93% patient satisfaction and an average postoperative UCLA score improvement of 18.8. Moser et al[80] reported on 38 patients with massive rotator cuff tears treated with complete repair, partial repair, or debridement alone. Using the Shoulder Pain and Disability Index, those patients treated with complete or partial repair fared better than those treated with debridement alone. A retrospective study of partial repair of massive rotator cuff tears in 24 patients reported excellent results in 11 patients (46%), good in 5 (21%), fair in 7 (29%), and poor in 1 (4%), with 92% overall patient satisfaction and 83% satisfactory pain relief.[27]

Biceps Tendon Surgery

Rotator cuff injury or disease is often associated with biceps tendon degeneration. Treatment of biceps tendon degeneration includes simple debridement, tenotomy, or tenodesis. In patients with massive irreparable rotator cuff tears, both isolated arthroscopic biceps tenotomy or tenodesis can be used to treat severe pain or dysfunction.[8,10,114] Tenodesis has been favored by some in patients age 50 or younger because it reduces the risk of cosmetic deformity and muscle weakness.[41,60,77,93]

Several authors have also advocated using the biceps tendon as a graft for rotator cuff treatment.[6,82,123] Rhee et al[92] described both open and arthroscopic repair of irreparable massive rotator cuff tears augmented with tenotomized biceps, noting excellent outcomes in 15 of 31 (48.4%) and good outcomes in 13 of 31 (41.9%) at an average of 32 months of follow-up.

TENDON TRANSFERS

Transfers of other rotator cuff muscles or distant muscle/tendon transfers may be options for treating irreparable massive rotator cuff tears. The latissimus dorsi muscle transfer to the greater tuberosity is the most commonly performed. It is often recommended, however, as a salvage procedure rather than the initial treatment for massive rotator cuff tears for chronic, disabling shoulder pain with significant functional impairment.[78] Miniaci and MacLeod[78] reported significant pain relief and improvement in function with the latissimus dorsi transfer. Gerber[37] reported poor results with latissimus transfer in the setting of a torn subscapularis, which Werner et al[120] attributed to inability of the latissimus transfer to center the humeral head with abduction and elevation without an opposing subscapularis.

Some of the factors associated with improved clinical results with latissimus transfers include synchronous in-phase contraction of the transferred muscle (variable finding) and preoperative shoulder function and general strength.[54] In the review by Iannotti et al,[54] female patients with poor preoperative shoulder function and strength were at greater risk for a poor clinical result.

Subcoracoid pectoralis major transfer has been used in patients with anterosuperior subluxation associated with massive rotator cuff tears. Of 14 patients who underwent this procedure, 11 (79%) demonstrated satisfactory results and 3 (21%) demonstrated unsatisfactory results at a

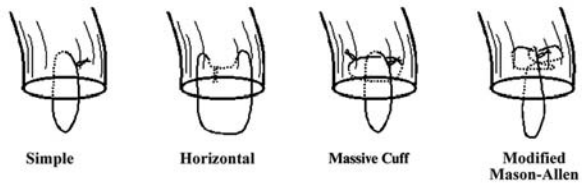

Figure 3. Different options for rotator cuff stitches. The massive cuff stitch is both simple to perform and has excellent biomechanical properties. Reproduced with permission from Ma CB, Comerford L, Wilson J, et al. Biomechanical evaluation of arthroscopic rotator cuff repairs: double-row compared with single-row fixation. *J Bone Joint Surg Am.* 2006;88:403-410.[72]

mean 17.5 months of follow-up. Thirteen of the 14 patients had improved humeral head containment and ability to perform activities at waist level.[33] Other types of muscle transfers include teres minor, deltoid, and trapezius. These are infrequently used and are associated with compromised motor function.[6,52,83,86,118,121]

BIOLOGIC AUGMENTATION

Recent work on alternatives to tendon transfers for massive, retracted rotator cuff tears has focused on xenografts and synthetics. Porcine dermal collagen and small intestinal submucosa (SIS) have both been successfully used in a wide variety of surgical procedures to provide strength and support when soft connective tissues have been lost or damaged.[11,50,66,87,96,99] Derwin et al[26] examined the biochemical, biomechanical, and cellular properties of collagen-rich extracellular matrices, GraftJacket (Wright Medical Technology Inc, Arlington, Tennessee) and TissueMend (TEI Biosciences, Boston, Massachusetts), and 2 SIS grafts, Restore Orthobiologic Implant (DePuy Orthopaedics Inc, Warsaw, Indiana) and CuffPatch (Biomet Inc, Warsaw, Indiana). The SIS matrices were found to have higher elastic moduli than GraftJacket and TissueMend, and they reached their maximum elastic moduli at lower levels of stretch. All matrices had elastic moduli 1 order of magnitude lower than that reported for human infraspinatus tendon, suggesting that they could not be expected to carry large loads when used for rotator cuff augmentation.

These xenografts are now starting to be applied to rotator cuff repairs, particularly as an adjuvant for irreparable massive tears. Presently, however, scant clinical data exist supporting the use of porcine dermal collagen and SIS grafts for rotator cuff augmentation in humans.[3] Badhe et al[3] used the Zimmer patch (manufactured by Tissue Science Laboratories plc, Aldershot, United Kingdom, and distributed by Zimmer Inc, Warsaw, Indiana) to augment the repair of massive rotator cuff defects in 10 patients. One year after surgery, the authors found statistically significant improvements in the mean Constant score, preoperative pain score, abduction power, and range of motion in internal/external rotation as well as abduction. All patients were able to perform activities of daily living and there was a high degree of satisfaction in all but 1 patient. Imaging performed at an average of 4.5 years postoperatively showed only 2 of 10 grafts to be detached, which the authors use to support their recommendation of the graft for biologic augmentation. Soler et al[101] examined the ability of Permacol (porcine dermal collagen implants, Tissue Science Laboratories Inc, Andover, Massachusetts) to bridge residual massive cuff defects and serve as an augmentation material in massive rotator cuff repair. The authors' findings supported those of Badhe et al,[3] and they advocated using Permacol as an augmentation graft but not to bridge residual cuff defects.[3,101] All patients who received Permacol for the latter purpose ultimately experienced signs and symptoms of a recurrent rotator cuff tear. Sclamberg et al[98] found that SIS xenografting did not improve clinical outcomes and was ineffective in reinforcing large and massive rotator cuff tears. Ten of 11 patients had MRI-documented retears at 6 months postoperatively and 5 patients actually had worse clinical scores after surgery. Walton et al[116] recommended against using the Restore Orthobiologic Implant to augment rotator cuff repairs after finding that patients receiving the xenograft had similar retear rates compared with controls. Patients also had significantly less lift-off, internal rotation, and adduction strength, more impingement in external rotation and a higher incidence of postoperative reactions requiring surgical treatment. Iannotti et al[53] recommended against using porcine SIS for augmentation of large and massive rotator cuff tears in humans after performing a randomized controlled study that found significantly lower median postoperative functional scores as well as median total Penn Shoulder and patient satisfaction scores that did not differ significantly from controls.

Other research groups have focused on the complex tendon-bone interface with several studies aimed at unraveling the cellular and molecular interactions at these healing interfaces. Using a triphasic scaffold, Spalazzi et al[102] showed that fibroblasts and osteoblasts initially confined to soft tissue formation and bone formation areas, respectively, migrated into an intermediate scaffold region engineered to support both cell types that led to the production of a type 1 collagen matrix. Rodeo et al[94] examined the effects of a mixture of osteoinductive growth factors on tendon-to-bone healing in an acute infraspinatus repair model in sheep and found that repairs treated with cytokines generated a more robust fibrocartilage zone that yielded higher failure loads as compared with controls; however, when normalized for tissue volume it appeared that cytokine treatment resulted in the production of poor-quality scar tissue rather than true tissue regeneration. Kovacevic and Rodeo[63] also examined the effects of recombinant human bone morphogenic protein-12 (rhBMP-12), a novel cytokine that is expressed at tendon insertion sites during embryonic development, on tendon-to-bone healing in an ovine model and found that repair constructs had increased load-to-failure and stiffness compared to sponge carrier alone and control repairs at 2 months postoperatively.[63] Additionally, increased amounts of glycosaminoglycan were found in the rhBMP-12 treatment groups, which correlated positively with the maximum load. Chen et al[20] studied the effects of tenocyte-seeded bioscaffolds (Restore, porcine SIS, and ACI-Maix, type I/III collagen [Genzyme Biosurgery, Cambridge, Massachusetts]) on healing of massive rotator cuff defects in rabbits and

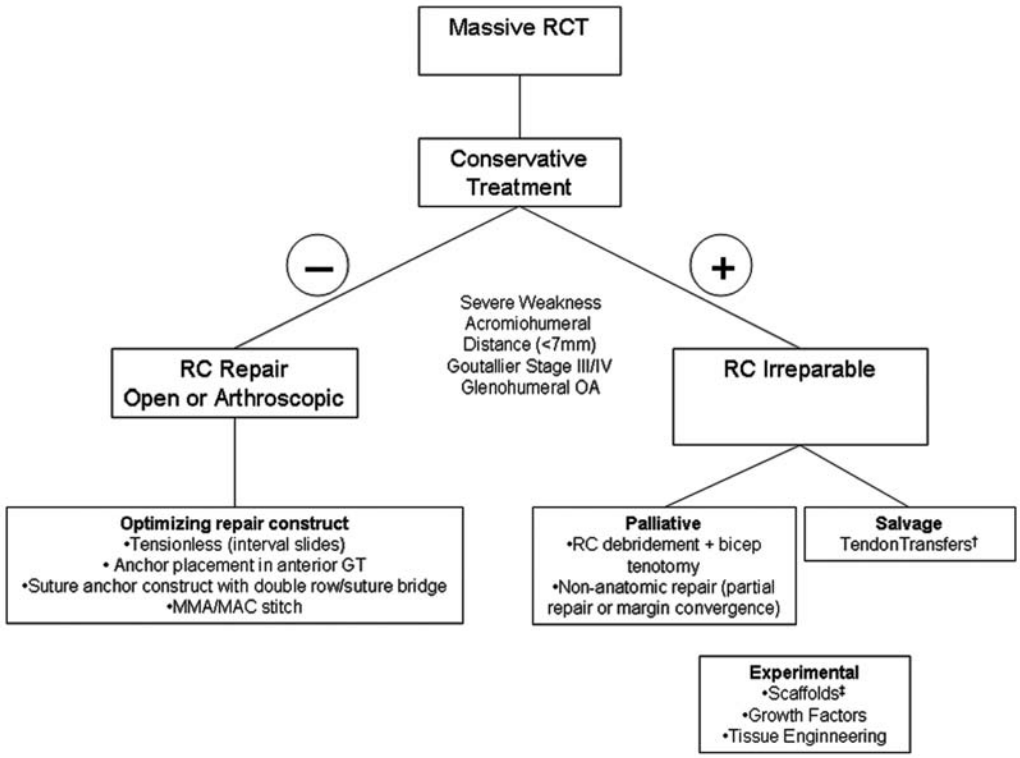

Figure 4. Treatment algorithm for massive rotator cuff tears. RCT, rotator cuff tears; RC, rotator cuff; OA, osteoarthritis; MMA, modified Mason-Allen stitch; MAC, massive cuff stitch. †Latissimus dorsi transfer, pectoralis major transfer, and others. ‡Xenografts and synthetics.

found that inflammatory changes were significantly less in the tenocyte-seeded bioscaffold repairs than in bare bioscaffolds, suggesting that tenocytes accelerate the graft-absorption process. The type 1 collagen positive cell ratio was significantly higher in the tenocyte-seeded bioscaffold repairs as compared with bare bioscaffold repairs. Additionally, by 8 weeks postoperatively, the ACI-Maix–seeded implant was histologically more similar to control autograft repairs than the group implanted without tenocytes.

Recent work on the matrix metalloproteases (MMPs) has shown an increase in expression of MMP-1 (collagenase), MMP-3 (stromelysin), and MMP-9 in rotator cuff disease, which correlates with tear size, although 1 study noted a decrease in MMP-3 messenger RNA levels.[7,71,112,126] Further work on the clinical significance of these findings and on the use of biologics or steroids to limit the catabolic effects of these enzymes is necessary.

TREATMENT ALGORITHM

The approach to a patient with massive rotator cuff degeneration must consider the patient-related and disease-related factors. Treatment should begin with activity modification, anti-inflammatory medications, steroid injections, and physical therapy. Surgical treatment may be appropriate for patients with failed nonoperative management and persistent pain. In addition to a meticulous history and physical examination, plain radiographs and MRI are useful in the evaluation process, and, in rare occasions, an EMG evaluation may be ordered to determine the reparability of the massive rotator cuff tear. Several preoperative factors have been associated with irreparable massive tears including significant external rotational weakness,[113] superior migration of the humeral head,[5,12,28,97] and muscle atrophy and fatty infiltration of the rotator cuff muscles.[38,42] On the basis of preoperative factors, the orthopaedic surgeon should attempt to classify the massive tear pattern as repairable or irreparable, and the final decision will be made at the time of surgery. If repairable, the goal is to produce the strongest, most anatomical repair possible using the various suture/fixation techniques available. If irreparable, the surgeon may elect to proceed with 1 of 2 approaches: (1) palliative treatment—rotator cuff debridement, synovectomy, biceps tenotomy,[8,10,114] nonanatomical repair with partial repair[15,27,80] or margin convergence[13,14] and possibly tuberoplasty[29]; and (2) salvage treatment—namely tendon transfers, such as latissimus dorsi for posterosuperior defects[18,37,54,120] and pectoralis major for anterosuperior defects.[33] Other experimental treatment options to be considered are tendon scaffolds to augment the repair, growth factors, and, eventually tenocyte-seeded scaffolds, although the literature does not fully support use of this technology at this time (Figure 4).

CONCLUSION

The goal of all rotator cuff repair surgery is to create a biomechanical construct that is capable of forming a lasting tendon-bone interface and promotes healing. In the case of massive cuff tears, the challenges of repair are even greater because the tissue is often chronically retracted and fibrotic. Changes in the histologic properties of the soft tissues about the glenohumeral joint and the biomechanics of the shoulder can lead to marked disability and pain. Initial surgical treatment consisted of open approaches that have now evolved to all-arthroscopic repairs. Although the results have been promising, construct integrity has been identified as an important factor in satisfactory outcomes, and researchers and clinicians are striving to improve the methods and modes of fixation.

Salvage procedures in irreparable massive cuff tears include tendon transfers, especially the latissimus dorsi for posterosuperior tears. Advances in synthetics and scaffolds provide a potentially new avenue of treatment as the contributions of biologics to therapy are incorporated. With further elucidation of the molecular and cellular subtleties taking place at tendon-bone healing interfaces, it is hoped that growth-factor or cell-coated scaffolds will one day be able to aid in the production or recreation of physiological grade soft tissue.

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