



Arthroscopic Rotator Cuff Repair Augmented with Autologous Subacromial Bursa Tissue, Concentrated Bone Marrow Aspirate, Platelet-Rich Plasma, Platelet-Poor Plasma, and Bovine Thrombin

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Abstract: As recurrent rotator cuff tears following repair remain a significant problem, improving healing potential using biologic adjuvants, including concentrated bone marrow aspirate (cBMA), platelet-rich plasma (PRP), or subacromial bursa tissue (SBT), has become increasingly popular in recent years. In an attempt to combine the benefits of these various biologic adjuvants and maximize the healing potential of the repaired tendon, an arthroscopic rotator cuff repair technique biologically augmented with autologous SBT, cBMA, PRP, platelet-poor plasma (PPP), and bovine thrombin has been developed. The created clot is used as a biologic scaffold for sufficient delivery, and it is stabilized using bovine thrombin in order to ensure maximum stability and retainment of the applied biologic augments at the repair site. **Classifications:** I: shoulder; II: rotator cuff.

Introduction

As recurrent rotator cuff tears following primary repair remain a significant problem, improving healing potential using biologic adjuvants has become increasingly popular in recent years.¹ Platelet-rich plasma

(PRP) is derived from autologous peripheral blood that is centrifuged to isolate a higher concentration of growth factors to promote healing.² Clinical outcomes following PRP application have been mixed; however, retear rates have been found to be significantly decreased.³ Further, application of concentrated bone marrow aspirate (cBMA),⁴ as the most common source of mesenchymal stem cells (MSCs) for biologic augmentation, has shown

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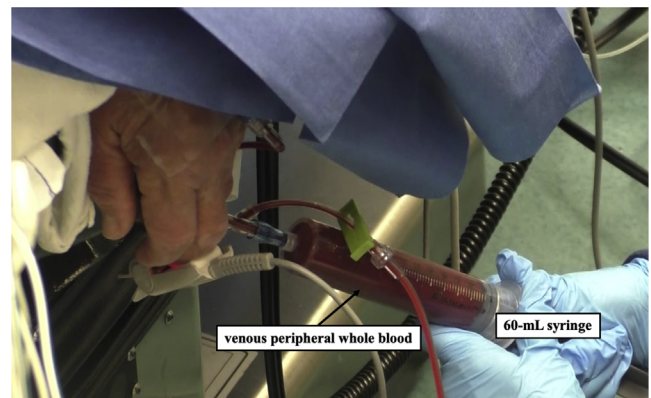


Fig 1. While setting up the patient for surgery, plasma harvest is started, in order to avoid delay in the subsequent course of surgery. Specifically, 52 mL of venous peripheral whole blood are drawn from the patient's contralateral arm using a 60-mL syringe prefilled with 8 mL anticoagulant citrate dextrose solution A.

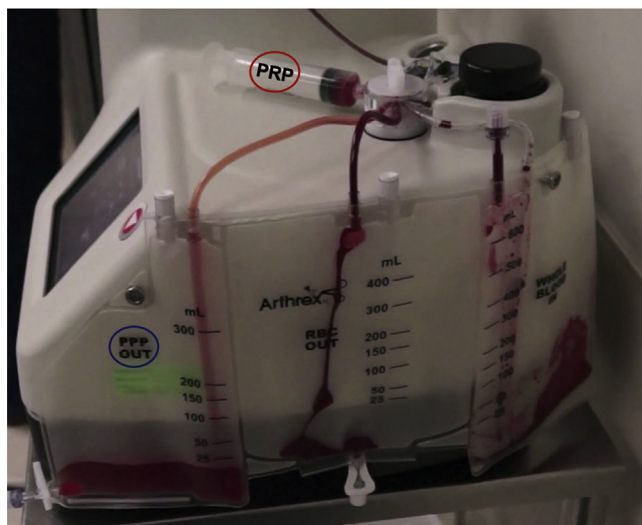


Fig 2. The blood is processed using a fully automated three-sensor technology system based on flow cytometry and light absorption (Angel System, Arthrex, Inc., Naples, FL) to obtain approximately 2 to 3 mL of platelet-rich plasma (PRP; red circle) and 20 to 25 mL of platelet-poor plasma (PPP; blue circle).

promising results in decreasing re-tear rates and improving healing outcomes.⁵

In addition, subacromial bursa tissue (SBT), which is often discarded during arthroscopic surgery to ensure visualization of the rotator cuff tear, has been suggested to be an easily accessible alternative source of MSCs.⁶⁻⁸ In vitro characterizations of SBT have shown that these cells fulfill all characteristics of MSCs, including high proliferative potential, similar expression of surface markers, and multilineage differentiation.^{6,8-14} Further, Morikawa et al. recently described a novel, effective, nonenzymatic method for mechanically isolating progenitor cells with MSC characteristics from SBT for clinical use.¹¹ More importantly, chopping SBT until becoming a finely minced particulate released significantly more cells when compared to minimally processed tissue.¹¹

In an attempt to combine the benefits of these various biologic adjuvants and to maximize the healing potential of the repaired tendon, an arthroscopic rotator cuff repair technique biologically augmented with autologous subacromial bursa tissue, concentrated bone marrow aspirate, PRP, platelet-poor plasma (PPP), and bovine thrombin has been developed.

Surgical Technique (With Video Illustration)

A detailed step-by-step description of the surgical technique is demonstrated in [Video 1](#).

Preoperative Planning

In addition to obtaining a thorough medical and surgical history, all patients undergoing surgery have

preoperative radiographs (true anterior/posterior view, axillary lateral view, scapular Y view) and magnetic resonance imaging (MRI) of the involved shoulder. Severity of cuff tear arthropathy is assessed on plain radiographs, according to Hamada et al.¹⁵ MRI scans are used to determine rotator cuff tear characteristics, including tear size, tendon retraction,¹⁶ fatty infiltration,¹⁷ and muscle atrophy.¹⁸ Prior to surgery, all patients receive detailed information regarding the operative technique and possible complications.

Patient Setup and Plasma Harvest

The patient is placed in the beach chair position, with the operative arm fixed in a movable arm holder. An interscalene block is performed, followed by draping of the operative area after successful induction of general anesthesia. While setting up the patient for surgery, plasma harvest is started in order to avoid delay in the subsequent course of surgery. Specifically, 52 mL of venous peripheral whole blood are drawn from the patient's contralateral arm using a 60-mL syringe prefilled with 8 mL Anticoagulant Citrate Dextrose Solution A (ACD-A; Baxter Healthcare Corp.; [Fig 1](#)).¹⁹ The blood is processed using a fully automated three-sensor technology system based on flow cytometry and light absorption (Angel System, Arthrex Inc., Naples, FL) to obtain approximately 2 to 3 mL of platelet-rich plasma (PRP) and 20 to 25 mL of platelet-poor plasma (PPP) ([Fig 2](#)).¹⁹ The high-spinning centrifugal process with a hematocrit setting of 7% takes up to 20 minutes.¹⁹

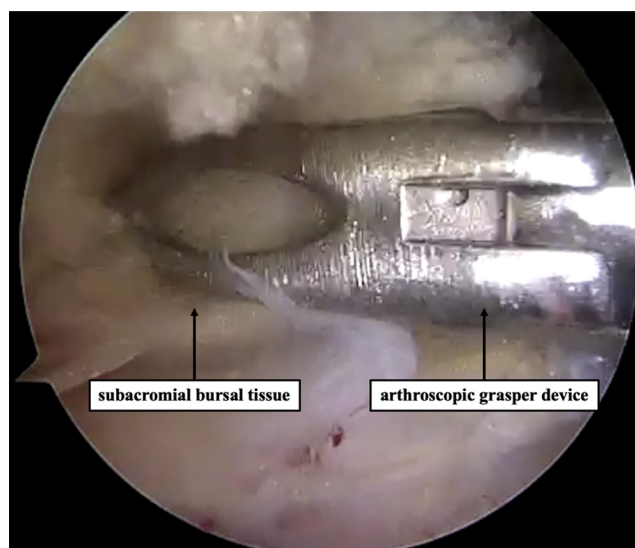


Fig 3. The arthroscope is switched to the subacromial space and subacromial bursa tissue is harvested from over the tendon and muscle using an arthroscopic grasper device.

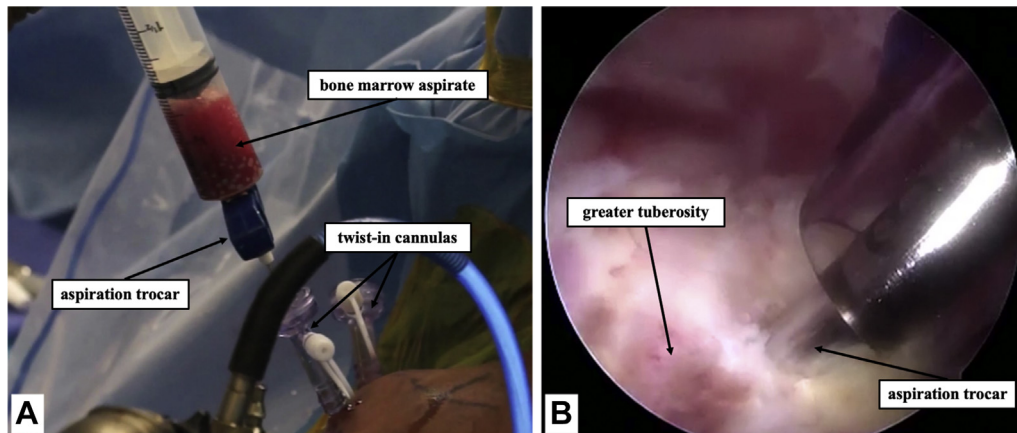


Fig 4. Harvest of bone marrow aspirate (BMA) from the proximal humeral head in a left shoulder. (A) A heparin-flushed nonfenestrated bone marrow aspiration trocar (14 gauge) is inserted 25 to 30 mm into the medial aspect of the greater tuberosity at the articular margin via the anterolateral portal (bone marrow aspiration kit; Arthrex, Inc., Naples, FL). The aspiration method is repeated six times allowing 18 mL of bone marrow aspirate (9:1 BMA to ACD-A ratio) to flow into each of the six 60-mL syringes for a total of 120 mL of aspirate. (B) Arthroscopic view via the posterolateral portal.

Diagnostic Arthroscopy, Subacromial Bursa Harvest, and Tear Assessment

At the beginning of surgery, diagnostic arthroscopy is performed using a standard posterior portal, in order to confirm the presence of the rotator cuff tear and evaluate for concomitant injuries within the glenohumeral joint. The arthroscope is then switched to the subacromial space, and subacromial bursa tissue is harvested from over the tendon and muscle using an arthroscopic grasper device (Fig 3).^{11,13} Alternatively, the bursa tissue can be obtained using a shaver connected to a special collection device. Subsequently, twist-in cannulas are positioned in the posterior (8.25 mm × 9 cm; Arthrex, Inc., Naples, FL), anterior (8.25 mm × 7 cm, Arthrex, Inc.) and anterolateral

(8.25 mm × 7 cm, Arthrex, Inc.) portal, while the camera is placed through the posterolateral portal, allowing for good visualization of the intra-articular structures.

The edges of the tear are then debrided using a shaver, and mobility of the torn rotator cuff tendons is assessed using a grasper device. Loose suture material and/or anchors from prior repairs are also removed. The greater tuberosity is prepared using a shaver and meniscal rasp, while preserving the cortical bone and avoiding creating a trough.

Bone Marrow Aspiration and Concentration

Next, bone marrow aspirate (BMA) is obtained from the proximal humeral head (Fig 4).^{4,20} A heparin-flushed (10,000 IU/mL) nonfenestrated bone marrow aspiration trocar (14 gauge) is inserted 25 to 30 mm into the medial aspect of the greater tuberosity at the articular margin (bone marrow aspiration kit; Arthrex, Inc., Naples, FL).^{19,20} After a 60-mL syringe containing 2 mL of ACD-A is connected to the trocar, the syringe is pulled back to maximize suction.^{19,20} This standardized aspiration method is repeated six times, allowing 18 mL of bone marrow aspirate (9:1 BMA to ACD-A ratio) to flow into each of the six 60-mL syringes for a total of 120 mL of aspirate.^{19,20} All syringes coming into contact with BMA are flushed with heparin (10,000 IU/mL) prior to use. The BMA, consisting of blood, bone marrow, and arthroscopic fluid, is then transferred to the Angel System (Arthrex, Inc., Naples, FL) and concentrated using a 15% hematocrit setting (cBMA).^{19,20}

In order to maximize the bone marrow harvest, the aspiration process should be the first time entering the

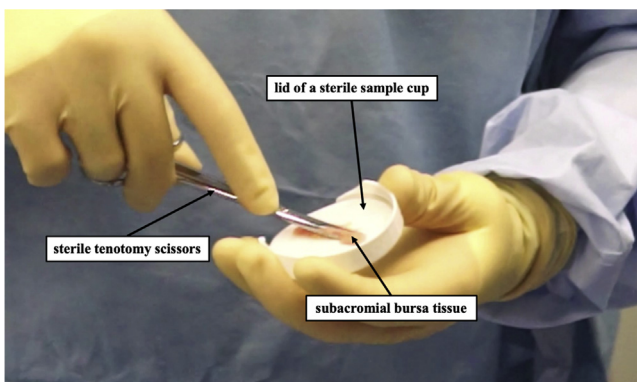


Fig 5. The subacromial bursa tissue sample is chopped on a lid of a sterile sample cup using sterile tenotomy scissors until becoming a finely minced, gooey particulate, in order to release the cells from their matrix.

Table 1. Pearls and Pitfalls

Pearls	Pitfalls
Sufficient mechanical processing of subacromial bursa tissue using sterile tenotomy scissors to release cells from their matrix.	Manipulation of bone marrow aspirate and platelet-rich plasma on and off the surgical field bears the risk for not maintaining sterile conditions during the procedure.
To maximize bone marrow harvest, the aspiration process should be the first time entering the bone. Thus, prior violation of the cortex should be avoided.	Mixing the various biologic adjuvants in an inaccurate ratio may result in an unstable clot, which may complicate delivery and tend to float away.
Take smaller bone marrow aspirate volumes to ensure that anticoagulation stays consistent.	
The first part of the clot should be inserted underneath the repaired tendon prior to tensioning down the second suture anchor of the lateral row in a horizontal mattress fashion.	

bone. The tunnel created for the aspiration is later used to insert the first suture anchor of the medial row at the articular margin.

Subacromial Bursa Sample Processing

Subacromial bursa tissue is obtained mainly from over the rotator cuff tendon using an arthroscopic grasper device. Previous work from our laboratory has shown that bursa from over the tendon comprises more connective tissue progenitor cells than bursa harvested from over the muscle.^{9,10} The bursa sample is then chopped on a lid of a sterile sample cup using sterile tenotomy scissors until becoming a finely minced, gooey particulate, in order to release the cells from their matrix (Fig 5, Table 1).^{9,11,13}

Clot Preparation

A clot is used as a biologic scaffold to deliver cBMA, growth factors, and autologous subacromial bursa tissue directly to the repair site to enhance the biological healing process. To ensure biological and mechanical stability of the clot, volumes of .1 cc of cBMA, .1 cc of

PRP, .6 cc of PPP containing the fibrinogen, .2 cc of bovine thrombin (5,000 IU/mL) and 2 cc of chopped subacromial bursal tissue are combined, scaled up and added to a 30-mL syringe, according to the amount of product produced (Fig 6). Bovine thrombin is used to activate and obtain a stable clot.¹⁹ During the clotting period, continuous mixing of the syringe content is essential, in order to prevent the heavier bursal tissue from dropping down to the bottom of the syringe. The clotting process takes about 30 to 60 seconds after adding the bovine thrombin. The final clot usually has a size of 16 to 24 cc.

Anchor Placement and Delivery of the Clot

During preparation of the clot, the medial row is placed at the articular margin using two double-loaded suture anchors (PEEK Corkscrew FT Suture Anchor, 5.5 mm × 14.7 mm with two no. 2 FiberWire, Arthrex Inc., Naples, FL) and tied. Subsequently, the first anchor of the lateral row (PEEK SwiveLock, 4.75 mm × 19.1 mm; Arthrex, Inc., Naples, FL) is placed. Prior to tensioning down, the second suture anchor of the

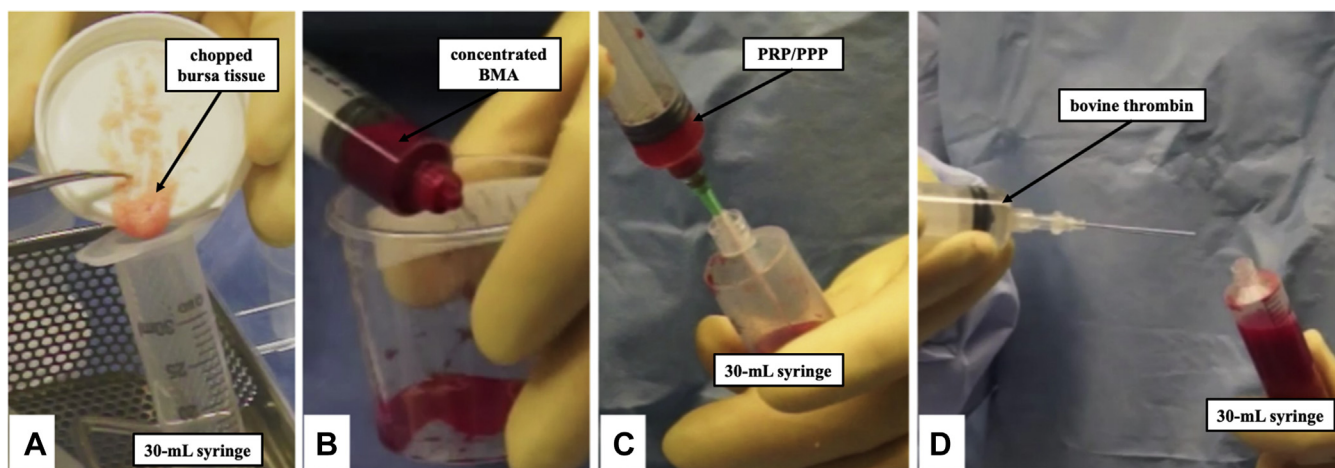
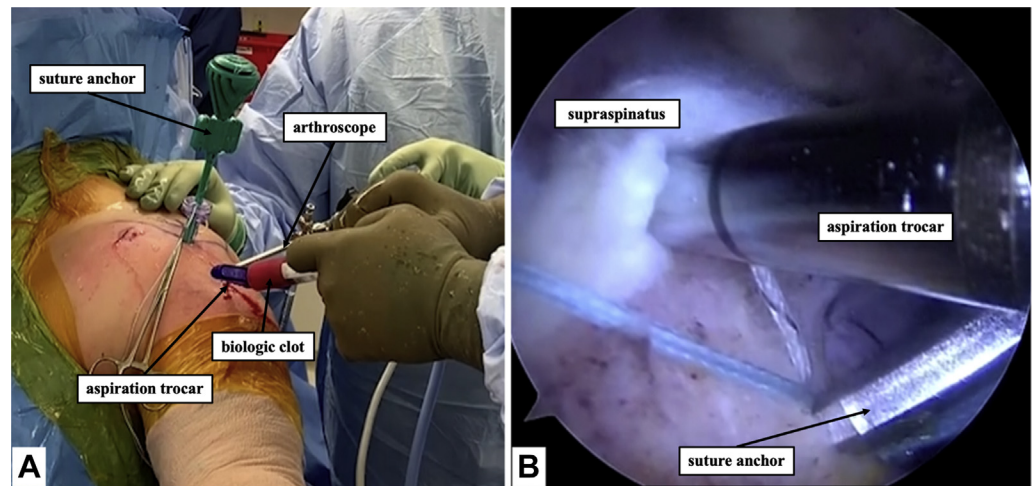


Fig 6. Chopped subacromial bursa tissue (A), concentrated BMA (B), PRP/PPP (C), and bovine thrombin (D) are subsequently combined, scaled up, and added to a 30-mL syringe to form a clot. BMA, bone marrow aspirate; PPP, platelet-poor plasma; PRP, platelet-rich plasma.

Fig 7. (A) Prior to tensioning down the second suture anchor of the lateral row in a horizontal mattress fashion via the anterolateral portal, the aspiration trocar is put underneath the double row repair, and the first part of the clot is inserted underneath the repaired tendon (demonstration in left shoulder). (B) Arthroscopic view via the posterolateral portal (left shoulder).



lateral row in a horizontal mattress fashion, the aspiration trocar is put underneath the double-row repair, and the first part of the clot is inserted underneath the repaired tendon (Fig 7). After insertion of the clot, the transosseous-equivalent anatomic double-row rotator cuff repair is then secured by tensioning down the final anchor of the lateral row (Fig 8). All portals are then closed except for the anterior and posterolateral portal. Lastly, the arthroscope is moved to the subacromial

space, and the rest of the clot is applied over the top of the repair, followed by closure of the anterior and posterolateral portal (Fig 9).

Postoperative Management

Patients are recommended to wear a sling for the first 6 weeks postoperatively. Within the first week, supporting hand, wrist, and elbow range of motion (ROM) should be performed. Until the 6th week postoperatively, glenohumeral abduction is limited to 45°, extension to 30°, and forward elevation to 180°. In week 6 to 12, the patient is allowed free active-assisted ROM in all planes, followed by free active ROM 12 to 2 weeks postoperatively.

Discussion

As the endogenous healing potential of the rotator cuff tendon seems to be limited, biologic augmentation options have garnered recent interest, including the clinical application of growth factors, platelet concentrates, or MSCs.⁵ Although bone marrow is still considered the most commonly used source of MSCs for biologic augmentation,⁵ subacromial bursa tissue, which is often discarded during arthroscopic surgery to ensure visualization of the rotator cuff tear, has been reported to be a significant, easily accessible, and inexpensive source of MSCs.^{6-8,10,11,13}

Although SBT has demonstrated superior engraftment to host tendon along with survival when compared to cBMA, there remains a lack of clinical data supporting these promising in vitro findings.^{10,21} Morikawa et al. recently described an effective, clinically feasible method for mechanically isolating progenitor cells with MSC characteristics from SBT.¹¹ As the authors highlighted that mechanically processing SBT is of great importance to achieve a significantly higher

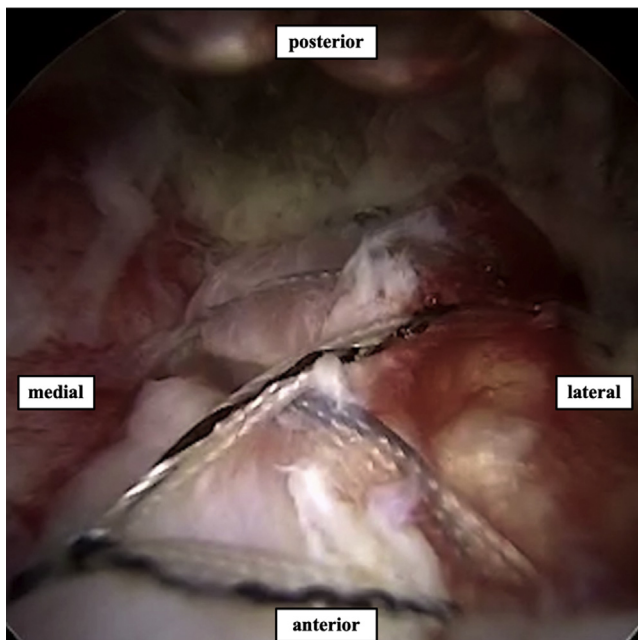


Fig 8. Arthroscopic view of the transosseous-equivalent anatomic double-row rotator cuff repair via the posterior portal in a left shoulder after tensioning down the final anchor of the lateral row.

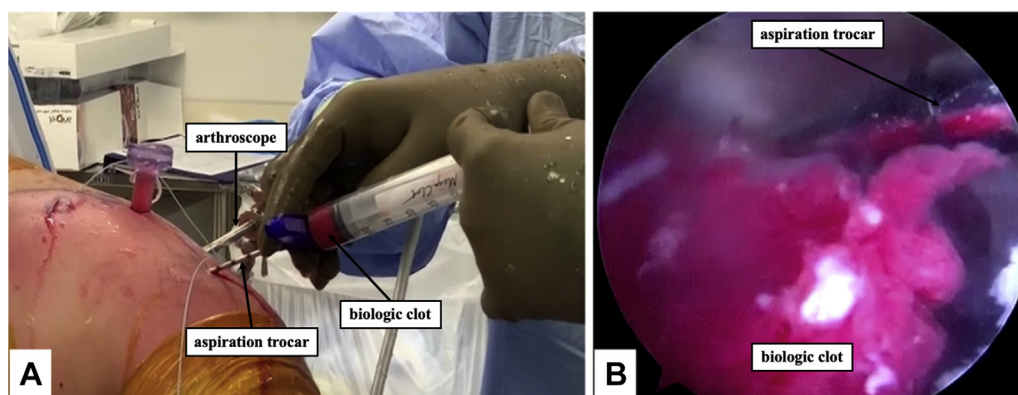


Fig 9. (A) The arthroscope is moved to the subacromial space, and the rest of the clot is applied over the top of the repair using the aspiration trocar. (B) Arthroscopic view via the posterior portal.

release of cells when compared to no manipulation, the SBT is chopped using tenotomy scissors until becoming a finely minced particulate.¹¹ Further, SBT was found to demonstrate a high cellular proliferation potential regardless of patient demographics, rotator cuff tear characteristics, and severity of glenohumeral joint degeneration.¹³ These findings may alleviate concerns that SBT loses in cellular proliferation potential when being used for biologic augmentation in massive and degenerated rotator cuff tears.¹³

Delivery of biologic adjuvants during repair has been described using various techniques, with the ultimate goal to promote healing. The clot used for this technique presents with great volume and robustness to reduce the risk of floating away, as well as to provide an easy delivery. In addition to its unknown cost-effectiveness, it has to be acknowledged that it is a complex technique, as various biologic adjuvants have to be mixed in the correct ratio (Table 2). As maintenance of a sufficient rotator cuff function has been shown to be vital in delaying the development of glenohumeral arthritis, the clot was stabilized using bovine thrombin, in order to ensure maximum stability and retainment of the applied biologic augments at the repair site.

However, there is a lack of confirmation that the delivered clot containing the potent adjuvants remains at the repair site during the postoperative period. Consequently, the potential of the applied clot floating away should be considered as one of the main risks of the technique. Besides, the large patient-individual variability in harvested biologic adjuvants may not allow for expecting homogenous effects in every patient.^{19,22} This concern may be alleviated by the combination of various adjuvants, including MSCs and growth factors in high concentrations, in an attempt to maximize support of the endogenous healing potential. Further, the manipulation of BMA and PRP on and off the surgical field bears the risk for not maintaining sterile conditions during the procedure. In addition, the used bovine thrombin for stabilization of the clot may be limited in its interaction with the harvested biologic adjuvants; thus, the use of autologous thrombin should be kept in mind as a more desirable option when further advancing the technique in the future. However, a recent case series of patients undergoing the present technique showed a significant improvement in functional outcomes at a minimum 1-year follow-up, with 93.8% of patients reaching substantial clinical benefit.²³

Table 2. Advantages and Disadvantages

Advantages	Disadvantages
Use of autologous tissue to support the endogenous healing response	Increased amount of time and effort of both surgeon and staff in the operating room
Creation of a robust and stable clot with great volume	Higher costs with unknown cost-effectiveness
Minimal manipulation of harvested biologic adjuvants	Difficult delivery of the clot
Harvest of bone marrow aspirate from the proximal humerus, thus avoiding the need for using the iliac crest.	Patient-individual variability in harvested biologic adjuvants
Mechanical processing of subacromial bursa tissue increases release of cells from their matrix.	Lack of confirmation that the delivered clot containing the potent adjuvants remains at the repair site during the postoperative period
Can be applied to any technique of rotator cuff repair	Limited evidence regarding clinical efficacy

References

- Zumstein MA, Ladermann A, Raniga S, Schar MO. The biology of rotator cuff healing. *Orthop Traumatol Surg Res* 2017;103:S1-S10.
- Lubkowska A, Dolegowska B, Banfi G. Growth factor content in PRP and their applicability in medicine. *J Biol Regul Homeost Agents* 2012;26:3S-22S.
- Warth RJ, Dornan GJ, James EW, Horan MP, Millett PJ. Clinical and structural outcomes after arthroscopic repair of full-thickness rotator cuff tears with and without platelet-rich product supplementation: a meta-analysis and meta-regression. *Arthroscopy* 2015;31:306-320.
- Otto A, Muench LN, Kia C, et al. Proximal humerus and ilium are reliable sources of bone marrow aspirates for biologic augmentation during arthroscopic surgery. *Arthroscopy* 2020;36:2403-2411.
- Imam MA, Holton J, Horriat S, et al. A systematic review of the concept and clinical applications of bone marrow aspirate concentrate in tendon pathology. *SICOT J* 2017;3:58.
- Utsunomiya H, Uchida S, Sekiya I, Sakai A, Moridera K, Nakamura T. Isolation and characterization of human mesenchymal stem cells derived from shoulder tissues involved in rotator cuff tears. *Am J Sports Med* 2013;41:657-668.
- Song N, Armstrong AD, Li F, Ouyang H, Niyibizi C. Multipotent mesenchymal stem cells from human subacromial bursa: potential for cell based tendon tissue engineering. *Tissue Eng Part A* 2014;20:239-249.
- Steinert AF, Kunz M, Prager P, et al. Characterization of bursa subacromialis-derived mesenchymal stem cells. *Stem Cell Res Ther* 2015;6:114.
- Baldino JB, Muench LN, Kia C, et al. Intraoperative and in vitro classification of subacromial bursal tissue. *Arthroscopy* 2020;36:2057-2068.
- Morikawa D, Johnson JD, Kia C, et al. Examining the potency of subacromial bursal cells as a potential augmentation for rotator cuff healing: An in vitro study. *Arthroscopy* 2019;35:2978-2988.
- Morikawa D, Muench LN, Baldino JB, et al. Comparison of preparation techniques for isolating subacromial bursa-derived cells as a potential augment for rotator cuff repair. *Arthroscopy* 2020;36:80-85.
- Muench LN, Berthold DP, Kia C, et al. Concentrated bone marrow aspirate and subacromial bursa-derived cells demonstrate similar cellular adhesion and proliferation potential on demineralized bone matrix scaffolds for biologic augmentation of rotator cuff repair. *Muscle Ligaments Tendons J* 2020;10:48-56.
- Muench LN, Baldino JB, Berthold DP, et al. Subacromial bursa-derived cells demonstrate high proliferation potential regardless of patient demographics and rotator cuff tear characteristics. *Arthroscopy* 2020;36:2794-2802.
- Landry A, Levy BJ, McCarthy MB, et al. Analysis of time to form colony units for connective tissue progenitor cells (stem cells) harvested from concentrated bone marrow aspirate and subacromial bursa tissue in patients undergoing rotator cuff repair. *Arthrosc Sports Med Rehabil* 2020;2:e629-e636.
- Hamada K, Yamanaka K, Uchiyama Y, Mikasa T, Mikasa M. A radiographic classification of massive rotator cuff tear arthritis. *Clin Orthop Relat Res* 2011;469:2452-2460.
- Patte D. Classification of rotator cuff lesions. *Clin Orthop Relat Res* 1990;254:81-86.
- Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. *Clin Orthop Relat Res* 1994;304:78-83.
- Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly. Assessment by MRI in 55 patients with rotator cuff pathology. *Acta Orthop Scand* 1996;67:264-268.
- Voss A, McCarthy MB, Allen D, et al. Fibrin scaffold as a carrier for mesenchymal stem cells and growth factors in shoulder rotator cuff repair. *Arthrosc Tech* 2016;5:e447-e451.
- Mazzocca AD, McCarthy MB, Chowanec DM, et al. Rapid isolation of human stem cells (connective tissue progenitor cells) from the proximal humerus during arthroscopic rotator cuff surgery. *Am J Sports Med* 2010;38:1438-1447.
- Dyrna F, Zakko P, Pauzenberger L, McCarthy MB, Mazzocca AD, Dymont NA. Human subacromial bursal cells display superior engraftment versus bone marrow stromal cells in murine tendon repair. *Am J Sports Med* 2018;46:3511-3520.
- Mazzocca AD, McCarthy MB, Chowanec DM, et al. Platelet-rich plasma differs according to preparation method and human variability. *J Bone Joint Surg Am* 2012;94:308-316.
- Muench LN, Kia C, Berthold DP, et al. Preliminary clinical outcomes following biologic augmentation of arthroscopic rotator cuff repair using subacromial bursa, concentrated bone marrow aspirate, and platelet-rich plasma. *Arthrosc Sports Med Rehabil* 2020;2:e803-e813.