Patch Augmentation for Massive Rotator Cuff Tears

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Rotator cuff tears commonly affect the shoulder joints. Despite developments in surgical techniques and instrumentation, the treatment of massive rotator cuff tears remains challenging. The problems associated with rotator cuff repairs, such as inferior mechanical properties and high retear rates are yet to be solved. Recently, patch augmentation has been suggested as an alternative treatment because it can reinforce mechanical properties at the initial stage of healing and reduce gap formation. The purpose of this article was to comprehensively summarize the concepts and the consensus surrounding patch augmentation and evaluate the clinical and anatomical outcomes after patch augmentation for massive rotator cuff tears.

(Clin Shoulder Elbow 2017;20(2):105-112)

Key Words: Rotator cuff; Tear; Tendon; Shoulder

Introduction

A rotator cuff tear is a common disease of the shoulder. These tears are often classified by their size as small, medium, large, or massive. The most severe, massive tears are defined as a complete separation of two or more tendons. And, although literature reports vary in terms of its prevalence, massive rotator cuff tears have been shown to account for around 10% to 30% of all cuff tears.1 The first-line of treatment for rotator cuff tears should ideally be conservative, and failed conservative management or large tears should be treated surgically. Among the surgical treatments, the primary rotator cuff repair has been shown to give a functionally complete recovery and is also the recommended choice of treatment. However, for massive rotator cuff repairs, which often include the repair of the anatomical footprint, only a subset of studies has shown good outcomes.2,3 This is thought to be because the stiffened and shortened cuff tendons in patients with massive cuff tears causes sufficient footprint coverage. Despite developments in surgical techniques and instrumentation, repairs of massive cuff tears remain a challenge to many orthopedic surgeons.

Furthermore, outcomes of massive rotator cuff repairs have often been shown to be either unsatisfactory or unpredictable. And the early-stage excessive tension that the cuff complex has to endure has been associated with the high failure rates of this procedure even when a successful restoration is initially observed.4,5 The reported values of this failure rate differ depending on tear size, patient age, muscle atrophy, fatty degeneration, and chronicity, even reaching a rate of 94%.6-10 Improving the success rates of rotator cuff repairs, thereby the clinical outcomes, involves two essential requirements: 1) the rotator cuff complex must be able to endure early tension during the early reparative stage (between the repair of mechanical properties and the formation of tendon) and 2) biological ability that maximizes the healing capacity of the bone-tendon junction must be obtained. As a solution to these milestones, an augmentation graft made up of patch material was introduced for large-to-massive rotator cuff tears, for irreparable tears, or for poor quality tendons (Fig. 1).
Classification of Patch Grafts

Patch grafts can be classified broadly into xenografts, synthetic grafts, allografts, and autografts. The common harvest sources for xenografts are the porcine dermis and the porcine small intestinal submucosa; for synthetic grafts, the polyglycolic acid sheet, polypropylenes, the mersilene mesh, the gore-tex patch, and etc.; for allografts, the human dermal matrix and freeze-dried cadaveric rotator cuffs; and for autografts, the biceps tendon, the fascia lata, and the patellar tendon (Table 1). In the past, xenografts had been the most widespread form of patch grafts, but they fell out of popularity because, compared to other grafts, they were associated with less favorable structural healing rates. Its superiority to primary repairs was never demonstrated and there were several reports of immunogenic complications that disfavored their use. Further, compared to groups that had not use synthetic grafts or to groups that had used allografts, groups that had used synthetic grafts were associated with better structural and functional results. Theoretically, these synthetic composite materials can be engineered in a way that key biomechanical properties, such as strength are optimally manipulated. But the biological consequences of these synthetic materials, such as foreign body reaction, poor integration, and synovitis, upon insertion into the body may be inevitable. Well designed controlled studies that investigate the effectiveness of these synthetic grafts are still lacking.

Findings from a recent systemic review of animal and clinical experiments suggest that the effectiveness of xenografts are questionable, whereas those for synthetic grafts and allografts indicated they were associated with good clinical outcomes. A study that estimated re-tear rates according to patch graft type reported that xenografts showed the worst re-tear rate (xenografts [44%] vs. synthetic graft [15%] vs. allografts [23%]). These negative findings of xenografts have been succeeded with a corresponding decrease in the use of xenografts in the clinic. As an alternative to xenografts, patch grafts—a type of allografts consisting of human dermal matrix—are increasingly coming under light because of their low incidence of complications, such as disease transmission and graft rejection, and their relatively safety. Patch grafts are de-cellularized freeze-dried human cadaveric material consisting of collagen type I, II, IV, and VII, elastin, chondroitin sulfate, proteoglycans, and fibroblast growth factors and has in it preserved basement membrane and vascular channels, two constituents which have been shown to help host incorporation. However, well-designed and long-term studies that investigate the mechanism of patch grafts and their effects are limited. And the possibility of remnant allogenic proteins within the scaffolds means that inflammatory responses may occur and cause tissue degeneration. Furthermore, bony in-growth formation, which is fundamental for functional restoration of the tendon, is nonexistent in allografts, restricting their use.

Common harvest sources of autografts include the tensor fascia lata, the biceps long head tendon, the hamstring tendon, the patellar tendon, and the Achilles tendon. Because these grafts originate from the person’s own body, they are regarded as the gold-standard choice of graft. Studies on autografts have shown favorable clinical outcomes and the successful outcomes have been shown to be dependent on cells within scaffolds that activate collagen synthesis and, thereby, start the process of tendon re-formation. Accordingly, autografts with viable donor cells are preferred over frozen allografts with unviable donor cells. Biomechanically, autografts have been reported to be stronger than allografts. However, using allografts has disadvantages of causing donor site morbidity and of limited availability; normally, finding an appropriate graft is difficult because a graft must be both sufficiently thick and sufficiently sturdy to withstand the

| Classification of Patch Grafts |
|-------------------------------|
| **Xenografts** | Porcine dermal graft, porcine small intestine submucosa, fetal bovine dermis |
| **Allografts** | Human dermal matrix, freeze-dried cadaveric rotator cuffs, freeze-dried cadaveric Achilles tendon |
| **Synthetic grafts** | Polyglycolic acid sheet, poly-L-lactide polymer, polyurethane polymer, polyethylene terephthalate, mersilene mesh, Gore-Tex patch, carbon fiber tow, polytetrafluoroethylene |
| **Autografts** | Biceps tendon, fascia lata, patellar tendon, Achilles tendon, quadriceps tendon |

Fig. 1. Insertion of the patch graft during an arthroscopic rotator cuff repair.
early postoperative mechanical loading. Thus, choosing the right graft material is also very important for a successful treatment.

**Clinical Results**

The research on the clinical outcomes of rotator cuff repairs using various types of patch augmentation is abundant. Most of these studies have investigated large-to-massive tears while only a few have investigated smaller tears. However, studies on the effectiveness of collagen patch grafts and polypropylene patch grafts are extremely limited. And the fact that many studies do not include control groups makes it difficult to conduct comparative analyses (Table 2). Studies that compare outcomes of graft augmentation with those of other control surgical techniques, such as the conventional repair technique, are summarized in Table 3.

| Author | Type | Graft | Year | No. of patient | Technique | Tear size | Mean F/U (mo) | Main clinical finding |
|--------|------|-------|------|---------------|-----------|-----------|--------------|----------------------|
| Ozaki et al. | Synthetic | Polytetrafluoroethylene | 1986 | 25 | Open | Massive | 25 | ROM: abduction 44.16 → 133.2, strength: abduction 3+ → 4*, ER 3+ → 4* |
| Visuri et al. | Synthetic | Carbon fiber tow | 1991 | 14 | Open | > 3 cm | 48.9 | ROM: abduction 72.9 → 157.1 |
| Metcalf et al. | Xenograft | Porcine small intestine submucosa | 2002 | 12 | Open | Massive | 24 | ROM: FE 30 → 90, abduction 27 → 86, ER 0 → 40, IR 3 → 40, strength: abduction 0.8 → 3.1*, UCLA score 9.3 → 19.9 |
| Hirooka et al. | Synthetic | Gore-Tex patch | 2006 | 39 | Open | Massive | 43 | ROM: FE 69.2 → 136, abduction 68.4 → 133.7, ER 32.4 → 38.3, IR 3.4 → 7.5 of 10 points, strength: abduction 0 → 7 → 9*, Constant score 25.7 → 72.1 |
| Badhe et al. | Xenograft | Porcine dermal collagen | 2008 | 10 | Open | Massive | 52 | Strength: abduction 6.3 → 9.8, Constant score 41.5 → 62.2 |
| Phipatanakul and Petersen | Xenograft | Porcine small intestine submucosa | 2009 | 11 | Open | Massive | 26 | ROM: FE 109 → 126, ER 37 → 28, ASES score 36.3 → 71.8, UCLA score 13.9 → 25.7 |
| Wong et al. | Allograft | Human dermal matrix | 2010 | 45 | Arthroscopic | Large to massive | 48 | UCLA score 18.4 → 27.5 |
| Nada et al. | Synthetic | Polyethylene terephthalate | 2010 | 21 | Mini open | Massive | 36 | ROM: FE 65 → 120, abduction 60 → 120, ER 39 → 57, IR 4.2 → 8.4, strength: abduction 3.9 → 5*, Constant score 46.7 → 84.5 |
| Rotini et al. | Allograft | Human dermal matrix | 2011 | 5 | Open/Arthroscopic | Large to massive | 13.6 | Constant score 64 → 98 |
| Encalada-Diaz et al. | Synthetic | Polyurethane polymer | 2011 | 10 | Mini open | All size | 12 | ROM: FE 90 → 160, abduction 70 → 155, ER 15 → 30, SR sacrum = T12, ASES score 44 → 73.3 |
| Gupta et al. | Allograft | Human dermal matrix | 2012 | 24 | Mini open | Massive | 36 | ROM: FE 111.7 → 157.3, abduction 105 → 151.7, ER 46.2 → 65.1, strength: abduction 7.2 → 9.4*, ER 7.8 → 9.3*, ASES score 66.6 → 88.7 |
| Venouziou et al. | Allograft | Human dermal matrix | 2013 | 14 | Open | Massive | 30.2 | ROM: FE 73.6 → 128.3, abduction 67.5 → 117.9, ER 7.9 → 43.2, ASES score 23.8 → 72.3 |
| Petrie and Ismael | Synthetic | Ligament augmentation Reconstruction system | 2013 | 29 | Open | Massive | 40 | - |
| Proctor | Synthetic | Poly-L-lactide polymer | 2014 | 18 | Arthroscopic | Large to massive | 42 | ASES score 25 → 70 |
| Giannotti et al. | Xenograft | Porcine dermal collagen patch | 2014 | 9 | Open | Massive | 36 | ASES score 38 → 79, Constant score 42 → 73 |
| Cho et al. | Xenograft | Porcine dermal collagen | 2014 | 5 | Mini open | Massive | 20.6 | ASES score 39.4 → 86.4, UCLA score 15.4 → 31.2 |
| Lenart et al. | Synthetic | Poly-L-lactide polymer | 2015 | 13 | Open | Massive or retear | 18 | ROM: FE 145 → 160, ASES score 32.8 → 74.2 |
| Petri et al. | Allograft | Human dermal matrix | 2016 | 13 | Open | Large to massive | 30 | ASES score 64.5 → 86.0 |

*Based on the 5-point Medical Research Council Scale. Power assessed as part of Constant-Murley score. Based on the 10-point Modified Medical Research Council Scale.

Table 2. Uncontrolled Clinical Studies on Patch Grafts for Rotator Cuff Tears

F/U: follow-up, ROM: range of motion, ER: external rotation, FE: forward elevation, IR: internal rotation, UCLA: University of California-Los Angeles, ASES: American Shoulder and Elbow Surgeons Evaluation Form.
### Table 3. Controlled Clinical Studies on Patch Grafts for Rotator Cuff Tears

| Authors          | Type               | Graft                        | Year | No. of patient | Technique    | Tear size     | Mean F/U (mo) | Control group | Clinical outcomes | Radiologic outcomes |
|------------------|--------------------|------------------------------|------|----------------|--------------|---------------|---------------|---------------|-------------------|---------------------|
| Iannotti et al.  | Xenograft          | Porcine small intestine submucosa | 2006 | 15             | Open         | Large to massive | 14            | Conventional   | Penn: 83 (patch), 91 (control) | MRI at 1 year 4/15 (patch) vs. 9/19 (control) |
| Walton et al.    | Xenograft          | Porcine small intestine submucosa | 2007 | 16             | Open         | Large to massive | 24            | Conventional   | Less strength (lift-off, IR, adduction), slower rate of resolution of pain, less sports participation in xenograft | MRI mean tendon thickness 1.50 mm (patch) vs. 1.58 mm (control) |
| Barber et al.    | Allograft          | Human dermal matrix          | 2012 | 22             | Arthroscopic | Large to massive | 24            | Conventional   | ASES (p=0.035), Constant (p=0.008), UCLA (p=0.43) | MRI intact cuffs in 85% of repairs in patch group vs 40% in control (p<0.001) |
| Modi et al.      | Allograft          | Human dermal matrix          | 2013 | 61             | Open         | > 3 cm         | 43.2          | Partial repair | Constant (p=0.001), ASES (p=0.021), VAS (p=0.028) | MRI Graft: 8.3% retear, control: 41.7% retear (p=0.015) |
| Campi et al.     | Synthetic (synthetic) | Polypropylene                | 2014 | 52             | Open         | Massive        | 36            | Conventional   | UCLA score at 36 months was significantly higher (p=0.001) | USG after 12 months 41% (21/51) for the control group vs. 17% (9/52) for the polypropylene group |
| Campi et al.     | Xenograft (collagen) | Bovine pericardium derived collagen | 2014 | 49             | Open         | Massive        | 36            | Conventional   | UCLA score at 36 months was not significantly higher | USG after 12 months 41% (21/51) for the control group vs. 51% (25/49) for the collagen group, |
| Yoon et al.      | Allograft          | Human dermal matrix          | 2016 | 21             | Arthroscopic | Massive        | 23            | Conventional   | 1 year and final follow up: not significant (VAS, SST, UCLA, Constant, ASES) | MRI 12 months retear: 19.0% (patch) vs. 46.3% (control) |

F/U: follow-up, IR: internal rotation, ASES: American Shoulder and Elbow Surgeons Evaluation Form, UCLA: University of California-Los Angeles, VAS: visual analog scale, SST: simple shoulder test, MRI: magnetic resonance imaging, USG: ultrasonography.
In almost all studies, whichever graft was used, clinical parameters, such as range of motion, the American Shoulder and Elbow Surgeons Evaluation Form (ASES) score, the University of California-Los Angeles (UCLA) score, and the Constant score significantly improved with patch augmentation. However, many of these studies do not have a control group; thus, we cannot be certain that these improved results are attributable to patch augmentation. In terms of graft type, we found that compared to other patch grafts, the synthetic grafts had significantly larger improvements in forward flexion and in abduction, whilst allografts showed the highest improvement in external rotation.

The anatomical results obtained using postoperative follow-up imaging were compared by study (Table 3). Interestingly, we found that most of the studies that had reported no significant difference between grafting and the conventional repair had used xenografts.

Studies generally showed improved muscle strength after patch augmentation, in particular a significant improvement in abduction strength. A few studies also showed that external rotation strength is improved after grafting. However, Walton et al. presented anomalous data wherein patients without patch augmentation compared to those with had better abduction strength. Similarly, a different study reported that patients who had not received augmentation had greater external rotation strength than those who had received augmentation. Interestingly, the patients who had not received patch augmentation in this study had been treated using xenografts (restore orthobiologic implant).

Almost all studies on patch augmentation report improvements in clinical parameters, specifically the ASES, the UCLA, the Constant, the Penn, and the Oxford scores. These improvements appeared irrespectively of graft type, but when comparing xenografts to synthetic grafts and allografts, we found that their improvement was relatively smaller. Other clinical parameters such as pain, satisfaction, ADL performance, and return to sports or to daily activities showed significant improvements in various papers.

In the literature, the rates of retear measured through postoperative evaluation of anatomical outcomes show a substantial variation ranging from 8.3% to 73.4%, depending on the surgical indication, the treatment method, and the mode of assessment. A recent systemic review on 22 studies calculating retear rates showed that the overall retear rate was 22% for complete tears and 2.7% for partial tears. Among complete tears, the overall retear rates by graft type were 15.0% for synthetic grafts, 42.0% for xenograft, and 9.9% for allografts. Among partial tears, the corresponding percent values were 0%, 1.7%, and 12.7%, respectively.

A few explanations are given in the literature for how patch augmentation may reduce the occurrence of retears. For example, it has been suggested to reduce the tension applied to the torn tendon by pulling the edges of torn tendons in massive cuff tears toward the lateral footprint (Fig. 2). Taking the same action (that is, pulling the torn tendons as laterally as possible to cover the rotator cuff footprint) in medial row repairs would exacerbate tension overloading because massive rotator cuff tears usually have much retracted and stiffened tendons. Thus, patch graft repairs in contrast would allow less lateralization of the torn tendon ends, resulting in less tension.

Postoperative complications differentially appear by graft type; for instance, xenografts are often associated with infection-induced immune responses. The more recent types—allografts and autografts—are commonly associated with bursitis, deep infection, skin rash, severe inflammatory reaction, humeral fracture, and cystic changes of the humeral head. Besides these, complications that generally occur with rotator cuff repairs have all been reported with grafting.

**Consensus for Patch Grafts**

For the treatment of massive or irreparable cuff tears, treatment modalities other than patch augmentation may be indi-
cated; a few examples are conservative treatment, subacromial debridement and decompression, partial repair, muscle transfer, superior capsular reconstruction, subacromial spacer, and reverse shoulder arthroplasty. Each treatment modality has been reported with favorable clinical outcomes.51–56

Controversy as to whether patch augmentation is the most ideal treatment for massive or irreparable cuff arthropathies remains, and some studies have attempted to answer this. In the American Academy of Orthopaedic Surgeons (AAOS)’s guidelines,57 xenografts are not recommended, while partial repairs, debridement, and muscle transfer are weakly recommended. And whilst allografts are not recommended, the guidelines states there is not sufficient evidence to back their claim. In a survey that asked ASES members whether they agreed to the AAOS guidelines,58 86.5% of respondents agreed that partial repairs are appropriate for irreparable cuff tears and 64.6% agreed that debridement is appropriate. Only 11.2% and 45.4% of respondents said that allografts should be used for primary treatment and for revision treatment, respectively. Taking these findings into account, it seems that there is yet insufficient evidence, both empirically and consensually, that justifies the use of patch grafts.

Conclusions

No gold standard of treatment exists for massive rotator cuff tears, especially for irreparable cuff tears. These tears have been shown to be challenging to treat in young and active patients. The antecedent xenografts for cuff tear arthropathies were associated with unfavorable clinical outcomes and postoperative complications. For these reasons xenografts are no longer used in the clinic. The more current patch augmentation such as through human dermal allografts has been reported to have favorable outcomes, but well-designed, long-term randomized control studies are required to evaluate the cost-effectiveness of this treatment. Because there is a wide range of options for irreparable rotator cuff tears besides patch augmentation, such as debridement, partial repair, superior capsular reconstruction, and reverse arthroplasty, the choice of treatment should be carefully selected on the basis of the relative benefits and limitations of each method.

References

1. Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C. The clinical and structural long-term results of open repair of massive tears of the rotator cuff. J Bone Joint Surg Am. 2008;90(11):2423-31.
2. Melillo AS, Savoie FH 3rd, Field LD. Massive rotator cuff tears: debridement versus repair. Orthop Clin North Am. 1997;28(1):117-24.
3. Moser M, Jablonski MV, Horodyski M, Wright TW. Functional outcome of surgically treated massive rotator cuff tears: a comparison of complete repair, partial repair, and debridement. Orthopedics. 2007;30(6):479-82.
4. Burkhart SS, Barth JR, Richards DP, Zlatkin MB, Larsen M. Arthroscopic repair of massive rotator cuff tears with stage 3 and 4 fatty degeneration. Arthroscopy. 2007;23(4):347-54.
5. Galatz LM, Ball CM, Teeffey SA, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. J Bone Joint Surg Am. 2004;86(2):219-24.
6. Boileau P, Brassat N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am. 2005;87(6):1229-40.
7. Cole BJ, McCarty LP 3rd, Kang RW, Alford W, Lewis PB, Hayden JK. Arthroscopic rotator cuff repair: prospective functional outcome and repair integrity at minimum 2-year follow-up. J Shoulder Elbow Surg. 2007;16:579-85.
8. Coleman SH, Fealy S, Ehteshami JR, et al. Chronic rotator cuff injury and repair model in sheep. J Bone Joint Surg Am. 2003;85(12):2391-402.
9. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. J Shoulder Elbow Surg. 1999;8(6):599-605.
10. Goutallier D, Postel JM, Lavau L, Bernageau J. Impact of fatty degeneration of the supraspinatus and infraspinatus muscles on the prognosis of surgical repair of the rotator cuff. Rev Chir Orthop Reparatrice Appar Mot. 1999;85(7):668-76.
11. Bond JL, Dopirak RM, Higgins J, Burns J, Snyder SJ. Arthroscopic replacement of massive, irreparable rotator cuff tears using a graftjacket allograft: technique and preliminary results. Arthroscopy. 2008;24(4):403-9.e1.
12. Derwin KA, Baker AR, Spragg RK, Leigh DR, Iannotti JP. Commercial extracellular matrix scaffolds for rotator cuff tendon repair. Biomechanical, biochemical, and cellular properties. J Bone Joint Surg Am. 2006;88(12):2663-72.
13. Soler JA, Gidwani S, Curtis MJ. Early complications from the use of porcine dermal collagen implants (Permacol) as bridging constructs in the repair of massive rotator cuff tears. A report of 4 cases. Acta Orthop Belg. 2007;73(4):432-6.
14. Ferguson DP, Lewington MR, Smith TD, Wong IH. Graft utilization in the augmentation of large-to-massive rotator cuff repairs: a systematic review. Am J Sports Med. 2016;44(11):2984-92.
15. Thangarajah T, Pendegrass CJ, Shahbazi S, Lambert S, Alexander S, Blunn GW. Augmentation of rotator cuff repair with soft tissue scaffolds. Orthop J Sports Med. 2015;3(6):2325967115587495.
16. Steinhaus ME, Makhni EC, Cole BJ, Romeo AA, Verma NN. Outcomes after patch use in rotator cuff repair. Arthroscopy. 2016;32(8):1676-90.
17. Wong I, Burns J, Snyder S. Arthroscopic graftjacket repair of rotator cuff tears. J Shoulder Elbow Surg. 2010;19(2 Suppl):104-9.
18. Nasca RJ. The use of freeze-dried allografts in the management of global rotator cuff tears. Clin Orthop Relat Res. 1988;(228):218-26.
19. Rotini R, Marinelli A, Guerra E, et al. Human dermal matrix scaffold augmentation for large and massive rotator cuff repairs: preliminary clinical and MRI results at 1-year follow-up. Musculoskelet Surg. 2011;95 Suppl 1:S13-23.
20. Gilbert TW, Freund JM, Badylak SF. Quantification of DNA in biologic scaffold materials. J Surg Res. 2009;152(1):135-9.
21. Cheung EV, Silverio L, Sperling JW. Strategies in biologic augmentation of rotator cuff repair: a review. Clin Orthop Relat Res. 2010;468(6):1476-84.
22. Bedi A, Maak T, Walsh C, et al. Cytokines in rotator cuff degeneration and repair. J Shoulder Elbow Surg. 2012;21(2):218-27.
23. Sano H, Kumagai J, Sawai T. Experimental fascial autografting for the supraspinatus tendon defect: remodeling process of the grafted fascia and the insertion into bone. J Shoulder Elbow Surg. 2002;11(2):166-73.
24. Cho NS, Yi JW, Rhee YG. Arthroscopic biceps augmentation for avoiding undue tension in repair of massive rotator cuff tears. Arthroscopy. 2009;25(2):183-91.
25. Mori D, Funakoshi N, Yamashita F. Arthroscopic surgery of irreparable large or massive rotator cuff tears with low-grade fatty degeneration of the infraspinatus: patch autograft procedure versus partial repair procedure. Arthroscopy. 2013;29(12):1911-21.
26. Tachiiri H, Morihara T, Iwata Y, et al. Characteristics of donor and host cells in the early remodeling process after transplant of Achilles tendon with and without live cells for the treatment of rotator cuff defect: what is the ideal graft for the treatment of massive rotator cuff defects? J Shoulder Elbow Surg. 2010;19(6):891-8.
27. Barber FA, Burns JP, Deutsch A, Labbé MR, Litchfield RB. A prospective, randomized evaluation of acellular human dermal matrix augmentation for arthroscopic rotator cuff repair. Arthroscopy. 2012;28(1):8-15.
28. Giampi P, Scotti C, Nonis A, et al. The benefit of synthetic versus biological patch augmentation in the repair of posterosuperior massive rotator cuff tears: a 3-year follow-up study. Am J Sports Med. 2014;42(5):1169-75.
29. Encalada-Díaz I, Cole BJ, Macgilivray JD, et al. Rotator cuff repair augmentation using a novel polycarbonate polyurethane patch: preliminary results at 12 months’ follow-up. J Shoulder Elbow Surg. 2011;20(5):788-94.
30. Hirooka A, Yoneda M, Wakaitani S, et al. Augmentation with a Gore-Tex patch for repair of large rotator cuff tears that cannot be sutured. J Orthop Sci. 2002;7(4):451-6.
31. Visuri T, Kiviluoto O, Eskelin M. Carbon fiber for repair of the rotator cuff. A 4-year follow-up of 14 cases. Acta Orthop Scand. 1991;62(4):356-9.
32. Walton JR, Bowman NK, Khatib Y, Linklater J, Murrell GA. Restore orthobiologic implant: not recommended for augmentation of rotator cuff repairs. J Bone Joint Surg Am. 2007;89(4):786-91.
33. Badhe SP, Lawrence TM, Smith FD, Lunn PG. An assessment of porcine dermal xenograft as an augmentation graft in the treatment of extensive rotator cuff tears. J Shoulder Elbow Surg. 2008;17(1 Suppl):35S-95.
34. Venouziou AI, Kokkalis ZT, Sotereanos DG. Human dermal allograft interposition for the reconstruction of massive irreparable rotator cuff tears. Am J Orthop (Belle Mead NJ). 2013;42(2):63-70.
35. Audenaert E, Van Nuffel J, Schepens A, Verhelst M, Verdonk R. Reconstruction of massive rotator cuff lesions with a synthetic interposition graft: a prospective study of 41 patients. Knee Surg Sports Traumatol Arthrosc. 2006;14(4):360-4.
36. Ozaki J, Fujimoto S, Masuhara K, Tamai S, Yoshimoto S. Reconstruction of chronic massive rotator cuff tears with synthetic materials. Clin Orthop Relat Res. 1986;(202):173-83.
37. Metcalf MH, Savoie FH, Kellum B. Surgical technique for xenograft (SIS) augmentation of rotator-cuff repairs. Oper Tech Orthop. 2002;12(3):204-8.
38. Burkhead WZ Jr., Schiffern SC, Krishnan SG. Use of graft jacket as an augmentation for massive rotator cuff tears. Semin Arthroplast. 2007;18(1):11-8.
39. Phipatanakul WP, Petersen SA. Porcine small intestine submucosa xenograft augmentation in repair of massive rotator cuff tears. Am J Orthop (Belle Mead NJ). 2009;38(11):572-5.
40. Nada AN, Debnath UK, Robinson DA, Jordan C. Treatment of massive rotator-cuff tears with a polyester ligament (Da-Cron) augmentation: clinical outcome. J Bone Joint Surg Br. 2010;92(10):1397-402.
41. Gupta AK, Hug K, Berkoff DJ, et al. Dermal tissue allograft for the repair of massive irreparable rotator cuff tears. Am J Sports Med. 2012;40(1):141-7.
42. Petrie MJ, Ismaiel AH. Treatment of massive rotator-cuff tears with a polyester ligament (LARS) patch. Acta Orthop Belg. 2013;79(6):620-5.
43. Proctor CS. Long-term successful arthroscopic repair of large and massive rotator cuff tears with a functional and degradable reinforcement device. J Shoulder Elbow Surg. 2014;23(10):1508-13.
44. Lenart BA, Martens KA, Kearns KA, Gillespie RJ, Zoga AC, Williams GR. Treatment of massive and recurrent rotator cuff tears augmented with a poly-L-lactide graft, a preliminary study. J Shoulder Elbow Surg. 2015;24(6):915-21.
45. Giannotti S, Ghilardi M, Dell’Osso G, et al. Study of the porcine dermal collagen repair patch in morpho-functional recov-
ery of the rotator cuff after minimum follow-up of 2.5 years. Surg Technol Int. 2014;24:348-52.

46. Cho CH, Lee SM, Lee YK, Shin HK. Mini-open suture bridge repair with porcine dermal patch augmentation for massive rotator cuff tear: surgical technique and preliminary results. Clin Orthop Surg. 2014;6(3):329-35.

47. Petri M, Warth RJ, Horan MP, Greenspoon JA, Millett PJ. Outcomes after open revision repair of massive rotator cuff tears with biologic patch augmentation. Arthroscopy. 2016;32(9):1752-60.

48. Modi A, Singh HP, Pandey R, Armstrong A. Management of irreparable rotator cuff tears with the graftjacket allograft as an interpositional graft. Shoulder Elbow. 2013;5(3):188-94.

49. Iannotti JP, Codsi MJ, Kwon YW, Derwin K, Ciccone J, Brems JJ. Porcine small intestine submucosa augmentation of surgical repair of chronic two-tendon rotator cuff tears. A randomized, controlled trial. J Bone Joint Surg Am. 2006;88(6):1238-44.

50. Yoon JP, Chung SW, Kim JY, et al. Outcomes of combined bone marrow stimulation and patch augmentation for massive rotator cuff tears. Am J Sports Med. 2016;44(4):963-71.

51. Burkhart SS. Partial repair of massive rotator cuff tears: the evolution of a concept. Orthop Clin North Am. 1997;28(1):125-32.

52. Drake GN, O’Connor DP, Edwards TB. Indications for reverse total shoulder arthroplasty in rotator cuff disease. Clin Orthop Relat Res. 2010;468(6):1526-33.

53. Lo IK, Lind CC, Burkhart SS. Glenohumeral arthroscopy portals established using an outside-in technique: neurovascular anatomy at risk. Arthroscopy. 2004;20(6):596-602.

54. Namdari S, Voleti P, Baldwin K, Glaser D, Huffman GR. Latissimus dorsi tendon transfer for irreparable rotator cuff tears: a systematic review. J Bone Joint Surg Am. 2012;94(10):891-8.

55. Senekovic V, Poberaj B, Kovacic L, Mikek M, Adar E, Dekel A. Prospective clinical study of a novel biodegradable subacromial spacer in treatment of massive irreparable rotator cuff tears. Eur J Orthop Surg Traumatol. 2013;23(3):311-6.

56. Moore DR, Cain EL, Schwartz ML, Clancy WG Jr. Allograft reconstruction for massive, irreparable rotator cuff tears. Am J Sports Med. 2006;34(3):392-6.

57. Tashjian RZ. AAOS clinical practice guideline: optimizing the management of rotator cuff problems. J Am Acad Orthop Surg. 2011;19(6):380-3.

58. Paxton ES, Matzon JL, Narzikul AC, Beredjiklian PK, Abboud JA. Agreement among ASES members on the AAOS clinical practice guidelines. Orthopedics. 2015;38(3):e169-77.