J Shoulder Elbow Surg (2019) 28, 1363–1370

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Bone healing potential of fascia lata autografts to the humeral head footprint in rotator cuff reconstruction based on magnetic resonance imaging and histologic evaluations

Daisuke Mori, MD[a,*], Yoshikazu Kida, MD, PhD[b], Kazuha Kizaki, MD[a], Naoki Umatani, MD[a], Noboru Funakoshi, MD[a], Yasuyuki Mizuno, MD[a], Fumiharu Yamashita, MD, PhD[a], Masahiko Kobayashi, MD, PhD[a]

[a]*Department of Orthopaedic Surgery, Kyoto Shimogamo Hospital, Kyoto, Japan*
[b]*Department of Orthopaedics, Graduate School of Medical Science, Kyoto Prefectural University of Medicine, Kyoto, Japan*

Background: The purpose of the study was to evaluate the bone healing potential of fascia lata autograft (FLA) by magnetic resonance imaging (MRI) and histologic analysis.
Methods: The study included 69 patients assessed by MRI after an FLA patch procedure. Three of the 69 patients underwent a revision procedure after the primary FLA procedure; 1 underwent a second-look arthroscopy and 2 underwent reverse shoulder arthroplasties (RSAs). In the 2 RSA patients, we histologically evaluated greater tuberosities with the repaired graft. Moreover, as a control, we harvested the greater tuberosity with the cuff tendon at the time of RSA for failed open reduction–internal fixation of 4-part proximal humeral fracture. Based on MRI, retear cases were divided into type 1 (the graft did not remain on the greater tuberosity) and type 2 (the graft remained on the greater tuberosity). Histologic sections were evaluated to examine fascia-bone or rotator cuff–bone interfaces.
Results: There were 35 intact repairs: 7 type 1 and 27 type 2 shoulders (type 1 vs. type 2, $P < .001$). Second-look arthroscopic findings confirmed that the graft was securely attached to the greater tuberosity. Histologic analysis of greater tuberosities in RSA patients showed solid continuity of the graft to the bone, with cells with nuclei in the collagen matrix oriented in parallel. The FLA to bone junction consisted of the FLA, fibrocartilage, and bone, which is similar to the normal cuff tendon to bone junction.
Conclusions: These results indicate that a fresh cellular FLA has good to excellent bone healing potential.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Rotator cuff tear; irreparable rotator cuff tear; fascia lata autograft; patch graft; histologic analysis; similarity of normal cuff tendon–bone interface

Institutional Review Board approval was received from Kyoto Shimogamo Hospital (No. 2014-002). Informed consent was obtained from all patients before inclusion in the study.

*Reprint requests: Daisuke Mori, MD, Kyoto Shimogamo Hospital, 17 Shimogamo Higashimorigamaecho, Sakyo-ku, Kyoto, 606-0866, Japan.
E-mail address: altair.0421@gmail.com (D. Mori).

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2018.11.067

Whereas reported short- and long-term clinical results of primary repair for large to massive rotator cuff tears are good or excellent, high retear rates and subsequent worse outcomes after primary rotator cuff repair suggest the need for alternative surgical options.[3,6,10] As an alternative, graft surgery is becoming more popular for large to massive rotator cuff tears. However, the clinical and structural outcomes of graft use differ in studies,[29,28] possibly because grafts are used in 2 different scenarios: augmentation of a reparable cuff tear and bridging of an irreparable defect. A second reason for study differences is that the graft material varies and includes autografts, allografts, xenografts, and synthetic grafts. Therefore, operative indications and techniques as well as graft selection may cause controversy when grafts are used to treat large to massive rotator cuff tears.[29]

Ideally, to maintain the mechanical stress of reconstructed soft tissues after graft procedures, both the graft-bone junction and implanted graft should show a normal histologic structure after healing is complete. Researchers have defined the functional effectiveness of a graft in soft tissue augmentation applications as showing a lack of inflammatory response, oriented collagen fibers, cellular repopulation, tissue ingrowth, and vascular network while also decreasing the in vivo mechanical forces on the repair site during postoperative tendon healing.[2,14,19] Some studies have shown such effectiveness using magnetic resonance imaging (MRI),[5,22] biomechanical studies,[4,10,23,27] and histologic evaluations.[1,17,20,28,30,31] Among these studies, Sano et al[30] showed the effectiveness of autograft fascia to bone healing in a rabbit model.

We performed a cellular fresh fascia lata autograft (FLA) patch procedure for large to massive rotator cuff tears based on the study by Sano et al.[25,26,30] We reported 24 (43.3%) nonintact repairs in a series of 45 patients after the procedure by MRI.[26] Moreover, we found a unique pattern of retear of the FLA remaining in the greater tuberosity of most shoulders. We performed second-look arthroscopy after the FLA patch procedure in 1 shoulder and harvested the FLA remaining on the greater tuberosity at the time of reverse shoulder arthroplasty (RSA) after the patch procedure as revision surgery to macroscopically and histologically analyze the FLA in another 2 shoulders. The purpose of the study was to evaluate the bone healing potential of FLA by MRI and histologic analysis.

Materials and methods

Selection of patients

Data were prospectively collected from our database and reviewed retrospectively. A consecutive 77 patients with irreparable large or massive posterosuperior rotator cuff tears with Goutallier stage 3 or stage 4 degeneration of the supraspinatus and stage 1 to stage 4 degeneration of the infraspinatus were treated with an arthroscopic fascia lata patch graft procedure between June 2007 and March 2016.[7,11] Of these 77 patients, 1 was lost during follow-up, 4 refused the postoperative MRI scans, and 3 had postoperative MRI scans at 5 months postoperatively. Some studies have reported that retears after rotator cuff repairs occurred within 6 months postoperatively.[15,24] Hence, the 3 patients were excluded from the study. The inclusion criterion for this study was availability of postoperative MRI scans to evaluate the integrity of rotator cuff tendons and autografts before surgery at a minimum of >6 months postoperatively. The exclusion criterion was that postoperative MRI scans were not available at >6 months postoperatively. We assessed 69 MRI scans of the 69 patients who underwent the FLA patch procedure. Right-sided shoulders were involved in 54 cases (78.3%). The dominant shoulder was involved in 56 cases (81.2%). Of the 69 patients, 3 patients had revision surgery after the FLA patch procedure. One patient (a 53-year-old man, right shoulder) underwent an arthroscopy-assisted modified Debeyre muscle advancement procedure at 10 months after the initial arthroscopic FLA patch procedure because of persistent pain and poor functional recovery with concomitant structural failure. The remaining 2 patients (a 70-year-old man for left shoulder and an 80-year-old woman for right shoulder) underwent RSA at 29 and 32 months after the initial arthroscopic FLA patch procedure, respectively. Finally, we evaluated the histologic features of the greater tuberosity in a 79-year-old woman for the right shoulder at the time of RSA after failed open reduction–internal fixation of a 4-part proximal humeral fracture to assess the rotator cuff tendon insertion (control shoulder). Consequently, the cases included 70 shoulders in 70 patients. We assessed 69 postoperative MRI scans at a minimum of 6 months postoperatively for 69 patients (45 men and 24 women; mean age of 66.8 years at the time of surgery) after the FLA patch procedure and the histologic features of the cuff tendon or FLA including the greater tuberosity in the 3 RSA patients.

Autograft fascia lata patch procedure and rehabilitation

Arthroscopic FLA patch procedures were performed by the senior author (D.M.). The arthroscopic operative techniques, such as FLA interposition and fixation of the native tendon and the graft, have been described in detail previously.[25,26] We reconstructed the cuff tendons by repairing the infraspinatus and attaching the patch directly to the bone. No. 2 permanent anchor sutures were placed in the posterior native cuff by advancing the torn edge of the posterior native cuff anterolaterally toward the greater tuberosity by the double-row technique. The graft was introduced into the subacromial space through the anterior portal. The graft was then attached to the native cuff (subscapularis, supraspinatus, and infraspinatus) in a mattress fashion and repaired to the greater tuberosity by a single-row technique. Thus, our arthroscopic technique was a bridging technique.

The rehabilitation protocol was started on the first postoperative day with relaxation of the shoulder girdle muscles. After 2 weeks, the patients were instructed to begin isometric exercises and active assisted exercises, avoiding provocation of pain. After 6 weeks, the patients started strengthening exercises of the rotator cuff and the scapular stabilizers. Their shoulders were immobilized for 8 weeks

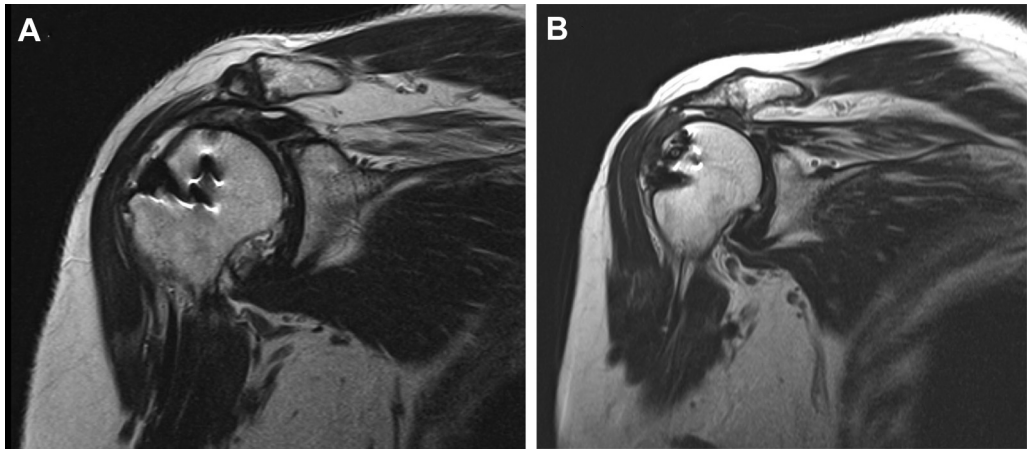

Figure 1 Postoperative coronal magnetic resonance images. (**A**) Type 1 retear. None of the fascial autograft repair remained on the greater tuberosity, and the torn repaired native cuff tendon was retracted medially after patch surgery. (**B**) Type 2 retear. The repaired fascial autograft remained on the greater tuberosity, and the repaired native cuff tendon was retracted medially after patch surgery.

postoperatively with an abduction pillow. Patients were allowed to return to sports and heavy labor after 9 months, depending on each individual's functional recovery.

MRI assessment

MRI was performed with a 1.5T closed-type scanner (EXCELART Vantage powered by Atlas or VISART/EX; Toshiba, Ohtawara, Japan). Oblique coronal, oblique sagittal, and axial T2-weighted images were acquired for structural and qualitative assessment of the rotator cuff tendons and autografts. The slice thickness was 4 mm, and the interslice gap was 0.5 mm in the EXCELART scanner and 0.8 mm in the VISART/EX scanner. Preoperative fatty degeneration was evaluated with MRI by the treating surgeon and a blinded musculoskeletal radiologist who was not involved in the study and was blinded to the clinical findings. Full-thickness native cuff tendon retears were diagnosed as the presence of a high signal intensity or when discontinuity of the infraspinatus or subscapularis tendon was found in one or more of the T2-weighted images. The patch repair was classified as intact or nonintact on the basis of the appearance of the native cuff, tendon-graft interface, and graft at the anatomic footprint on the humeral head. Intact repairs showed no high signal intensity areas in the native cuff, tendon-graft interface, or graft-humerus interface. Nonintact repairs showed an insufficient thickness (partial defect) or full-thickness high-intensity area (complete defect) in the native cuff, tendon-graft interface, or graft-humerus interface. These criteria were based on previous studies using ultrasound.[12,13,26] For images showing a full-thickness high-intensity area, patients were divided into type 1 (Fig. 1, *A*) if the FLA at the insertion site of the rotator cuff was not completely absent on the greater tuberosity or type 2 (Fig. 1, *B*) if the FLA remained at the insertion site despite a retear. We established the criteria on the basis of a study by Cho et al.[8] Retear patterns were divided into type 1 (cuff tissue repaired at the insertion site of the rotator cuff was not observed as remaining on the greater tuberosity) and type 2 (remnant cuff tissue remained at the insertion site despite a retear).[8] The diagnosis of a retear was performed by 1 treating orthopedic surgeon (D.M.) and 2 non-treating experienced orthopedic surgeons (K.K. and N.F.). In cases in which there was a discrepancy between the assessments, the worse assessment was used.

Histologic assessment

During the 3 RSAs (2 revisions after FLA patch surgery and 1 revision after open reduction–internal fixation), the greater tuberosity and attached soft tissue (fascia lata or rotator cuff) were resected en bloc. The specimens were fixed in 10% neutral buffered formalin and then decalcified in a 0.5 mol/L ethylenediaminetetraacetic acid solution for 4 weeks at room temperature and embedded in paraffin. Serial coronal sections (5 μm in thickness) parallel to the long axis of the soft tissue fibers were obtained. Each section was cut and stained with hematoxylin and eosin and safranin O.

Histologic sections prepared from samples were analyzed by 1 examiner (Y.K.) who is an orthopedic surgeon and well experienced in tendon pathologic examination. The examiner did not know the clinical and radiographic information but was aware of the tissue origin. The sections were inspected under a microscope, assessing the histologic appearances of the fascia (or rotator cuff)–bone interface, midsubstance of fascia lata graft (or rotator cuff), and tear portion site (Fig. 2). In addition, we assessed the histologic findings semiquantitatively, using the modified tendon maturing score reported by Ide et al[16] and Watkins et al[33] (Supplementary data). The score was evaluated only by the investigator.

Statistical analysis

The χ^2 test was used to compare the frequency of type 1 and type 2 retears. Values of $P < .05$ were considered to indicate statistical significance. Moreover, we used a 2-way random-effects model to calculate the interobserver reliability of retear types. All statistical analyses were performed using SAS version 9.2 software (SAS Institute, Cary, NC, USA).

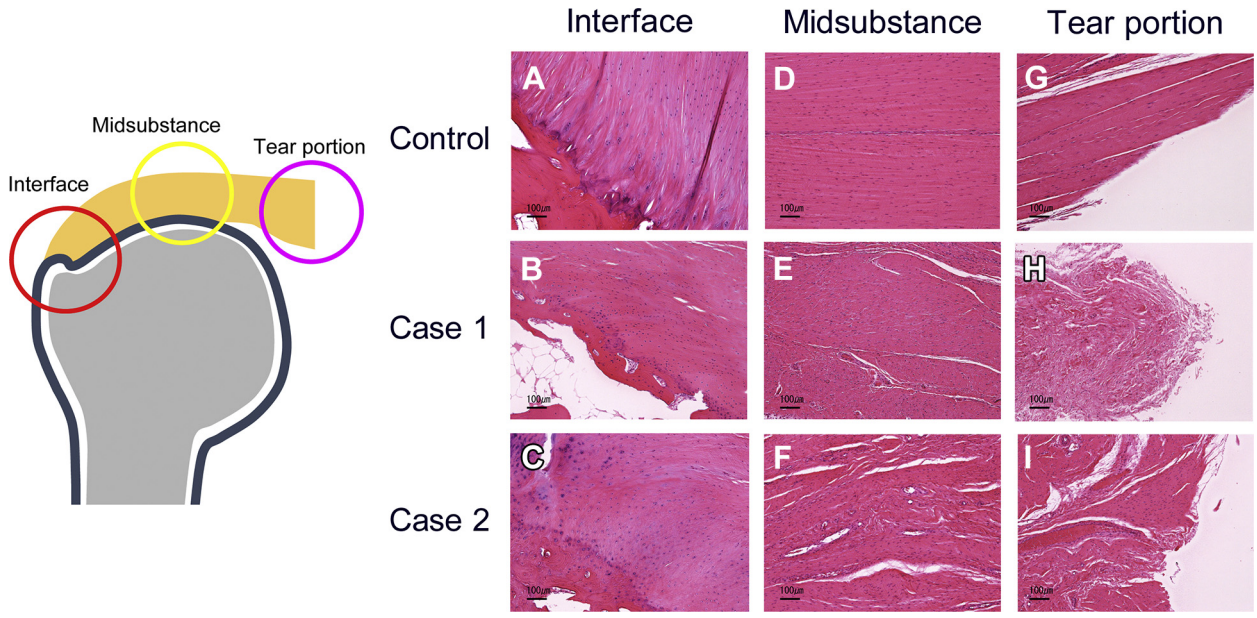

Figure 2 *Left*, Illustration of the tissue harvest portion; *red circle*, interface portion; *yellow circle*, midsubstance portion; *purple circle*, tear portion. (**A-C**) Interface portion of each case. (**D-F**) Midsubstance portion of each case. (**G-I**) Tear portion of each case. Hematoxylin and eosin staining, original magnification ×100.

Results

MRI findings

The interobserver reliability of retear types was 0.92 (95% confidence interval, 0.88-0.95). Postoperative MRI at a mean of 35.6 months (range, 10-78 months) showed that 35 shoulders (50.7%) had intact repairs. Of the 35 shoulders in 35 patients, 7 patients did not reach 2 years of follow-up but underwent MRI at 1-year follow-up postoperatively. For the 3 revision patients (the Debeyre patient and RSA patients), all had type 2 shoulders. There was a significant difference between the 27 type 2 shoulders and 7 type 1 shoulders among the remaining 34 nonintact repair shoulders ($P < .001$). The fascia lata remained on the greater tuberosity in 62 of the 69 shoulders (89.9%).

Macroscopic results

For the Debeyre patient, using a probe, we arthroscopically observed retracted native cuff tendons and the repaired fascia lata robustly remaining on the anterior greater tuberosity (Fig. 3). For the 2 RSA patients, we exposed the greater tuberosity using the deltopectoral approach and confirmed tendon-like soft tissue in the anterior greater tuberosity and the tissue robustly fixed on the anterior tuberosity when we harvested the anterior greater tuberosity (Fig. 4).

Histologic findings

In the control shoulder, dense, parallel normal collagen fibers presenting a typical wavy pattern were oriented along the long axis of the tendon. Many oval to spindle-shaped fibroblasts were seen in the tendon proper (Fig. 2, *A*). For cases 1 and 2, histologic analysis of the greater tuberosity showed solid continuity of the graft to bone, with cells with nuclei in the collagen matrix oriented in parallel (Fig. 2, *B* and *C*). The FLA-bone junction consisted of a layered enthesis pattern, such as fascia lata, fibrocartilage, and bone (Figs. 5, *A* and 6, *A*). There was some safranin O–stained layer representing the fibrocartilage (Figs. 5, *B* and 6, *B*). At the midsubstance site of the control rotator cuff, collagen fibers were oriented in parallel, and most cells resembled tenocytes oriented in parallel along the fibers (Fig. 2, *D*). In contrast, in cases 1 and 2, there were fewer fibers oriented in parallel and cells resembling tenocytes (Fig. 2, *E* and *F*). In the tear site of the control rotator cuff, the end of the stump was sharply resected, whereas the stumps in cases 1 and 2 were not sharp, and cell and fiber alignments were disarrayed. Cellularity and vascularity were also denser than in the control rotator cuff tissue (Fig. 2, *G-I*).

Discussion

To the best of our knowledge, this is the first study to histologically evaluate the greater tuberosity and autologous grafted fascia lata harvested en bloc from patients who underwent an FLA patch procedure. Notably, histologic findings revealed that the fascia-bone insertion included 3 zones, fascia (like tendon), fibrocartilage, and bone, which is similar to the normal cuff tendon–bone junction.

MRI and histologic results support that a fresh cellular fascia autograft would have a good potential for bone

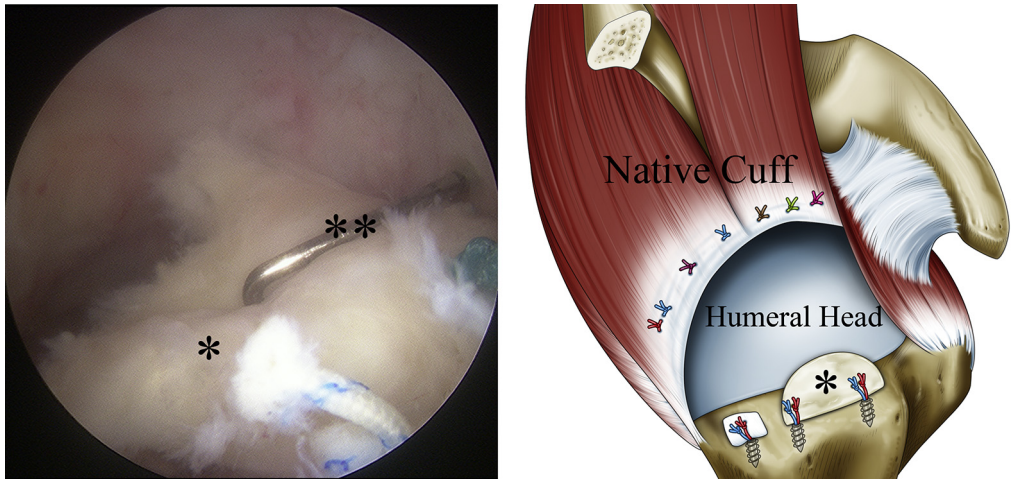

Figure 3 Arthroscopic second look at the time of modified Debeyre muscle advancement procedure. Tendon-like tissue (*) was firmly fixed on the anterior greater tuberosity using a probe (**).

healing. The MRI findings showed that 63 of 69 shoulders (91.3%) had a low-intensity area on the anterior greater tuberosity. Because the arthroscopic second-look finding in the Debeyre patient with a type 2 retear showed that the graft remained on the anterior greater tuberosity at 8 months postoperatively after primary FLA patch surgery, we expected that the 63 shoulders would have the FLA firmly fixed on the greater tuberosity.

Histologic results showed some safranin O–stained fibrocartilage between the bone and fascia graft. Sano et al[30] examined the use of a fresh FLA as an interpositional graft in a rabbit supraspinatus injury model. The authors concluded that the newly formed insertion showed a histologic structure similar to that of a normal supraspinatus insertion with fibrocartilage at 8 weeks after the index surgery. The study of Sano et al supports that the structure at the fascia-bone interface is similar in appearance to the normal cuff tendon–bone interface in our series. However, these were qualitative assessments.

There remains much controversy about which graft material has better healing rates and clinical outcomes after graft reinforcement in large to massive rotator cuff tears. In one meta-analysis, the authors found no significant difference in healing rates between autografts, allografts, xenografts, and synthetic grafts.[29] The advantages of using a fresh cellular autograft include a low risk of infection and aseptic inflammatory reactions, regardless of the controversy. A small number of studies have investigated the efficacy of cellular fresh autografts in animal models of experimental rotator cuff defects regarding incorporation of the graft to bone.[18,32] Iwata et al[18] found that host cells commenced proliferation in the interposed autologous graft. The authors also found that the number of graft-derived cells decreased over time. Tachiiri et al[32] examined the characteristics of donor and host cells in the early remodeling process after autologous Achilles tendon transplantation to treat a rotator cuff defect in a rat model. They concluded that autografts with live donor cells are superior to frozen allografts or synthetic materials without live donor cells in the early remodeling process. These studies support the validity of our graft choice, although the studies did not clarify whether the host cells retained their active role in rotator cuff healing with degenerative or avascular tears. Considering our radiographic and histologic results, even though we did not investigate the early remodeling process, we believe that a fresh cellular FLA has good to excellent bone healing potential as a valuable graft.

Several limitations in this study should be discussed. First, the size of the histologic tissue samples was small. In addition, we did not assess all of the patients' greater tuberosities. Therefore, our histologic findings are not universally representative. Second, the significant frequency of type 1 vs. type 2 shoulders implies that most retears occur between the native cuff tendons and autografts. The maturing scores of the midsubstance and tear portions in RSA cases 1 and 2 were lower than the control scores in our study (Table S2). In the study by Ono et al,[29] the authors concluded that although several factors other than graft material, such as tear size, approach (open vs. arthroscopic), and indications (augmentation vs. bridging), may be important considerations, the graft type affected clinical outcomes. We previously reported a 10.5% healing rate with FLAs in a series of patients with severe fatty degeneration (Goutallier stage 3 or stage 4, H group) of the supraspinatus and infraspinatus. However, when we evaluated a similar series of patients with severe fatty degeneration isolated to only the supraspinatus, a significantly higher healing rate (73.1%) was seen.[26] Indeed, significant differences in the preoperative medial to lateral tear size and global fatty degeneration index might have resulted in the significant difference in the healing rate between the 2 groups. However, these differences and this study could not clarify the etiology of such retears. Third,

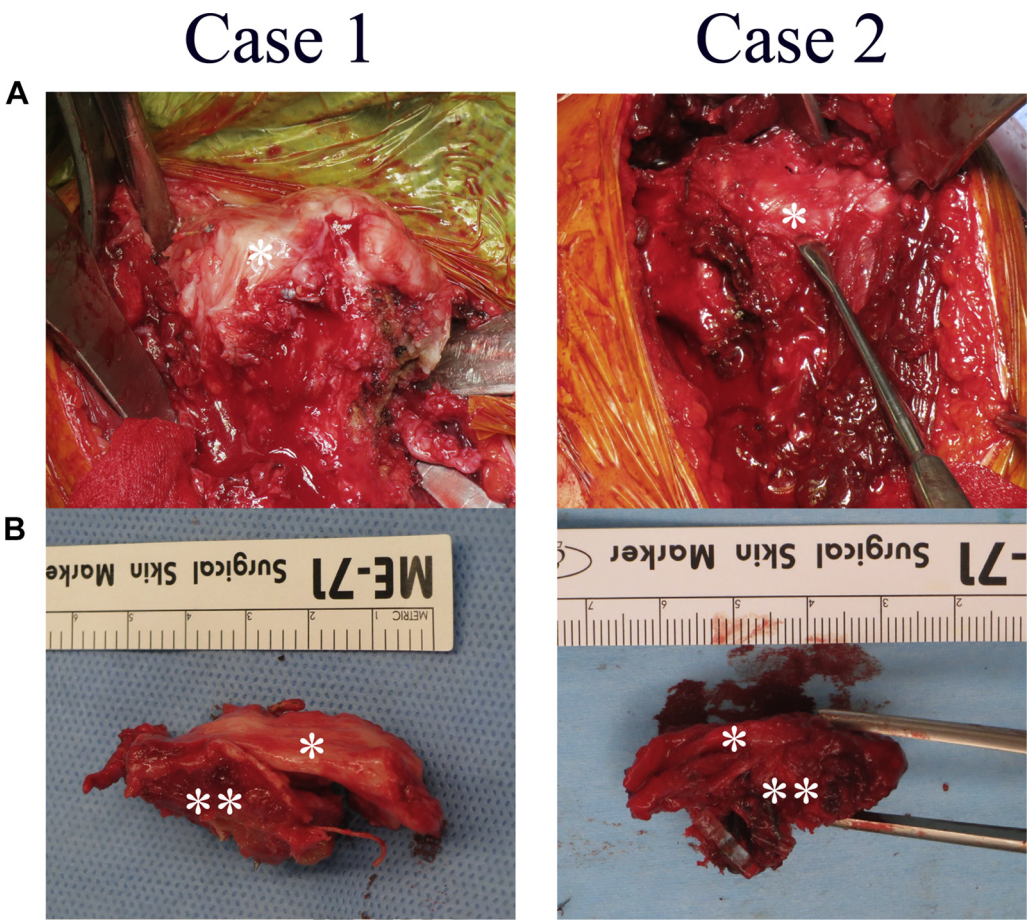

Figure 4 (**A**) Exposed fascia lata autograft on the greater tuberosity for right shoulder. (**B**) Harvested fascia lata autograft on the greater tuberosity for left shoulder. *, Fascia lata autograft; **, anterior greater tuberosity. These images show that the fascial autograft was attached to the greater tuberosity.

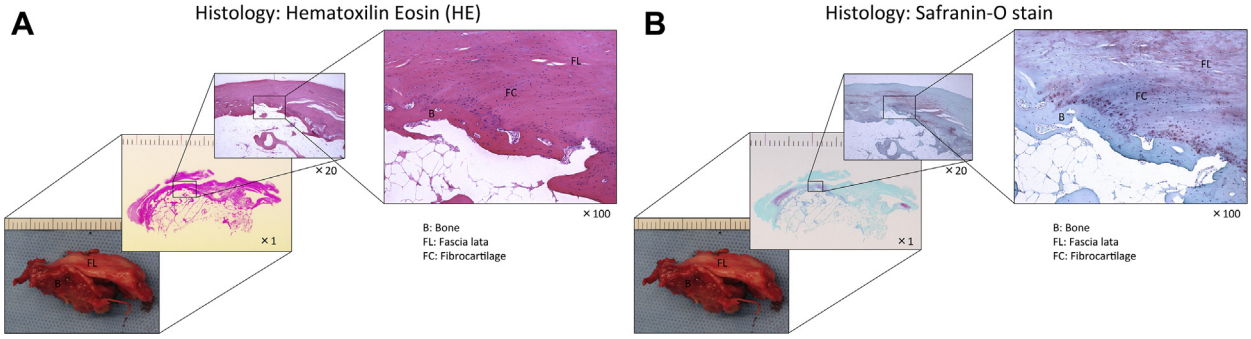

Figure 5 Histologic evaluation of the fascia lata autograft–bone interface in case 1. The greater tuberosity shows solid continuity of the graft-bone interface, with cells with nuclei in the collagen matrix oriented in parallel. The fascia lata autograft–bone junction consisted of the fascia lata, fibrocartilage, and bone. Note the perpendicular pattern of the collagen fibers inserted in the bone. Some safranin O–stained layer was seen. (**A**) Hematoxylin and eosin stain, original magnifications ×1, ×20, and ×100. (**B**) Safranin O stain, original magnifications ×1, ×20, and ×100.

the follow-up period for 7 patients except the Debeyre patient did not reach the minimum 2 years. However, this study is not clinical. In addition, all 7 patients had intact repairs at 1 year postoperatively. Some studies have reported that retears after rotator cuff repair occur within 6 months postoperatively, indicating that postoperative MRI scans at >6 months postoperatively would be reasonable to evaluate the bone healing potential of FLAs.[15,24] In addition, we included patients whose follow-up did not reach 2 years postoperatively in this study. Fourth, we had no control group in terms of other graft operations and materials. Recent graft operations include mostly bridging,

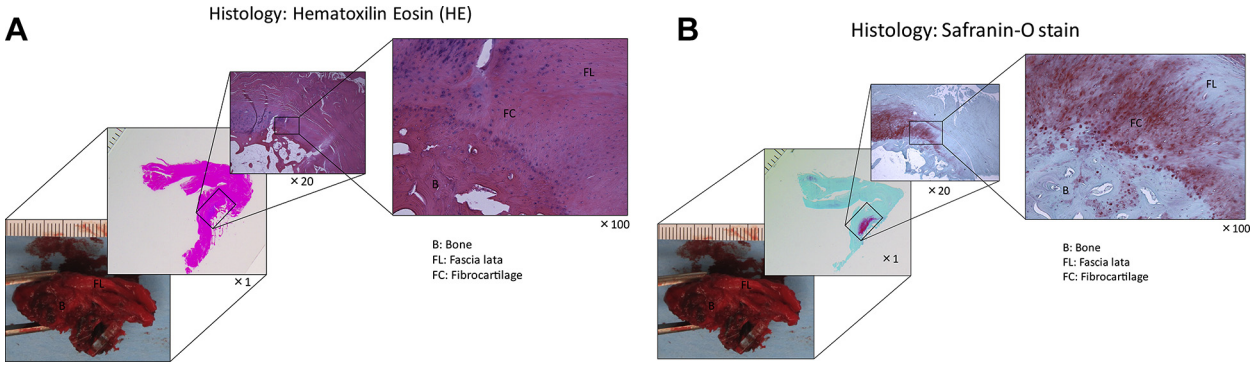

Figure 6 Histologic evaluation of the fascia lata autograft–bone interface in case 2. The greater tuberosity showed solid continuity of the graft-bone interface, with cells with nuclei in the collagen matrix oriented in parallel. The fascia lata autograft–bone junction consisted of the fascia lata, fibrocartilage, and bone. Note the perpendicular pattern of the collagen fibers inserted in the bone. Some safranin O–stained layer was seen. (**A**) Hematoxylin and eosin stain, original magnifications ×1, ×20, and ×100. (**B**) Safranin O stain, original magnifications ×1, ×20, and ×100.

augmentation, and arthroscopic superior capsular reconstruction. Mihata et al[22] showed excellent healing outcomes (83.3%) after arthroscopic superior capsular reconstruction using FLAs for massive rotator cuff tears. The technique involves attaching the FLA medially to the glenoid superior tubercle and laterally to the greater tuberosity. In addition, a systematic review by Ono et al[28] concluded that bridging grafts had no significant difference in healing outcomes compared with grafts used for augmentation. These two studies might indicate good to excellent bone healing potential of FLAs despite this study's including only patients who underwent the bridging technique.[22,28] However, the results cannot be generalized to all patients. Fifth, a single examiner evaluated the histologic findings. The possibility of observer bias remains, even though the examiner did not know the clinical or radiographic information. In addition, the possibility of MRI observer bias remains because the MRI observers included the treating surgeon, although the interobserver reliability of retear types was 0.92. Finally, we did not assess the biomechanical properties of the grafts in this study because we wanted to avoid the risk of graft injury. Two biomechanical studies have demonstrated good to excellent properties of fascia lata grafts.[9,21] However, considering that the graft remained on the greater tuberosity in 62 of the MRI results, FLAs appear to have good fixation to the greater tuberosity.

Conclusion

This study noted 2 main findings. One was that 62 postoperative MRI scans (89.9%) showed that the FLA remained on the greater tuberosity among 69 MRIs in 69 patients who underwent FLA patch procedures. The other was that the histologic findings revealed that the fascia to bone insertion includes layers, such as the fascia (like tendon), fibrocartilage, and bone, which is similar to the normal cuff tendon to bone junction. Therefore, our results indicate that a fresh cellular FLA has good to excellent bone healing potential.

Acknowledgments

The authors thank Hajime Yamakage, MD, for the statistical analyses, and Mutsumi Nishida, PhD, for valuable discussion. They also thank Mr. Tadanori Yamaguchi, Ayabe City Hospital, Kyoto, for the help of euthanasia and preparation of histologic specimens. We also thank M. Arico from Edanz Group (www.edanzediting.com/ac) for editing a draft of this manuscript.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2018.11.067.

References

1. Arnoczky SP, Bishai SK, Scofield B, Sigman S, Bushnell BD, Hommen JP, et al. Histologic evaluation of biopsy specimens obtained after rotator cuff repair augmented with a highly porous collagen

implant. Arthroscopy 2017;33:277-83. https://doi.org/10.1016/j.arthro.2016.06.047
2. Arnoczky SP, Warren RF, Minei JP. Replacement of the anterior cruciate ligament using a synthetic prosthesis. An evaluation of graft biology in the dog. Am J Sports Med 1986;14:1-6.
3. 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;28:8-15. https://doi.org/10.1016/j.arthro.2011.06.038
4. Barber FA, Herbert MA, Coons DA. Tendon augmentation grafts: biomechanical failure loads and failure patterns. Arthroscopy 2006;22:534-8. https://doi.org/10.1016/j.arthro.2005.12.021
5. Bokor DJ, Sonnabend D, Deady L, Cass B, Young A, Van Kampen C, et al. Preliminary investigation of a biological augmentation of rotator cuff repairs using a collagen implant: a 2-year MRI follow-up. Muscles Ligaments Tendons J 2015;5:144-50. http://dx.doi.org/10.11138/mltj/2015.5.3.144
6. 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;24:403-9.e1. https://doi.org/10.1016/j.arthro.2007.07.033
7. Burkhart SS, Barth JR, Richards DP, Zlatkin MB, Larsen M. Arthroscopic repair of massive, irreparable rotator cuff tears with stage 3 and 4 fatty degeneration. Arthroscopy 2007;23:347-54. https://doi.org/10.1016/j.arthro. 2006.12.012
8. Cho NS, Yi JW, Lee BG, Rhee YG. Retear patterns after arthroscopic rotator cuff repair: single-row versus suture bridge technique. Am J Sports Med 2010;38:664-71. https://doi.org/10.1177/0363546509350081
9. Derwin KA, Baker AR, Spragg RK, Leigh DR, Farhat W, Iannotti JP. Regional variability, processing methods, and biophysical properties of human fascia lata extracellular matrix. J Biomed Mater Res A 2008;84:500-7. https://doi.org/10.1002/jbm.a.31455
10. 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;12:2665-72. https://doi.org/10.2106/JBJS.E.01307
11. Goutallier D, Postel JM, Gleyze P, Leguilloux P, Van Driessche S. Influence of cuff muscle fatty degeneration on anatomic and functional outcomes after simple suture of full-thickness tears. J Shoulder Elbow Surg 2003;12:550-4. https://doi.org/10.1016/S1058-2746(03)00211-8
12. Gupta AK, Hug K, Berkoff DJ, Boggess BR, Gavigan M, Malley PC, et al. Dermal tissue allograft for the repair of massive irreparable rotator cuff tears. Am J Sports Med 2012;40:141-7. https://doi.org/10.1177/ 0363546511422795
13. Gupta AK, Hug K, Boggess B, Gavigan M, Toth AP. Massive or 2-tendon rotator cuff tears in active patients with minimal glenohumeral arthritis: clinical and radiographic outcomes of reconstruction using dermal tissue matrix xenograft. Am J Sports Med 2013;41:872-9. https://doi.org/10.1177/0363546512475204
14. Hoffmann MW, Wening JV, Apel R, Jungbluth KH. Repair and reconstruction of the anterior cruciate ligament by the "sandwich technique." A comparative microangiographic and histological study in the rabbit. Arch Orthop Trauma Surg 1993;112:113-20.
15. Iannotti JP, Deutsch A, Green A, Rudicel S, Christensen J, Marraffino S, et al. Time to failure after rotator cuff repair: a prospective imaging study. J Bone Joint Surg Am 2013;95:965-71. https://doi.org/10.2106/JBJS.L.00708
16. Ide J, Kikukawa K, Hirose J, Iyama K, Sakamoto H, Fujimoto T, et al. The effect of a local application of fibroblast growth factor-2 on tendon-to-bone insertion remodeling in rats with acute injury and repair of the supraspinatus tendon. J Shoulder Elbow Surg 2009;18:391-8. https://doi.org/10.1016/j.jse.2009.01.013
17. Ide J, Kikukawa K, Hirose J, Iyama K, Sakamoto H, Mizuta H. Reconstruction of large rotator-cuff tears with acellular dermal matrix grafts in rats. J Shoulder Elbow Surg 2009;18:288-95. https://doi.org/10.1016/j.jse.2008.09.004
18. Iwata Y, Morihara T, Tachiiri H, Kajikawa Y, Yoshida A, Arai Y, et al. Behavior of host and graft cells in the early remodeling process of rotator cuff defects in a transgenic animal model. J Shoulder Elbow Surg 2008;17:101-7. https://doi.org/10.1016/j.jse.2007.07.008
19. Jackson DW, Grood ES, Arnoczky SP, Butler DL, Simon TM. Cruciate reconstruction using freeze dried anterior cruciate ligament allograft and a ligament augmentation device (LAD). An experimental study in a goat model. Am J Sports Med 1987;15:528-38.
20. Kim JO, Lee JH, Kim KS, Ji JH, Koh SJ, Lee JH. Rotator cuff bridging repair using acellular dermal matrix in large to massive rotator cuff tears: histologic and clinical analysis. J Shoulder Elbow Surg 2017;26:1897-907. https://doi.org/10.1016/j.jse.2017.04.010
21. McCarron JA, Milks RA, Mesiha M, Aurora A, Walker E, Iannotti JP, et al. Reinforced fascia patch limits cyclic gapping of rotator cuff repairs in a human cadaveric model. J Shoulder Elbow Surg 2012;21:1680-6. https://doi.org/10.1016/j.jse.2011.11.039
22. Mihata T, Lee TQ, Watanabe C, Fukunishi K, Ohue M, Tsujimura T, et al. Clinical results of arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. Arthroscopy 2013;29:459-70. https://doi.org/10.1016/j.arthro.2012.10.022
23. Mihata T, McGarry MH, Pirolo JM, Kinoshita M, Lee TQ. Superior capsule reconstruction to restore superior stability in irreparable rotator cuff tears: a biomechanical cadaveric study. Am J Sports Med 2012;40:2248-55. https://doi.org/10.1177/0363546512456195
24. Miller BS, Downie BK, Kohen RB, Kijek T, Lesniak B, Jacobson JA, et al. When do rotator cuff repairs fail? Serial ultrasound examination after arthroscopic repair of large and massive rotator cuff tears. Am J Sports Med 2011;39:2064-70. https://doi.org/10. 1177/0363546511413372
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;29:1911-21. https://doi.org/10.1016/j.arthro.2013.08.032
26. Mori D, Funakoshi N, Yamashita F, Wakabayashi T. Effect of fatty degeneration of the infraspinatus on the efficacy of arthroscopic patch autograft procedure for large to massive rotator cuff tears. Am J Sports Med 2015;43:1108-17. https://doi.org/10.1177/0363546515569680
27. Mura N, O'Driscoll SW, Zobitz ME, Heers G, An KN. Biomechanical effect of patch graft for large rotator cuff tears: a cadaver study. Clin Orthop Relat Res 2003;415:131-8. https://doi.org/10.1097/01.blo.0000092967.12414.4c
28. Ono Y, Dávalos Herrera DA, Woodmass JM, Boorman RS, Thornton GM, Lo IK. Graft augmentation versus bridging for large to massive rotator cuff tears: a systematic review. Arthroscopy 2017;33:673-80. https://doi.org/10.1016/j.arthro.2016.08.030
29. Ono Y, Herrera AD, Woodmass JM, Boorman RS, Thornton GM, Lo IK. Healing rate and clinical outcomes of xenografts appear to be inferior when compared to other graft material in rotator cuff repair: a meta-analysis. J ISAKOS 2016;1:321-8. https://doi.org/10.1136/jisakos-2016-000076
30. 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;11:166-73. https://doi.org/10.1067/mse.2002.120808
31. Snyder SJ, Arnoczky SP, Bond JL, Dopirak R. Histological evaluation of a biopsy specimen obtained 3 months after rotator cuff augmentation with GraftJacket Matrix. Arthroscopy 2009;25:329-33. https://doi.org/10.1016/j.arthro.2008.05.023
32. Tachiiri H, Morihara T, Iwata Y, Yoshida A, Kajikawa Y, Kida 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 defects—what is the ideal graft for the treatment of massive rotator cuff defects? J Shoulder Elbow Surg 2010;19:891-8. https://doi.org/10.1016/j.jse.2010.02.001
33. Watkins JP, Auer JA, Gay S, Morgan SJ. Healing of surgically created defects in the equine superficial digital flexor tendon: collagen-type transformation and tissue morphologic reorganization. Am J Vet Res 1985;46:2091-6.