A Comparison of Two Arthroscopic Techniques for Interpositional Polytetrafluoroethylene Patch Repair for Massive Irreparable Rotator Cuff Tears: Speed and Biomechanics

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Abstract *Background:* Interpositional synthetic patch repairs are a novel method of treating massive irreparable rotator cuff tears. However, surgeons experience difficulty in the arthroscopic insertion of these patches. *Questions/Purposes:* We compared two methods of arthroscopic interpositional synthetic patch repair: the newly devised slide-and-grip technique, using pre-loaded sliding knots and no arthroscopic knots, and the weave technique, using less arthroscopic knot tying than the earlier mattress technique. Study questions were as follows: (1) Would the slide-and-grip technique take less time than the weave technique? (2) Would the biomechanical strength of the two methods be comparable? *Methods:* Fourteen paired ovine infraspinatus tendon ex vivo models of the degenerative human rotator cuff underwent timed repair with a synthetic polytetrafluoroethylene (PTFE) patch, using either the weave technique ($n = 7$) or the slide-and-grip technique ($n = 7$). Each was pulled to failure using a tensile testing machine, the Instron 8874. *Results:* The time to complete the slide-and-grip repairs was shorter (12 ± 0.9 min) than that of the weave repairs (23 ± 1 min). Ultimate load to failure was comparable for the slide-and-grip and weave techniques (211 ± 27 N vs. 295 ± 35 N, respectively), and the slide-and-grip was less stiff (14 ± 1 N/mm vs. 19 ± 1 N/mm). *Conclusions:* The slide-and-grip technique took less time than the weave technique for the interpositional patch repair

of massive irreparable rotator cuff tears and when correctly performed had comparable biomechanical strength.

Keywords arthroscopic · rotator cuff repair · biomechanical study · ovine model · polytetrafluoroethylene (PTFE) patch

Introduction

Surgical tendon-to-bone repairs are often ineffective in managing massive rotator cuff tears (tears with diameter of greater than 5 cm [7, 8]) with re-tear rates ranging from 23 to 89% [5, 6]. Furthermore, many massive rotator cuff tears are irreparable [2, 3, 7]. One way to manage massive rotator cuff tears is to use a synthetic polytetrafluoroethylene (PTFE) patch as a bridging or interpositional graft between the torn tendon and the humerus [9, 11–16].

Interpositional synthetic patch repair (ISPR) of massive rotator cuff tears, in ovine models, withstands 53% more load than tendon-to-bone repair before failing [9, 14]. A review of six patients who had an ISPR of a massive irreparable rotator cuff tear showed improvements in pain and range of motion for all patients at a mean of 10 years postoperatively [16]. Further positive clinical results were found in 16 patients who underwent ISPR of massive irreparable rotator cuff tears, with no re-tears or need for follow-up surgery 6 months postoperatively [13].

Both the multiple-mattress technique [14] and the later weave technique [13] were used at our institution for the arthroscopic insertion of the patch in ISPR. The multiple-mattress repair (64 min) and the weave technique (46 min) took significantly longer to perform than tendon-to-bone repairs (33 min) [13]. Furthermore, both techniques were complex and relied on surgical expertise to be performed effectively [12, 14]. Therefore, we developed the slide-and-grip technique, which incorporated pre-loaded sliding knots and required no arthroscopic knots. This technique, being

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simpler, has the potential to be faster than previous techniques.

The aims of this study were (1) to determine if the slide-and-grip technique could reduce the time needed for patch-to-tendon repair in ISPR of massive irreparable rotator cuff tears compared to the weave technique and (2) to compare the biomechanical strength of slide-and-grip repair to that of weave repair.

Materials and Methods

We set out to use pre-torn ovine infraspinatus tendon models to time repairs using either the slide-and-grip or weave technique at the patch-to-tendon interface and to perform biomechanical testing on these repairs.

The ovine rotator cuff tear model is a well-established *ex vivo* model in our institution for biomechanical studies [1, 9, 10, 12, 15]. Twenty-eight ovine infraspinatus tendons were dissected and paired according to their thickness. These paired tendons were labeled and then randomized into two repair groups with respect to the tendon thickness and width. Four horizontal mattress sutures were placed in the slide-and-grip group ($n = 7$) and four inverted horizontal mattress sutures were placed in the weave group ($n = 7$) using a Smart Stitch with PerfectPasser™ Connector (ArthroCare Corporation, Austin, TX, USA). These rotator cuff models were frozen and thawed at room temperature 15 times, which aimed to accelerate tissue degradation [4, 12].

The Two Techniques

A 30×50 -mm, 1.85-mm thick synthetic patch (low-porosity PTFE Felt, C.R. Bard, Inc., Murray Hill, NJ, USA) was attached to each pair of ovine infraspinatus tendons with either the slide-and-grip technique ($n = 7$) or the weave technique ($n = 7$).

All repairs were performed in a randomized order, by JS (fourth-year medical student), who was relatively unfamiliar with the two repair procedures. All repairs were timed.

For the slide-and-grip repair, 8 1.5-mm holes were placed 16 mm from the tendon edge of the slide-and-grip patches ($n = 7$). A 600-mm #2 suture (FiberWire®, Arthrex, Naples, FL, USA) and suture snare was used for the slide-and-grip knot. One suture limb was passed through the suture snare forming the post limb. The free limb was wrapped around the post limb twice and tied around the post limb and itself with a half-hitch twice (Fig. 1a, b). The post limb was then removed from the snare and threaded through the corresponding hole in the slide-and-grip patch. The snare with the knot was also inserted in its corresponding hole (Fig. 1c). This was repeated for the other three knots.

All repairs were performed through a 15-mm hole in a washer clamped to the laboratory bench representing the “arthroscopic portal.” A second clamp gripped the medial ends of the rotator cuff. A surgical drape was placed around the washer and the tendon. The ends of the tendon mattress sutures were passed through the arthroscopic portal and clamped onto the surgical drapes superiorly.

The weave technique was performed as described by Ronquillo et al. [12]. Four horizontal mattress sutures were placed into the medial edge of the patch using a Smart Stitch with PerfectPasser™ Connector (ArthroCare Corporation, Austin, TX). The patch sutures were used to shuttle the tendon sutures through the patch (Fig. 2a). The outermost suture limbs were then tied onto themselves using a square knot with five throws. The adjacent suture limbs were then similarly shuttled through the patch and tendon (Fig. 2b). The patch was advanced through the portal and onto the tendon while pulling the central sutures and removing excess slack (Fig. 2c). The remaining suture ends were tied with an arthroscopic square knot with five throws, using a single-holed knot pusher (Fig. 2d).

In the slide-and-grip technique, the post limb of the patch sutures was shuttled through the tendon using the tendon

Fig. 1. Preparation of the slide-and-grip knot and patch: **a** first wrap and locking throw; **b** second locking throw; and **c** insertion of the snare and sutures into the patch.

Fig. 2. Weave repair technique: **a** tendon sutures were shuttled (half-hitch loops made on patch “shuttling” sutures); **b** outermost limb was tied to itself and adjacent sutures were shuttled (transparent window shows sutures posterior to patch); **c** patch was advanced onto tendon; and **d** remaining suture limbs were tied arthroscopically.

sutures (Fig. 3). Each of the suture ends was passed through the corresponding suture snares. The suture snares were pulled out, passing the suture ends through the patch and knot. All four suture ends were pulled while passing the patch into the lateral portal and onto the lateral edge of the tendon (Fig. 3).

During our initial repair, only the post limb of each knot was tensioned using a knot pusher; however, this did not lock the knot in our arthroscopic model. The final step was subsequently corrected so that both limbs of the knot were tensioned with a knot pusher to lock the knot.

Fig. 3. Slide-and-grip repair technique: (1) half-hitch on the tendon “shuttling” suture tied around patch suture; (2) patch suture shuttled through tendon; (3) patch suture inserted into snare; and (4) snare pulled out of the patch and knot.

Failure Testing

All 14 repairs underwent pull-to-failure testing using a tensile testing machine (Instron 8874, High Wycombe UK). Each repair was secured to the testing machine using tendon-grasping clamps with the tendon secured to the base of the testing machine. Each repair was pulled along the longitudinal axis of the repair. The specimens were first preloaded with 10 N for 30 s and then pulled at 1.25 mm/s until failure.

All outcome data were reported as mean $\pm$ SEM. Unpaired student's *t* test was used to analyze the differences between the groups. All statistical analyses were performed using Prism version 6 (GraphPad Software, Inc. CA USA).

Results

The slide-and-grip patches took 5 ± 0.2 min to prepare. The weave technique took 23 ± 1 min to arthroscopically secure

patch to tendon, while the slide-and-grip technique took 12 ± 0.9 min ($p < 0.0001$) (Fig. 4a). Both techniques were faster to perform with each subsequent repair (Fig. 4b).

The initial testing of the slide-and-grip repairs showed the knots unraveled at low load (ultimate load to failure = 87 ± 13 N) due to a fault in the previously established knot-locking procedure. The slide-and-grip patches were subsequently reattached to the same tendons using the corrected procedure. When re-tested, there was an increase across all biomechanical properties. The weave repairs failed through the unraveling of the central knot (4/7), buttonholing of the knot through the patch (2/7), and sutures cutting through tendon (1/7). The revised slide-and-grip repairs failed through unraveling of each knot (4/7) and the suture cutting through the tendon (3/7).

As the weave repairs were loaded, there was more bunching of the construct compared to the slide-and-grip repairs (Fig. 5a). The load-displacement curve showed the weave repairs had a gradual failure pattern compared to the

slide-and-grip repairs (Fig. 5b). The weave repairs and slide-and-grip repairs had similar ultimate load to failure (295 ± 35 N vs. 211 ± 27 N; $p = 0.11$) (Fig. 6a), peak energy (3 ± 0.6 Nm vs. 2 ± 0.3 Nm; $p = 0.08$) (Fig. 6b), and total energy (4 ± 0.8 Nm vs. 2 ± 0.3 Nm; $p = 0.12$) (Fig. 6c). The weave repairs were stiffer than the slide-and-grip repairs (19 ± 1 N/mm vs. 14 ± 1 N/mm; $p = 0.01$) (Fig. 6d).

Discussion

This study describes the slide-and-grip technique for attaching the patch to tendon during ISPR of massive rotator cuff tears. Repairs using the slide-and-grip technique were comparatively faster to perform than the weave technique. With the improved knot-locking technique, the biomechanical properties of the corrected slide-and-grip and the weave repairs were similar, with the exception that the weave had a greater stiffness than the slide-and-grip.

Fig. 4. **a** Comparison of repair times: weave (23 ± 1 min) and slide-and-grip (12 ± 0.9 min) repair; **b** each subsequent weave and slide-and-grip repair. *** $p < 0.001$.

Fig. 5. **a** Method of failure for weave technique (top) and slide-and-grip repairs (bottom). **b** Load-displacement curves for weave and slide-and-grip repairs (samples curves chosen from specimens from each group).

Fig. 6. Comparison of the biomechanical properties of weave repair ($n = 7$) and slide-and-grip repair (initial $n = 7$; corrected $n = 7$) during pull-to-failure testing: **a** ultimate load to failure—weave repair (295 ± 35 N), slide-and-grip repair (initial, 87 ± 13 N; corrected, 211 ± 27 N); **b** peak energy—weave repair (3 ± 0.6 Nm), slide-and-grip repair (initial, 0.6 ± 0.1 Nm; corrected, 2 ± 0.3 Nm); **c** total energy—weave repair (4 ± 1 Nm), slide-and-grip repair (initial, 1 ± 0.2 Nm; corrected, 2 ± 0.3 Nm); and **d** stiffness—weave repair (19 ± 1 N/mm), slide-and-grip repair (initial, 10 ± 1 N/mm; corrected, 14 ± 1 N/mm). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

The slide-and-grip repairs, when correctly locked, matched the strength of weave repairs. The ultimate load to failure of the slide-and-grip repairs was similar to results described in previous biomechanical studies of ISPR of ex vivo ovine rotator cuffs [12] and reported higher ultimate failure loads than single and double row tendon-to-bone repairs of similar ex vivo ovine models [10]. Furthermore, failure by slicing through the tendon was a shared method of failure in both weave and slide-and-grip repairs, suggesting that the degenerative tendon is often the weakest link in these repairs.

However, when the slide-and-grip knots were “locked” with the original procedure, tensioning only the post limb, the knots were susceptible to unraveling, reducing the strength of the repair. Tension must be applied to both suture limbs of the slide-and-grip knot in order to achieve proper locking of the knot and the reported biomechanical results.

There were several limitations to this study that should be considered. The ex vivo ovine tendon models used, despite many similarities, have structural differences to the degenerative human tendon and lack the natural in vivo healing responses. The repairs were performed through an arthroscopic model in a laboratory setting and not in the surgical theater. The influence of learning curve on operative time was not assessed in this study, and this factor could narrow the difference in operative times between the two groups.

In conclusion, the slide-and-grip technique was a novel alternative for ISPR of massive irreparable rotator cuff tears. The slide-and-grip technique was quicker to perform than the weave technique and, when correctly locked, had similar biomechanical strength.

Compliance with Ethical Standards

Conflict of Interest: Joo Y. Sunwoo, Patrick H. Lam, PhD, and George A.C. Murrell, MD, DPhil, declare that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: N/A

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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