“Strings” (Multiple Tendon Interposition Autografts) for Reconstruction of Presumably Irreparable Rotator Cuff Tears

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Abstract: Irreparable rotator cuff tears are challenging to treat. Especially in younger patients without concomitant osteoarthritic changes, joint-preserving procedures are warranted. To date, no treatment guideline exists because none of the available techniques has shown superiority over the others, and long-term survivorship data are missing. The aim of the “Strings” is to provide an arthroscopic solution to anatomically reconstruct presumably irreparable rotator cuff tears by bridging the gap with multiple string-like tendon interposition autografts.

Massive irreparable rotator cuff tears (IRCT) account for approximately 40% of all rotator cuff tears and over time can lead to superior migration of the humeral head because of altered glenohumeral biomechanics and progressive secondary osteoarthritic changes, called cuff-arthropathy. Although reverse total shoulder arthroplasty is a viable treatment option in the elderly suffering from progressed cuff-arthropathy, controversy exists in the management of young and active patients with massive IRCTs with no or mild secondary osteoarthritis.

Several joint-preserving treatment options, including debridement with or without biceps tenotomy, partial rotator cuff repair, subacromial spacer implantation, tendon transfers, and the modern superior capsular reconstruction (SCR) have been described. Nevertheless, no treatment guideline exists because long-term survivorship data are missing, and none of these techniques has shown superiority over the others.

In the case of an IRCT, partial rotator cuff repair has been proven beneficial in regaining a biomechanically functional shoulder in patients with IRCT by restoring the horizontal force couple. Above proposed techniques aiming at mechanical lowering and coverage of the head (e.g., subacromial spacer, SCR), as well as tendon transfers acting as rotator cuff surrogate, are used separately or in addition to partial rotator cuff repair in an attempt to improve the outcome. However, complete reconstruction of the entire rotator cuff is of capital importance to restore shoulder functional range of motion and strength. In this Technical Note we present the “Strings” technique for treatment of IRCTs in an attempt to fully reconstruct presumably irreparable rotator cuff tears by means of multiple string-like tendon interposition autografts.

Surgical Technique

Indication

Patient selection bears special mention including a thorough preoperative workup. Strings are indicated if (1) patients suffer from shoulder pain and strength deficit with or without loss of range of motion based on a massive IRCT, (2) irreparability of the rotator cuff is revealed on magnetic resonance imaging (MRI) because of severe tendon retraction (and confirmed during surgery) (3) at least residual muscle volume is visible on preoperative MRI, and (4) only mild to moderate osteoarthritic changes are present. Our
technique is contraindicated if the head shows static superior migration with full contact to the acromion on x-rays films taken in standing patients.

**Preoperative Setup**

The patient is placed in the beach chair position and the affected shoulder and ipsilateral knee are prepared and draped. The arm is placed in a pneumatic limb positioner (Fig 1).

**Diagnostic Arthroscopy and Repair of the Horizontal Force Couple**

After the bony landmarks (clavicle, spine of the scapula, acromion, coracoid process, acromioclavicular joint) are identified and marked, a standard posterior portal is placed.

A 30° arthroscope is used for viewing throughout the procedure (Fig 2). An anteroinferior working portal within the rotator interval is then established with an outside-in technique, and a diagnostic arthroscopy is performed to assess any glenohumeral pathology. The long head of the biceps tendon is usually treated with tenotomy or tenodesis (Fig 3). Further concomitant interventions include chondroplasty, synovectomy, as well as debridement as deemed necessary. Specific attention is then given to the rotator cuff tear. An attempt is made to perform at least a partial repair of the torn rotator cuff both to regain the horizontal force couple and to reduce the superior tendon defect. This may involve the teres minor tendon, infraspinatus tendon, or the subscapularis tendon. For this purpose the footprint of the cuff is prepared by removing the soft-tissue with a radiofrequency device and then debrided using a motorized shaver and burr until a bleeding surface is achieved to favor tendon-to-bone healing. After an extensive release and trial reduction of the tendons using a grasper device, a single-row or double-row repair of the tendon is then performed (Fig 4).

**Portals and Preparation Used for the Strings**

If complete repair of the rotator cuff cannot be achieved, the decision is made to proceed with Strings. (Video 1) For that purpose an anterolateral, lateral as well as posterolateral portal is established if not already present and the arthroscope is inserted into the subacromial space from lateral. Any excessive bursal tissue is debrided using a motorized shaver to gain the best visualization of the remaining rotator cuff tear. The free tendon edge is debrided from all tissue that does not seem adequate for refixation.

Mediolateral measurements are taken to size the autograft correctly. Therefore an arthroscopic ruler is inserted through the lateral portal while lateralizing the retracted tendon with a grasping device. It is crucial to start measuring at least 20 mm medially.

![Fig 1](image)

**Fig 1.** Positioning of the patient in the beach chair position with the affected arm, as well as the ipsilateral knee, prepared and draped.

![Fig 2](image)

**Fig 2.** Arthroscopic image viewing from the posterior portal of the right shoulder. The posterosuperior rotator cuff is completely detached from its footprint at the greater tuberosity (black arrows). The long head of the biceps tendon is partially torn (blue arrow).
from the free tendon edge to both grasp vital tendon tissue avoiding a cut-out of the sutures and to guarantee an overlap of the autograft to enhance tendon healing. Furthermore, the measurement must extend to the lateral aspect of the greater tuberosity in order to fully cover the anatomic footprint.

**Graft Harvesting and Preparation**

Hamstring tendon harvest is performed according to the surgeon’s preference. In our setting, the fascia is opened slightly superior to the semitendinosus tendon insertion. The tendon is then identified and freed from vinculae. Then the tendon is placed through an open tendon stripper and released from its muscular attachment proximally and finally also distally using a knife. Excess muscular tissue is removed, and the tendon and is then sized (approximately 25 cm in length). Depending on the tear dimension, the tendon graft is then divided into several Strings. Usually 4 to 5 pieces of 5 cm length are obtainable. The needed number of Strings is then assessed, and each of them is armed with nonabsorbable no. 2 sutures (Fiberloop; Arthex, Naples, FL) in a running stitch technique at both ends (Fig 5).

**Tendon Graft Delivery and Medial as Well as Lateral Fixation**

Once the tendon graft has been prepared, a working cannula (Passport; Arthrex) is placed into the lateral portal to ease suture management and allow autograft passage. With the arthroscope in the posterolateral portal, a strand from String no. 1 is passed through the posterior tendon stump (approximately 20 mm medial to the lateral edge of the tear) using a retrograde suture-passing device (Scorpion; Arthrex) in a reverse fashion (Fig 6). This step is then repeated for the second strand to complete the reversed horizontal mattress stitch meaning that the Strings end up on top.
of the tendon stump and the knot on the bottom. Alternative configurations with Strings on the bottom and knot on top, as well as both on top, can be created.

Both suture strands are then passed out of the anterolateral portal for appropriate suture management. A grasper or clamp is then used to push String no. 1 into the joint through the portal while pulling on both

Fig 5. Preparation of the harvested autograft. (A) The tendon graft is divided into several Strings of approximately 5 cm each. (B) The Strings are armed with nonabsorbable no. 2 sutures in a running stitch technique at both ends (red arrows).
strands previously passed through the cuff (Fig 7). The medial end of the graft is now overlapping the free tendon edge. To complete the inverse mattress stitch, an arthroscopic knot is securely tied. After medial fixation, the graft is tensioned and then fixed to the tuberosity under slight tension using a knotless suture anchor (Swivelock; Arthrex). These procedures are now repeated one-by-one with further Strings. Although medial attachment remains individual per String, lateral attachment can be achieved in pairs to minimize implants (Fig 8). In a large IRCT, approximately 4 Strings with 2 lateral suture anchors are necessary to reconstruct the rotator cuff (Figs 9 and 10).

Postoperative Care
Directly after surgery, the affected arm is supported in an abduction brace for 6 weeks. Rehabilitation protocol is equally to that after arthroscopic repair of a large rotator cuff tear. Within the first 6 weeks, only pain-free passive range of motion is permitted. To improve both tendon and autograft healing, a gradual increase in passive motion starting with week 4 is encouraged. At week 7, active full range of motion exercised are started. Strength exercises are added after 3 months.

Discussion
Recently, different joint-preserving surgical options have been evolved to treat IRCTs in younger patients with no to mild secondary glenohumeral arthritis. Both, insertion of a subacromial balloon spacer and SCR combined with an arthroscopic partial rotator cuff repair were found to be effective to a certain extent with promising short-term results. The concept of both procedures is to stabilize the humeral head to produce functional gains. Current techniques for SCR using either an autograft or allograft use bone to bone fixation of the graft resulting in a static structure. Thus the graft loses its tension and thus its stabilizing effect at higher abduction levels. Furthermore, previous studies demonstrated that graft material and thickness influenced both biomechanics and graft healing. A repair failure of approximately 50% was found using an allograft and of approximately 5% using an autograft, respectively. In a recent systematic review the overall complication rate was 17% for SCR.

From a technical point of view, interposition grafting seeks to restore rotator cuff continuity by extending the retracted tendon and thus to recruit the former nonfunctional muscle. The basic concept is not new because different open, as well as arthroscopic, techniques have been described to bridge the gap in IRCTs. In 2008, Rhee et al. demonstrated the clinical and radiographic results after autologous long head of the
biceps tendon grafting in 31 patients. Although no complication occurred within a 2-year follow-up, a re-tear was revealed in 21% using MRI. Overall, the constant score as primary outcome measurement improved from preoperative 48 points to 82 points at final follow-up. A comparative study between fascia lata autograft interpositioning (group A, n = 24) and partial rotator cuff repair (group B, n = 24) highlighted the clinical superiority of the bridging technique. A total of 5 patients in group A had either a re-tear of the infraspinatus tendon (8%) or the autograft (12%), whereas the repair failure was 42% in group B. Again, no complication was reported. Some short-term studies exist reporting on the results after allograft interposition. Although clinical and radiographic outcomes were found to be equivalent, some deep infections occurred after allografts were used.18,19

Strings are a feasible option including several advantages of both the minimally-invasive arthroscopic surgery and the usage of multiple interposition grafts (Table 1). First, the restoration of the native continuity of the deficient rotator cuff might lead to superior joint biomechanics as the autograft restores the cuff as a dynamic stabilizer in the throughout range of motion. Second, Strings might be superior to previously described interposition grafting techniques because the load is shared among multiple grafts, thus improving stability. Third, our procedure is technically fairly easy to perform, with multiple grafts being inserted step by step while maintaining good visibility. For example, in SCR improper suture management can lead to graft twisting and suture tangling, which constitutes an enormous technical challenge to even the most experienced surgeon.20 The level of technical challenge and risks with Strings is similar to a standard large rotator cuff repair (Table 2).

Regarding the choice of graft type, several options are possible. The hamstring tendon autograft is easy to harvest with little donor site morbidity.21,22 Furthermore, biomechanical properties of this autograft were demonstrated to be >1400N23 and thus exceed the native requirements of 630N by far.24 In contrast, the most commonly used autograft in both bridging and SCR techniques is the fascia lata with a mean load to failure of approximately 40N,25 whereas allograft
materials resist up to 200N.\textsuperscript{26} However, potential alternative grafts for the Strings could include the long head of the biceps tendon, quadriceps, or triceps, as well as other different tendon allografts.

Fig 10. Schematic illustration of the use of Strings for reconstruction of an irreparable rotator cuff tear in various planes (A-D). Strings can be attached on top (C) or on the bottom (D) of the remaining tendon stump of the rotator cuff.

In summary Strings provide an arthroscopic solution to anatomically reconstruct presumably irreparable rotator cuff tears by bridging the gap with multiple string-like tendon interposition autografts.
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