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ORIGINAL RESEARCH

Biomechanical Comparison of a Transosseous-Equivalent All-Knotless Rotator Cuff Repair versus Traditional Double-Row Repair

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ABSTRACT

Introduction: Currently controversy remains as to which arthroscopic techniques are superior regarding strength of repair, surgical time, healing, and clinical results. The purpose of this study was to perform a biomechanical comparison of a traditional tied double-row construct utilizing a horizontal mattress technique for the medial row versus a transosseous-equivalent all-knotless (TEAK) construct utilizing a load-sharing suture technique for the medial row.
Methods: Rotator cuff repairs were performed on shoulders from five matched porcine pairs randomly assigned to either a traditional tied double-row repair technique or a TEAK repair construct. The constructs were tested in tension up to 3,000 cycles, then loaded at 2mm/sec until failure and biomechanical differences between constructs were determined by paired t-tests.
Results: There were no statistically significant biomechanical differences between the traditional tied and TEAK repairs. 2 traditional tied repairs failed during cycling; the remaining 3 failed through tearing at the suture-tendon interface; 3 of the all-knotless repairs failed through sutures pulling through the bone anchor and 2 failed by sutures tearing at the suture-tendon interface.
Discussion: In a porcine rotator cuff model, the TEAK construct was biomechanically comparable to a traditional tied double row repair.
Level of Evidence: Experimental study.
Keywords: Rotator cuff tear; Arthroscopy; Knotless suture rotator cuff repair.

INTRODUCTION

The rotator cuff functions to dynamically stabilize the glenohumeral joint and allow for humeral range of motion in multiple planes. Rotator cuff tear etiology follows a bimodal age distribution; younger individuals typically experience injuries with overhead throwing activities, while elderly patients suffer from chronic degenerative tears. Orthopaedic literature has speculated that repetitive microtrauma secondary

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to eccentric traction forces at the supraspinatus and infraspinatus tendons during the latter stages of the overhead throwing motion contributes to articular-sided rotator cuff tears [1]. Shear stresses at the articular aspect of the cuff are maximized when the arm is rotated into an abducted and externally rotated position, and these forces consequently contribute to rotator cuff tears [2].

Operative management of rotator cuff tears includes open, mini-open, and arthroscopic procedures; however, currently the trend amongst most orthopaedic surgeons today favors arthroscopic cuff repairs. Arthroscopy permits cuff repair with less dissection of the surrounding soft-tissue, has a lower incidence of developing fibrous adhesions and allows for earlier post-operative range of motion exercises [3-6]. A common complication is structural failure of the cuff repair, upwards of 90% in certain published studies. This has been attributed in part to an inadequately restored anatomical footprint, consequently hindering bone-to-tendon healing [4,7-12]. Other factors contributing to rotator cuff repair failure include suture anchor loosening, suture failure, knot loosening, failure at the suture-tendon interface, and fatty degeneration or muscular atrophy of the cuff [4,8,9-11,13-15].

Orthopedic literature has shifted focus toward studies of arthroscopic repair techniques aimed at providing stability with cyclic loading, minimizing gap formation, and restoration of the anatomical footprint [16]. Primary concerns with rotator cuff repair include biomechanical stability (gap formation, construct stiffness, cycles to failure, load to failure, and ultimate tensile strength) and fixation offered by single-row versus double-row repair [4,15,16]. Reapproximating the rotator cuff footprint theoretically allows for greater surface area of contact between the tendon and bone, which improves force distribution and healing potential [3,4,11,13,16-18]. Other techniques utilized in rotator cuff repair include the transosseous method (soft-tissue fixation with sutures placed into transosseous tunnels) utilized in open and miniopen techniques and the arthroscopic transosseous-equivalent (TE) method [15]. TE suture bridge techniques include knotless and traditional knot-tying approaches. It is theorized that the combination of a knotless construct with a medial load sharing technique offers greater tissue holding, an inherent rip stop which prevents tendon pullout, and theoretically reduced likelihood of medial row tissue strangulation which consequently may lower retear rates [19].

While there exist numerous biomechanical studies in the literature comparing various constructs for rotator cuff tear repairs, controversy remains as to which arthroscopic techniques are superior regarding strength of repair, surgical time, ultimate healing, and final clinical results.

The purpose of this study was to perform a biomechanical comparison of a traditional double-row construct utilizing a horizontal mattress technique for the medial row versus a TE all-knotless (TEAK) construct utilizing a load-sharing suture technique for the medial row. The null hypothesis was that there will be no significant differences in repair site gapping, stiffness, or ultimate load to failure between the 2 constructs.

MATERIALS & METHODS

Study Design

A power analysis based on a pilot study of 2 fresh-frozen porcine shoulder pairs indicated that 5 matched pairs would be sufficient to detect a difference in constructs at 80% and alpha of 0.05. 5 matched porcine shoulder pairs were dissected down to the humerus and posterior superior rotator cuff with removal of the scapula and additional soft tissue. The infraspinatus muscle and tendon was identified on each specimen, after which the remaining soft tissues were carefully dissected off of their attachment on the humerus. The infraspinatus tendon attachment was sharply dissected completely from its insertion at the greater tuberosity to mimic a full-thickness retracted rotator cuff tear. For a pairwise comparison, right and left shoulders were randomly assigned to either the traditional tied double-row repair technique or the TEAK repair construct.

Suture Techniques

The traditional tied double-row construct utilized four 4.5mm single-loaded suture anchors with 2 horizontal mattress knots tied at the medial row and 2 vertical mattress knots in the lateral row. The medial row anchors were placed 8mm medial to the tendon edge with the suture placed 10mm medial to the tendon edge. The lateral row anchors were placed 8mm lateral to the tendon edge and tied in a vertical fashion with one limb passing around the medial row horizontal mattress knot. A 1cm distance was kept between the medial and lateral anchors in the anteroposterior direction (Figure 1A, Figure 2A). The TEAK construct is composed of four suture anchors per repair, 2 double-loaded Healix Advance 4.5mm anchors (Mitek Sports Medicine, Raynham, MA) for the medial row and two knotless Healix Advance 4.75mm anchors in the lateral row. One of the suture anchors was placed 8 mm medial to the tendon insertion site, and one of the sutures from the double-loaded anchor was removed and used to create an inverted horizontal mattress suture placed approximately 10mm from the tendon edge to function as a rip-stop. The two tails from the remaining suture within the medial anchor were placed medial to the inverted mattress technique suture in a narrow horizontal pattern and left untied. All four of the suture tails were then placed within the 4.75mm anchor and secured with appropriate tension 8mm lateral to the lateral border of the tendon insertion site. This process was repeated in the same fashion, keeping a 1cm distance between the medial and lateral anchors (Figure 1B, Figure 2B).

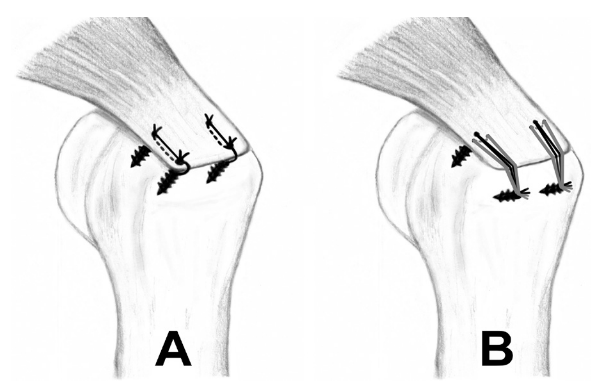

Figure 1. Rotator cuff repair constructs tested: (A) Traditional Double Row and (B) Knotless Transosseus Equivalent.

Figure 2. Rotator cuff repair specimen constructs: (A) Traditional Double Row and (B) Knotless Transosseus Equivalent.

Biomechanical Testing

The humeri were all transected at the midshaft region, then rigidly potted in polymethylmethacrylate, and secured to the load cell of an 858 Mini Bionix materials testing machine (MTS Corp., Eden Prairie, MN). The infraspinatus tendon was attached to a soft tissue freeze clamp, 2 cm from the humeral head tendon insertion at a physiologic angle of 135o to the mechanical axis of the humerus. The clamp was loaded with dry ice and the tendon tightly secured within once the temperature reached -10oC. A linear extensometer (Model 632.31F-24, MTS Systems, Eden Prairie, MN) was secured to the bone and the lateral tendon edge to measure continuous displacement (gap formation) at the repair site (Figure 3). Each specimen was then cycled in tension at 1Hz up to 3,000 cycles, or construct failure. The number of cycles achieved, gap length, total construct displacement, initial stiffness from the 10th cycle, and final stiffness from the 3,000th cycle, were determined. Constructs that survived the cyclic load protocol were then loaded in tension at 2mm/sec until failure. Construct displacement at failure, failure load, peak displacement, peak load, and stiffness (between 50N and 100N) were determined. Failure load was defined as the highest load attained before the first substantial decline in load, while peak load was defined as the highest load attained throughout the test. Differences between constructs for each measure were determined by paired t-tests with an alpha level set at 0.05.

RESULTS

Results of the biomechanical analysis of cyclic and failure testing are presented in Table 1, with means (standard deviation), *P*-values, and post-hoc power achieved for each test parameter. Cyclic testing of the traditional

Table 1. Biomechanical Results of Tied Double Row vs TEAK Rotator Cuff Repairs.

Cyclic Testing				
	Tied Repair	**Knotless Repair**	***P*-value**	**Achieved Power**
Repair Gap Length	3.21 (1.71)	2.45 (1.0)	0.45	0.44
Construct Displacement	10.41 (1.37)	10.20 (3.33)	0.93	0.07
Initial Stiffness	66.83 (9.91)	70.40 (12.20)	0.53	0.24
Final Cycle Stiffness	74.75 (18.27)	92.14 (5.00)	0.09	0.92
Number of Cycles	1,816.80 (1620.17)	3,000 (0.00)	0.18	0.69
Failure Testing				
	Tied Repair	**Knotless Repair**	***P*-value**	**Achieved Power**
Failure Displacement	9.90 (3.92)	8.64 (3.57)	0.72	0.21
Failure Load	234.31 (43.19)	189.78 (51.87)	0.25	0.76
Peak Displacement	9.90 (3.92)	8.64 (3.57)	0.30	0.25
Peak Load	234.31 (43.19)	189.78 (51.87)	0.25	0.85
Failure Stiffness	40.73 (3.00)	61.32 (29.04)	0.19	0.7

Values represent means and standard deviations (SD).

tied double-row repair and all-knotless constructs showed no statistically significant differences in repair gap length, total construct displacement, initial stiffness, or final cycle stiffness. Three of the five traditional tied constructs survived the 3,000-cycle protocol; of the two that did not, one failed at 37 cycles and the other at 47 cycles, both at the suture-tendon interface by the sutures tearing through the infraspinatus tendon. All 5 of the TE all-knotless constructs survived the 3,000 cycles of cyclic testing.

Failure testing of the traditional tied double-row repair and TEAK constructs also showed no statistically significant differences in displacement at failure, failure load, peak displacement, peak load, or stiffness. The 3 traditional tied constructs that survived cycling all failed at the suture-tendon interface by the sutures tearing through the infraspinatus tendon (Figure 4A). The observed mode of failure

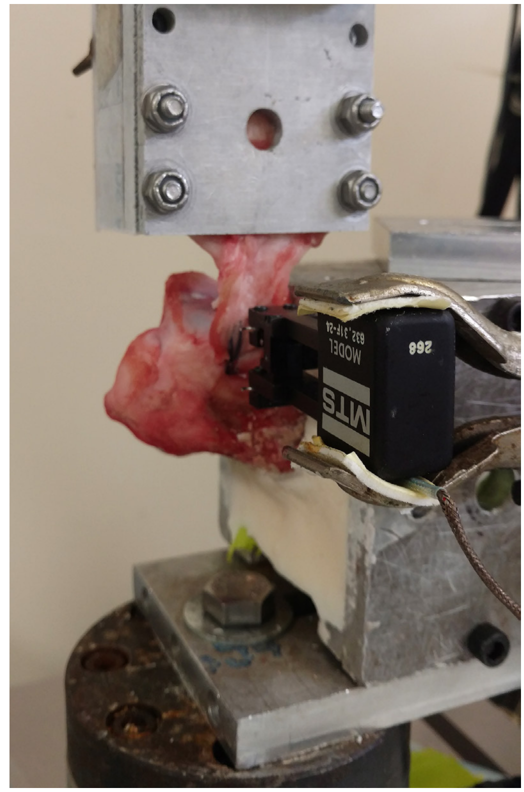

Figure 3. Biomechanical testing setup for comparing the 2 rotator cuff tear repair suture techniques.

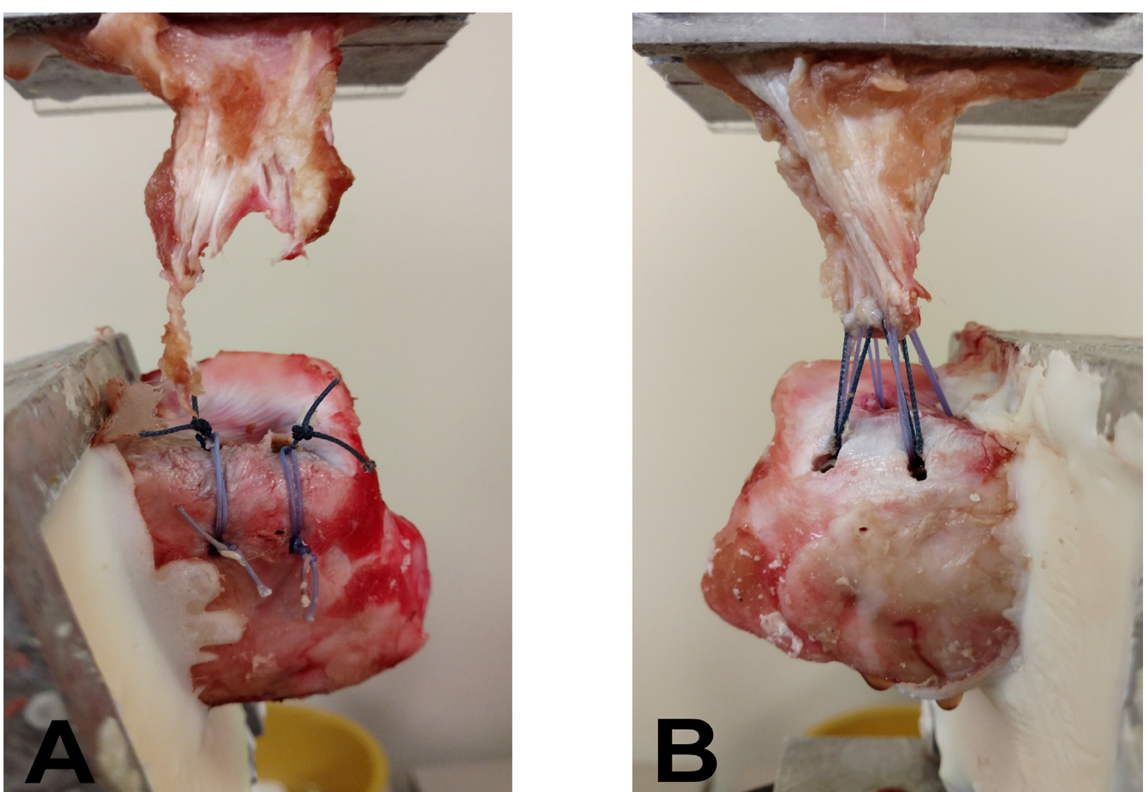

Figure 4. Observed mode of failure of the 2 rotator cuff tear repair suture techniques: (A) Traditional Double Row and (B) Knotless Transosseus Equivalent.

in the TEAK repair constructs was by sutures tearing through the infraspinatus tendon combined primarily with sutures pulling through the knotless bone anchor (Figure 4B).

DISCUSSION

While multiple options exist for the optimal rotator cuff repair technique, the orthopaedic literature is not conclusive. It has been demonstrated that the double-row technique is both biomechanically superior and restores the anatomic footprint to a greater extent than single-row fixation [3,4,8-11,13-15,17,18,20]. Domb et al. concluded that a double-row construct under tension at the rotator cuff footprint was biomechanically superior to a medialized reduced-tension single-row construct [7]. Other studies have also demonstrated the biomechanical superiority of double-row repairs compared to transosseous repairs [4,9,15,19,20]. With the advent of the suture-bridge repair techniques, investigative studies have suggested that TE rotator cuff repairs are biomechanically superior and have better reconstruction of the anatomical footprint, when compared to double-row repairs [8,15,21]. Mall et al. demonstrated in a systematic review of TE cuff repairs that tying the medial row versus a knotless construct was biomechanically superior with respect to restoration of the footprint, gap formation, stiffness, and load to failure [22]. However, the studies involved in that review all used a simple horizontal mattress suturing technique for the medial row without a load sharing technique to prevent suture pullout [1,3-5,7,9,10,12-14,17].

Further biomechanical studies examining various cuff repair techniques, have agreed that failure occurs predominately at the suture-tendon interface [3,4,8,9,14,15,20,21]. Examination of TE repairs have demonstrated that failure of the construct occurs primarily at the medial row near the musculotendinous junction and may possibly be attributed to strangulation and necrosis of the tendon at the medial row repair site [8,21]. Rhee et al. investigated the standard TE repair, which utilized a tied horizontal mattress technique at the medial row, versus a knotless TE repair, which employed a modified Mason-Allen load sharing technique at the medial row [21]. The TE knotless construct, while clinically equivalent to the standard TOE repair, demonstrated a lower re-tear rate on post-operative MRI. Additionally, the retears in the knotless constructs occurred at the bone-tendon interface while retears in the traditional tied group tended to occur medially at the musculotendinous junction. However, that study lacked a biomechanical evaluation of the knotless technique with medial load sharing.

In the porcine model of two rotator cuff repair techniques investigated here, there were no statistically significant differences found for any of the biomechanical factors tested between a traditional tied double-row construct and a TE all-knotless construct. The TE all-knotless repair was found to be comparable in failure strength to the traditional repair. An intriguing aspect of these findings is the differing modes of failure of the two repair techniques. All traditional tied double-row constructs failed at the suture-tendon interface by the sutures tearing through the infraspinatus tendon, including the two specimens which failed during cyclic testing. These finding agree with previously demonstrated failure of the traditional tied construct occurring predominately at the suture-tendon interface.

Although, the TEAK constructs exhibited some tearing at the suture-tendon interface at higher loads, the repairs primarily failed by the suture pulling through the bone anchors. This suggests that the use of a free suture in an inverted horizontal mattress fashion may offer an inherent rip stop to prevent tendon-suture pullout and greater fixation of the soft tissue. An additional, albeit theoretical, benefit is the decreased likelihood of medial row tissue strangulation and necrosis by avoiding tying knots at the musculotendinous junction. As this study demonstrated no significant biomechanical difference in comparison to traditional tied double-row repairs, the TE all-knotless construct may be a viable option for arthroscopic rotator cuff repairs. Given that the TE all-knotless repairs tended to fail at the bone anchors, it can be inferred that load sharing effect of this technique prevents pullout at the suture-tendon interface.

While the results of this study agree with those previously reported, there were limitations common to biomechanical studies. First, porcine specimens are an established medium for cuff repair studies, but, porcine shoulder anatomy does differ from human anatomy. Second, the linear extensometer used in this study limited the measurement of displacement to a single plane, thus the entirety of the motion at the bone-tendon junction at the repair site may not have fully been captured. Third, while extreme care was taken to ensure all repairs for both construct groups were performed in the same manner, inherent variations in tendon thickness, anchor placement, and knot tensioning were difficult to fully control. We attempted to minimize the inherent variability of the rotator cuff tendon anatomy by utilizing matched-pairs of porcine shoulders, with each specimen of a pair being randomly designated to one of two repair types. Finally, although there was adequate statistical power in the failure testing results, the small sample size may not have been adequate to detect more subtle biomechanical differences between repairs.

CONCLUSIONS

This biomechanical analysis demonstrated that a TEAK construct using a medial load-sharing technique is not significantly different than a traditional tied double row construct for rotator cuff repairs in a porcine shoulder model. In this limited series, the load-sharing design of the TEAK construct appeared to provide an inherent rip-stop for preventing tear-out at the suture-tendon interface. Further clinical studies utilizing TEAK repairs with medial row load sharing are warranted.

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