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Biologic augmentation of rotator cuff repair with microfragmented autologous subacromial bursal tissue enveloped in a patch of compressed autologous long head of biceps tendon tissue: the *Bio-Ravioli* technique

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Background: Rotator cuff repair is one of the most frequently performed procedures in orthopedic surgery. However, considering the limited healing potential of rotator cuff tendons, several augmentation strategies have evolved to enhance tendon healing. The purpose of this article was to present a new surgical technique called *Bio-Ravioli.*

Methods: Patients with repairable full-thickness posterosuperior rotator cuff tear and a moderate-to-high risk of healing failure were chosen as candidates for the *Bio-Ravioli* procedure. It is a biologic augmentation strategy to increase healing potential of arthroscopic rotator cuff repair by use of a biologic graft fixed at the bone-tendon interface. The *Bio-Ravioli* consists of microfragmented autologous subacromial bursal tissue enveloped in a patch of compressed autologous long head of biceps tendon tissue. The rotator cuff is then repaired to the bone and over the graft using a transosseus equivalent configuration.

Conclusion: The *Bio-Ravioli* technique represents an easy and reliable way to increase the healing potential at the bone-tendon interface by using autologous mesenchymal stem cells from different sources: subacromial bursa and long head of the biceps tendon.

Rotator cuff pathology is a growing problem with a high socioeconomic impact.[35] Although rotator cuff repair (RCR) is one of the most frequently performed procedures in orthopedic surgery,[28] high healing failure rate remains a clinically relevant issue, often correlating with poor postoperative outcome.[14,17] On considering the limited healing potential of rotator cuff tendons, several augmentation strategies have evolved to enhance tendon healing. These include growth factors (GFs), platelet concentrates, mesenchymal stem cells (MSCs), scaffolds, various medications, and different combinations of them.[12] Cell-based augmentation techniques seem to be promising, albeit optimal cell source has not been identified yet. Although efficacy of bone marrow stimulation has been largely reported in rotator cuff surgery,[33,34] recent interest arose around bursa-derived stromal cells (BDSCs).[2,15,21,30] A recent in vitro[21] study showed that cells derived from subacromial bursa showed significantly high differentiation ability and high gene expression indicative of chondrogenesis, osteogenesis, and adipogenesis. Muench et al[23] showed in vivo that subacromial bursa has a high cellular proliferation potential for tendon healing.

Several surgical techniques for using the subacromial bursal tissue during arthroscopic RCR have been described.[4,5,7,11,24] These approaches encounter challenges in the reimplantation process of microfragmented autologous subacromial bursal tissue (MASBT) or in the efficacy of suturing the intact bursa layer over the repair site. Indeed, injection cannot guarantee stable application of the material at the bone-tendon interface, where the maximum biologic effect would be required, while sutures are subjected to the thickness/fragility of the bursal tissue, posing a risk of pull out.

Institutional review board approval was not required for this surgical technique article.

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Therefore, a solid carrier or envelope, like a scaffold able to maintain MASBT at the application site, would be desirable. The long head of the biceps tendon (LHBT) has been largely used in shoulder surgery as augmentation in irreparable rotator cuff tears because it is an easily accessible autograft and a viable source of live tenocytes.[26] Recently, some authors[10,27] described a technique of biologic augmentation of RCR with compressed autologous LHBT. Besides its potential biologic effect as viable scaffold, LHBT patch might be suitable as carrier for MASBT during RCR.

The purpose of this article was to present the operative technique of biologic augmentation of arthroscopic RCR by use of a biologic graft fixed at the bone-tendon interface, which consists of MASBT enveloped in a patch of compressed autologous LHBT tissue. The technique was named *Bio-Ravioli*.

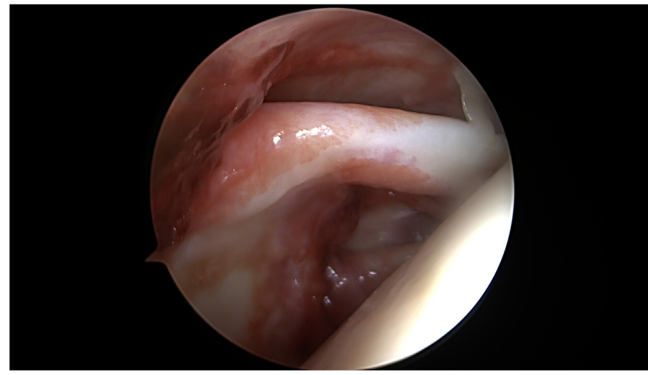

Figure 1 Right shoulder. Scope in the posterior portal: diagnostic arthroscopy. Long head of the biceps inspection.

Surgical technique

Indications and patient selection

Indication to biologic augmentation of RCR by *Bio-Ravioli* technique was based on patient's history, preoperative clinical examination, and imaging findings. Preoperative imaging consisted of a radiographic impingement series (true anteroposterior, axillary, and outlet view), magnetic resonance imaging of the affected shoulder on coronal oblique, sagittal oblique and axial T2 weighted and proton density views, and dual-energy X-ray absorptiometry. Patients with repairable full-thickness posterosuperior rotator cuff tear and with moderate-to-high risk of healing failure of RCR were considered as candidate to the procedure. Risk of healing failure was estimated using the Rotator Cuff Healing Index score[16] and according to the following variables as assessed at preoperative evaluation: age, anteroposterior tear size, tear retraction, fatty infiltration of infraspinatus muscle, bone mineral density, and level of work activity. According to Kwon et al,[16] risk of healing failure can be considered moderate to high when Rotator Cuff Healing Index score is > 5 points.

Contraindications included degenerative alterations affecting more than half of the intra-articular portion of LHBT or a history of complete rupture of the LHBT (Fig. 1). Furthermore, individuals with irreparable tears of the subscapularis and/or the posterosuperior cuff were deemed ineligible for the procedure as well as patients with previous surgeries or glenohumeral osteoarthritis.

Patient positioning and diagnostic arthroscopy

All the procedures were performed in beach-chair position and under regional anesthesia by interscalene block. Arthroscopy was performed using standard posterior, anterosuperior, posterior-lateral, lateral, and superior-lateral portals. The first step consisted of diagnostic arthroscopy to confirm indication to the planned surgery. Intra-articular repair of the subscapularis tendon was first accomplished when necessary. Thereafter, tear pattern and repairability of posterosuperior rotator cuff were assessed. Reparability of the tendon tear was defined as the possibility to reattach the tendon edge on the medial side of the tendon footprint without excessive tension.[19]

Preparation of biceps patch graft

Biceps tendon was freed from its groove using an electrocautery device. Then, the intra-articular part of the tendon was released from its proximal attachment on the superior pole of the glenoid and a proximal stump approximately 3 cm in length was harvested (Fig. 2 *A* and *B*). Tendon distal to the harvest site was managed as follows: in elderly patients (aged more than 65 years), the tendon was not fixed; in the other cases, biceps tenodesis was performed in the proximal part of the bicipital groove with one 4.75-mm knotless polyetheretherketone anchor (SwiveLock; Arthrex, Naples, FL, USA) double-loaded with 2 high-strength sutures (FiberWire; Arthrex, Naples, FL, USA) passed through the tendon with a "lasso-loop" configuration.

The biceps stump was formed into a patch graft and prepared for later reimplantation. The tendon was cut to a length of approximately 25 mm by removing proximal and distal ends, then it was placed into a tray (Biceps Autograft Tissue Compression Plate; Arthrex, Naples, FL, USA) consisting of 2 plates that provide a space for the biceps. The tray plates with the tendon tissue in between were then placed into a taper assembly press (Arthrex, Naples, FL, USA), and compression was applied until the gauge was centered between minimum and maximum and held for 4 minutes. The compression force was then released, and the biceps patch was removed. This device allows obtaining a biceps patch approximately 27 mm long and 22 mm wide[27] (Fig. 3 *A*, *B*, *C*).

MASBT harvesting and graft preparation

Subacromial bursectomy was performed with a 4-mm oscillating shaver and the bursal tissue was recovered using a tissue collection device (GraftNet Autologous Tissue Collector; Arthrex, Naples, FL, USA) attached to the suction on the shaver. The collector can contain up to 3cc of volume (Fig. 4 *A* and *B*). The acromial aspect of the anterolateral bursa over the rotator cuff tears was excised until it filled the collector. The rest of the bursa was left in place if it did not obstruct the view during the procedure. The extracted MASBT was then placed over the biceps patch, which was rolled up and closed like an envelope around the bursal tissue with 2-0 permanent braided sutures (Fig. 5 *A* and *B*). Two sutures were fixed at the 2 ends of the envelope to shuttle the graft inside the subacromial space.

Graft fixation

Two 2.6 soft anchors triple-loaded with SutureTape (FiberTak; Arthrex, Naples, FL, USA) were placed at the medial edge of the tendon footprint (Fig. 6). With the scope into the lateral portal, the graft was introduced through the anterior-superior portal and shuttled over the greater tuberosity at the insertion site of the suture anchors by pulling traction sutures from the posterior-lateral portal. From each of the suture anchors, 1 of the 3 suture tapes was passed around the graft and knot-tied to fix the graft at the medial edge of the tendon footprint (Fig. 7 *A* and *B*). Small vents on

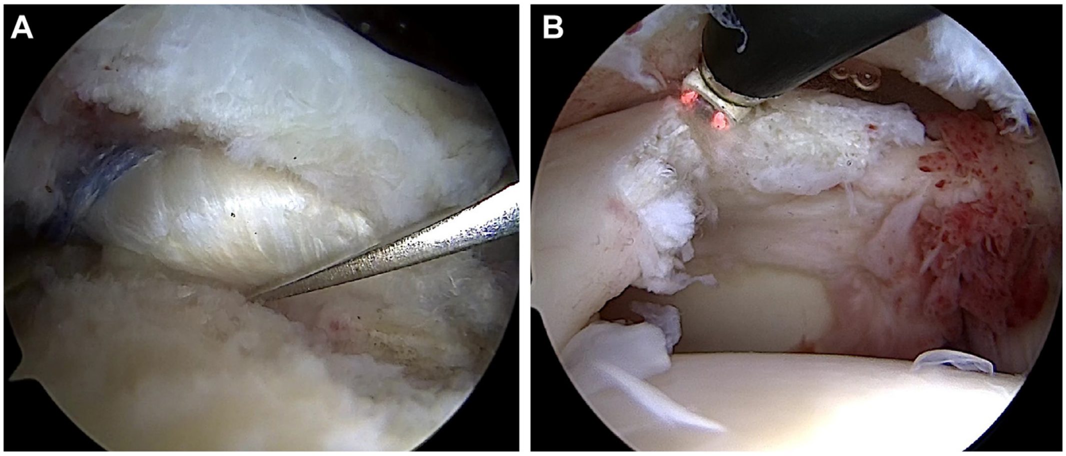

Figure 2 Right shoulder. Scope in the lateral portal: Long head of the biceps harvesting. Biceps tendon is freed from its groove and tenotomized (**A**); the intraarticular part of the tendon is released from its proximal attachment on the superior pole of the glenoid (**B**) and a proximal stump approximately 3 cm in length is harvested.

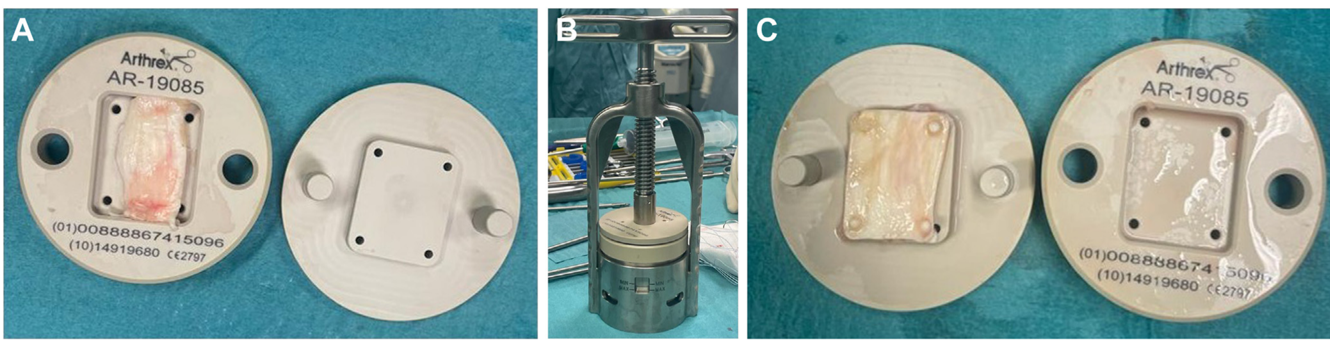

Figure 3 The tendon is cut to a length of approximately 25 mm by removing proximal and distal ends, then it was placed into a tray (Biceps Autograft Tissue Compression Plate; Arthrex) consisting of 2 plates that provide a space for the biceps (**A**). The tray plates with the tendon tissue in between are then placed into a taper assembly press (Arthrex), and compression is applied (**B**). The compression force is then released, and the biceps patch is ready (**C**).

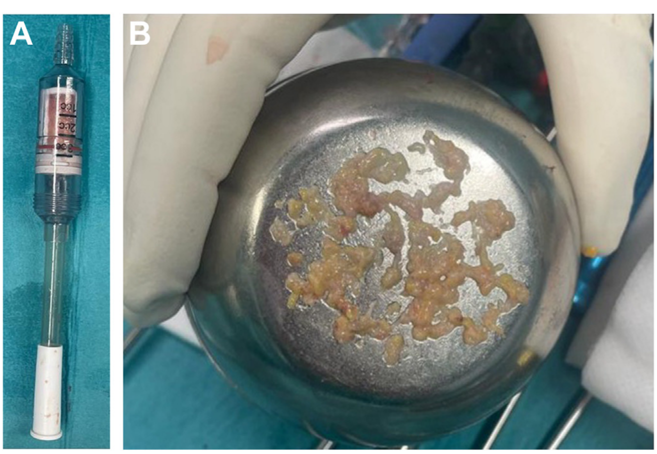

Figure 4 Subacromia bursa is collected in a specific device (GraftNet Autologous Tissue Collector; Arthrex) attached to the suction on the shaver (**A**). After bursectomy, the bursal tissue is extracted (**B**).

the graft were performed by using a needle; this allows for creating a connection with the surrounding environment, promoting the migration and differentiation of mesenchymal cells. At the same time, it prevents the dispersion of bursal tissue, as its gelatinous consistency retains it within the envelope (Fig. 8). The rotator cuff was then repaired to the bone and over the graft using the remaining suture tapes to maximize the healing potential at the bone-tendon interface.

Rotator cuff repair

Rotator cuff was repaired according to tear pattern. L-shaped, U-shaped, or V-shaped tears were first reduced to a crescent shape by performing margin convergence repair, consisting of side-to-side repair with #2 high-strength sutures (FiberWire), in accordance with force vectors and tendon mobility and reducibility. Tendon-to-bone repair was directly accomplished when the tear had a crescent shape. Soft anchors previously placed at the medial edge of the tendon footprint were used. Remaining suture tapes were passed through the tendon approximately 15 mm medial to the tear margin. Medial row was left unknotted. Small and deep bone vents of the greater tuberosity were performed by using a dedicated hand instrument (NanoFx microfracture system; Anika Therapeutics, Bedford, MA, USA) instead of standard cortical abrasion (Fig. 9). A Speed-Bridge configuration was chosen to improve the contact at the interface.[13] Two 4.75 SwiveLock polyetheretherketone anchors were used for lateral-row fixation (Fig. 10).

Postoperative care

Postoperatively, the operated arm was immobilized in an abduction sling with neutral rotation for 4 weeks; the

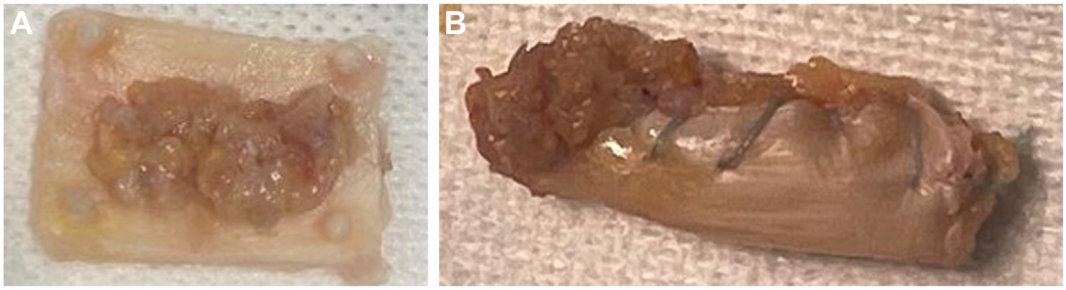

Figure 5 The extracted microfragmented subacromial bursa is placed over the biceps patch (**A**), which is then rolled up and closed like an envelope around the bursal tissue with 2-0 permanent braided sutures: the so called *Bio-Ravioli* (**B**).

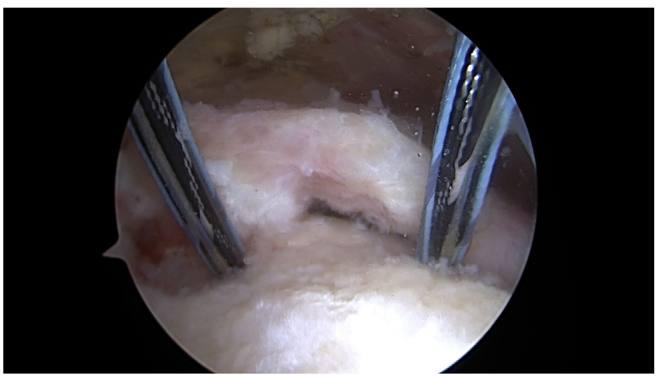

Figure 6 Right shoulder. Scope in the lateral portal. Two triple-loaded anchors are placed at the medial edge of the tendon footprint.

rehabilitation protocol started 4 weeks after surgery. Full passive and active range of motion was regained first and then strengthening exercises were allowed not earlier than 8 weeks after surgery. Full return to manual work and sports activities was achieved in 4 to 6 months.

Discussion

The *Bio-Ravioli* technique represents an easy and reliable way to increase the healing potential at the bone-tendon interface by using autologous MSCs from different sources. The technique aims to maximize the biological effect of the LHBT and the subacromial bursa. Both anatomic structures have long been considered as pain generators; therefore, biceps tenotomy and subacromial bursectomy are still routinely performed during shoulder arthroscopy. However, recent knowledge slightly changed the surgeon perspective. The proximal stump of the LHBT has been extensively used as RCR augmentation in several ways: interpositional graft,[1,31] superior capsule reconstruction,[6,8] or as patch graft over the repair.[10,27] Biceps tendon has been demonstrated to be a suitable cell source for tissue repair;[25] in addition, graft harvesting is easy and removal of the proximal 3 cm of the tendon, as required by the present technique, does not impair a further biceps tenodesis, if needed. On the other hand, the importance of subacromial bursa, which is often discarded during arthroscopic surgery to ensure visualization of the rotator cuff tear, was first highlighted by Uhthoff et al,[29] who stated that the bursal expansion during rotator cuff tears is related to a reparative response rather than to degenerative changes. A recent preclinical study supported the hypothesis that inflammatory status of the bursa correlates with the severity of the rotator cuff tear.[20] Furthermore, the subacromial bursal tissue appears to be an important reservoir of MSCs that may contribute to tendon healing.[2,18,21,30] Dyrna et al[9] showed that, as compared with bone marrow–derived MSCs, implanted subacromial bursal cells displayed superior tissue engraftment and survival. Moreover, it seems that subacromial bursa has a high cellular proliferation potential regardless of patient demographics, rotator cuff tear characteristics, and severity of glenohumeral joint degeneration.[18,23]

These assumptions opened the way to new surgical techniques aiming to maximize the healing potential of BDSCs as used alone[4,5,7,11,24] or in combination with scaffolds[3] or GFs.[23] Freislederer et al[11] first described a technique to mobilize the lateral bursa, which was then sutured over the RCR by using polydioxanone sutures. In a similar fashion, Bhatia et al[5] claimed a vasculature-preserving technique for subacromial bursal harvest. The author highlighted that care must be taken to preserve medial, posterior, and posterolateral bursa, so that the bursal tissue can be useful not only as a cell source but also as a source of vascularity. As stated by the authors,[5,11] possible disadvantage with those techniques may rely on the inability to predict the thickness or the fragility of the bursa as well as the ability to dissect an intact vascular bursal layer.

Dei Giudici et al[7] and Pancholi et al[24] harvested and minced the bursa by using the same device proposed in the present study. The former[7] injected the collected bursa between the footprint and the repaired tendon, while the latter[24] tried to deliver the bursa over the repair after turning off the water inflow and turning on the suction. Main concerns with both techniques rely on the possible displacement of the bursal tissue in the early postoperative stage. Muench et al[23] presented the Mega-Clot: a combination of minced subacromial bursa, bone marrow aspirate, and platelet-rich plasma. The aim was 2-fold: to maximize the biology and to create a stable product. However, the clot itself cannot be considered a real scaffold and therefore it is not easy to be kept in place. Berthold et al[3] recently combined a patch (dermal allograft or a collagen patch processed from a bovine achilles tendon) over the repair with GFs, bone marrow aspirate, and subacromial bursa injected underneath the patch. Although attractive from a biological standpoint, the last 2 techniques surely have higher costs compared to previous ones, with no certainty on the final outcome.

Interestingly, the bursal tissue has been used either way as a whole or minced as well as over the repair or as an interpositional graft. Morikawa et al[22] collected the subacromial bursa over the supraspinatus tendon from 7 patients. The bursa was then processed and analyzed using 4 different methods: (1) mechanical digestion with scissors (chopping), (2) collagenase digestion, (3) mechanical digestion with a tissue homogenizer, and (4) whole tissue with minimal manipulation. The authors showed that nonenzymatic mechanical isolation of BDSCs using a chopping technique has similar cell count compared with collagenase digestion, thus making their harvest even easier. In the present study, the bursa was harvested in accordance with the theory of

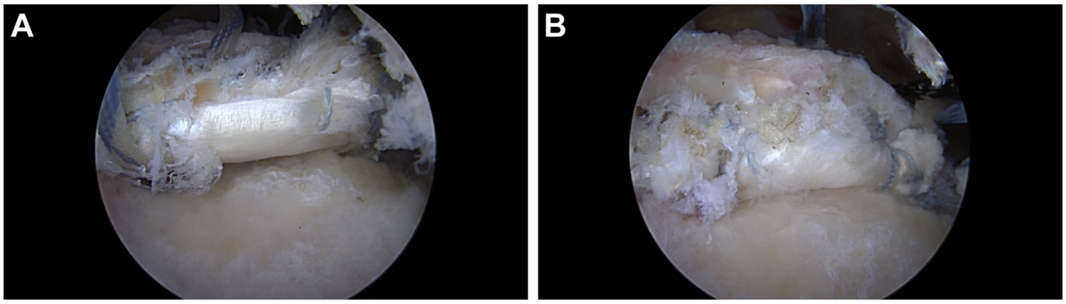

Figure 7 Right shoulder. Scope in the lateral portal. The graft is introduced through the anterior-superior portal and shuttled over the greater tuberosity at the insertion site of the suture anchors (**A**). From each of the suture anchors, 1 of the 3 suture tapes is used to fix the graft at the medial edge of the tendon footprint (**B**).

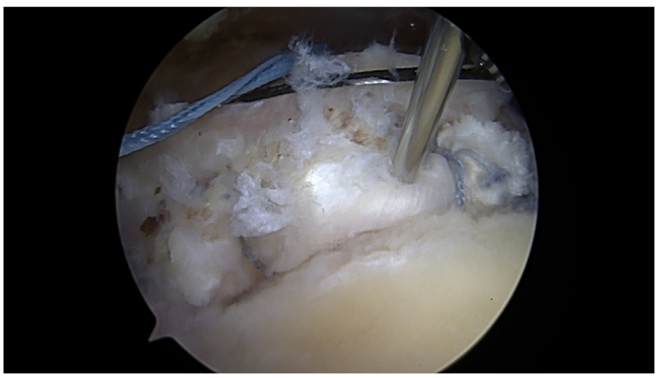

Figure 8 Right shoulder. Scope in the lateral portal. Small vents on the graft are performed by using a needle.

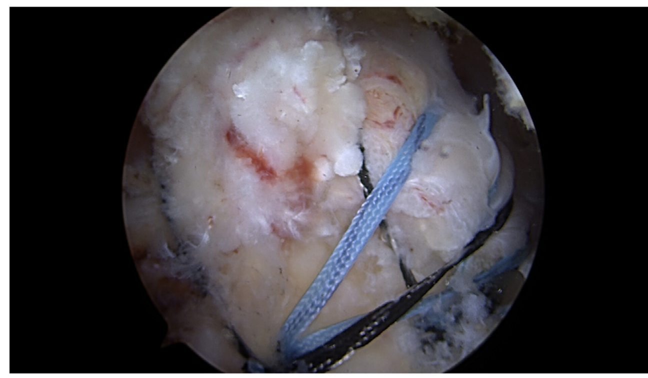

Figure 10 Right shoulder. Scope in the lateral portal. Final view: a speed bridge configuration is performed to repair the cuff over the *Bio-Ravioli*.

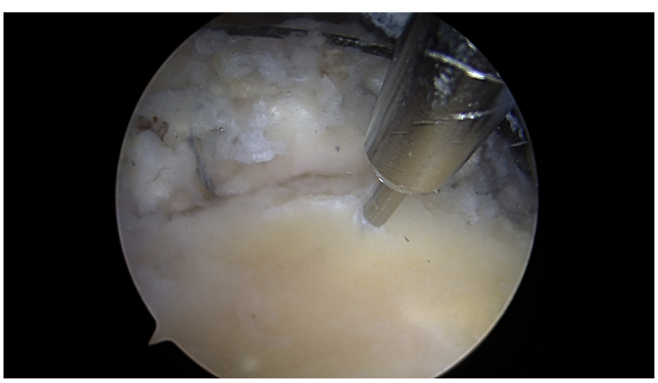

Figure 9 Right shoulder. Scope in the lateral portal. Nanofractures of the greater tuberosity.

vascular preservation[5] and was chopped according to Morikawa's[22] findings to maximize the likelihood of efficacy. More recently, Wang et al[32] conducted a preclinical study in a rat model and showed that either anatomical preservation or interpositional preservation of the bursa between tendon and bone can similarly facilitate the healing process. According to these evidences, the proposed technique places the chopped subacromial bursa beneath the repaired cuff and in contact with the bone, as the bone-tendon interface is the weakest link in the healing process.

From a technical standpoint, attention must be paid to the positioning of the graft in the shoulder and to suture management. An 8-mm soft cannula in the anterosuperior portal can facilitate the graft passage, avoiding soft tissue interposition. The graft must be positioned between the 2 ends of each suture. Then, it is important to secure the graft with 1 of the 3 sutures of each previously implanted soft anchors. After graft fixation, the repair returns to standard.

Main advantages of the present technique refer to the possibility to enhance biology easily and at limited costs with a very stable construct.

Conclusion

The *Bio-Ravioli* technique represents an easy and reliable way to increase the healing potential at the bone-tendon interface by using autologous MSCs from different sources: subacromial bursa and LHBT.

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Conflicts of interest: Giuseppe Milano reports a relationship with Arthrex Inc. that includes consulting or advisory. The other authors, their immediate families, and any research foundation 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.

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