Knotless Single-row Rotator Cuff Repair: A Comparative Biomechanical Study of 2 Knotless Suture Anchors

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Abstract

The purpose of this study was to compare the gap formation during cyclic loading, maximum repair strength, and failure mode of single-row full-thickness supraspinatus repairs performed using 2 knotless suture anchors with differing internal suture-retention mechanisms in a human cadaver model. Nine matched pairs of cadaver shoulders were used. Full-thickness tears were induced by detaching the supraspinatus tendon from the greater tuberosity. Single-row repairs were performed with either type I (Opus Magnum PI; ArthroCare, Austin, Texas) or type II (ReelX STT; Stryker, Mahwah, New Jersey) knotless suture anchors. The repaired tendon was cycled from 10 to 90 N for 500 cycles, followed by load to failure. Gap formation was measured at 5, 100, 200, 300, 400, and 500 cycles with a video digitizing system. Anchor type or location (anterior or posterior) had no effect on gap formation during cyclic loading regardless of position (anterior, \( P = .385 \); posterior, \( P = .389 \)). Maximum load to failure was significantly greater (\( P = .018 \)) for repairs performed with type II anchors (288 ± 62 N) compared with type I anchors (179 ± 39 N). Primary failure modes were anchor pullout and tendon tearing for type II anchors and suture slippage through the anchor for type I anchors.

The internal ratcheting suture-retention mechanism of type II anchors may have helped this anchor outperform the suture-cinching mechanism of type I anchors by supporting significantly higher loads before failure and minimizing suture slippage, potentially leading to stronger repairs clinically.
Rotator cuff tears are a common source of shoulder pain, weakness, and loss of motion and are reported to be found in approximately 10% to 20% of the general population. The prevalence of rotator cuff tears has been shown to vary with age. Sher et al found tears in 54% of studied patients older than 60 years of age, in 28% of patients aged between 40 and 60 years, and in 4% of patients aged between 19 to 39 years. These tears can be caused by degeneration, overuse (particularly in overhead athletes or laborers), heavy lifting, or a fall onto an outstretched arm. The incidence of rotator cuff tears is more common in the dominant arm. These tears can be treated with conservative treatment with success rates ranging from 25% to 82%. If conservative treatment fails, surgical management is often necessary to repair the torn tendons.

Rotator cuff repair can be accomplished with open, mini-open, or arthroscopic repair techniques. Arthroscopic repair is becoming increasingly prevalent due to its minimally invasive nature compared with open repair, with patient satisfaction ranging from 88% to 92%. Although satisfaction is generally high, repaired rotator cuffs can retear, with an incidence rate of approximately 20% or higher depending on the magnitude of the tear and the patient’s sex, age, and activity level. This high retear rate may be due in part to incomplete healing and gap formation commonly found between the repaired tendon and bone. Therefore, a goal of arthroscopic surgery is to create a repair that is strong enough to prevent failure during rehabilitation and to hold the damaged tissue in contact with the bone to allow for complete healing.

To accomplish this goal of arthroscopic surgery, devices and techniques are rapidly evolving to further improve clinical outcomes. Suture anchors are continuously evolving to improve anchor strength and to facilitate the arthroscopic procedure. In particular, knotless suture anchors have been developed to enable a secure repair without the need for time-consuming and technically challenging arthroscopic knot tying and without a reliance on knot security. However, without the presence of knots, the burden is on the anchor design, and specifically the suture-retention mechanism, to prevent the repair from loosening through slippage of the suture past the anchor. The design of knotless anchors continues to evolve to improve the suture retention strength to minimize suture slippage. The 2 anchors tested in the current study were type I (Opus Magnum PI; ArthroCare, Austin, Texas) and type II (ReelX STT; Stryker, Mahwah, New Jersey) knotless anchors (Figure 1). Type I anchors are designed with a cinching mechanism that clamps the suture, whereas type II anchors have a ratcheting mechanism whereby the suture is coiled around a central bore, which is then locked in place.

The purpose of this study was to compare the biomechanical performance of 2 polyetheretherketone (PEEK) knotless suture anchors with different suture-retention mechanisms in a single-row repair. It was hypothesized that no significant difference would exist in gap formation during cyclic loading, maximum repair strength, and mode of failure between the 2 different knotless suture anchors tested in a cadaver model.

**MATERIALS AND METHODS**

Nine matched pairs of human cadaver shoulders (ScienceCare, Inc, Phoenix, Arizona) were used for this study. Mean donor age was 68.7 years (range, 63-75 years). Three donors were women and 6 were men. The bone mineral density (BMD) of the humeral head was measured for all specimens using dual-energy X-ray absorptiometry (DEXA; Hologic, Inc, Bedford, Massachusetts). The specimens in each matched pair were randomly assigned to be repaired with either type I or type II knotless suture anchors (Figure 1).

The type I anchor is a made of PEEK-Optima (Invibio Biomaterial Solutions, West Conshohocken, Pennsylvania). The suture is tensioned by rotating a knob on the insertion handle. The suture is then secured by sliding a sleeve over the suture that cinches it in place on the shaft of the anchor. The type II anchor is a 5.5-mm PEEK anchor loaded with #2 force fiber (Stryker). The anchor consists of 6 individual stainless steel inner ratcheting locking mechanisms. A knob on the top of the inserter handle is turned to tension the suture and engage the ratcheting locking mechanisms.

Before proceeding with testing, the BMDs of the specimens assigned to the 2 groups were statistically compared using a paired t test to ensure that no significant difference in BMD existed that could potentially affect the biomechanical testing results.

The clavicle and all soft tissues were removed from the scapula and humerus except for the supraspinatus tendon. The
supraspinatus tendon was then excised from its insertion on the greater tuberosity, and the distal 10 mm of the tendon was resected to simulate a single-tendon, medium-sized rotator cuff tear. The width and thickness of the supraspinatus was measured with digital calipers, and the supraspinatus footprint area was marked and measured. The specimens were repaired with 2 knotless suture anchors each, either type I or II, by securing the supraspinatus tendon to the footprint with 2 inverted horizontal mattress sutures placed 10 to 15 mm laterally from the tear margin. The 2 anchors were spaced approximately one-fourth the width of the supraspinatus from the anterior margin and the posterior margin.

Mechanical testing was performed based on well-established testing protocols.20-22 The humerus was fixed to the base of an Instron model 1321 servohydraulic test system (Instron Corp, Canton, Massachusetts) at a 135° angle to simulate the anatomic direction of load applied to the supraspinatus (Figure 2).

The supraspinatus muscle was removed from the scapula, and the tendon and muscle were attached to the actuator of the Instron with a custom-built corrugated stainless steel clamp. Dots of India ink approximately 3 mm in diameter were used to mark the location of the anchors on the humerus and the sutures on the supraspinatus. A MaxTRAQ 3D dual camera digital tracking system (InnoVision Systems, Inc, Columbiaville, Michigan) was used to measure the gap formation at 30 frames per second between the humerus and the supraspinatus during testing by tracking the ink dots. A 10-N preload was applied to the tendon and held for 60 seconds. The tendon was then cycled with a haversine wave form from 10 to 90 N at 0.25 Hz for 500 cycles. After cyclic loading, the tendon was loaded to failure at 1 mm/s. Actuator load and displacement were recorded at 30 Hz on a computer equipped with a Keithley 1802 HC analog-to-digital board (Keithley Instruments, Inc, Cleveland, Ohio) and TestPoint data acquisition software (Capital Equipment Corp, Billerica, Massachusetts). Ultimate load and gap formation at 5, 100, 200, 300, 400, and 500 cycles were measured, and the failure mode was recorded.

Differences in ultimate load and physical properties were compared using paired t tests. In addition, the effect of anchor group on gap formation during cyclic loading was determined for the anterior and posterior sides of the repairs using a repeated-measures analysis of variance. Categorical data for failure mode were analyzed using the chi-square test to evaluate the effect of anchor type. All statistical analyses were performed using SYSTAT 12 statistical software (Systat Software, Inc, Chicago, Illinois), and differences were considered significant when P was less than .05.

RESULTS

No significant differences existed between the 2 groups for any of the physical properties: BMD, tendon thickness, tendon width, footprint thickness, or footprint width (Table 1). Two specimens failed during cyclic loading. One type II anchor failed by the anchor pulling out of the bone, and 1 type I anchor failed by the suture pulling out of the anchor. They were excluded from the analysis because data for all 500 cycles or load to failure were not available, leaving 7 matched pairs for analysis.

Anchor type was not found to have an effect on gap formation during cyclic loading (anterior, P=.385; posterior, P=.389) (Figure 3). Repairs performed with type II anchors exhibited a significantly greater ultimate load compared with type I anchors (288±62 vs 179±39 N, respectively; P=.018). Primary failure mode also differed between the 2 groups (x²=12.44; P=.006), with 71% of the type I anchors failing by suture slippage through the anchors, as opposed to 14% of the type II anchors failing through this mode (Table 2). Primary failure modes for repairs with the type II anchors were anchor pullout (36%) and tendon tearing (36%).
The purpose of this study was to examine the biomechanical performance of 2 PEEK knotless suture anchors with differing suture-retention mechanisms in a single-row repair. Both of the anchors evaluated in the study have internal mechanisms designed to prevent the suture from slipping. Although significant differences were not observed during cyclic mechanical testing, it was found that the failure modes differed for the 2 anchor types. The primary failure mode for type I anchors was suture slippage through the anchor; whereas most of the repairs performed with type II anchors failed at significantly higher loads through anchor pullout or tendon tearing. These results suggest that the internal ratcheting design of the type II anchor is better able to restrict suture slippage than the suture-cinching mechanism of type I. This reduction in suture slippage may be significant clinically because postoperative gap formation may be caused in part by suture slipping past knotless suture anchors over time.

In a similar study comparing single- and double-row repairs, Kim et al. observed similar gap formation for their single-row repairs performed with 2.5-mm metal anchors (first cycle, 3.1 ± 1.7 mm; 200th cycle, 7.6 ± 3.7 mm) as was observed in the current study for type I anchors (first cycle, 3.5 ± 1.7 mm; 200th cycle, 6.1 ± 2.9 mm). Repairs with type II anchors showed some improvement in gap formation (first cycle, 3.4 ± 1.5 mm; 200th cycle, 5.0 ± 2.9 mm), although the difference was not statistically significant between the 2 anchor types in the current study. However, the maximum load applied by Kim et al. during cyclic loading was 180 N as opposed to 90 N in the current study, so care must be taken in comparing displacements. Kim et al. also found that gap formation for the double-row repair was significantly smaller than that for the single-row repair. Double-row repairs were not performed in the current study to focus on the performance of the knotless anchors without transferring load to the medial row anchors.

Wieser et al. performed a study comparing the pullout strength and suture slippage in 4 different knotless suture anchors. They tested the Versalok (DePuy Mitek, Raynham, Massachusetts), Footprint PK (Smith & Nephew, Andover, Massachusetts), PopLok (ConMed Linvatec, Utica, New York), and BioPlug NT (Karl Storz AG, Tuttingen, Germany) in bovine femoral condyles. To test suture slippage, 1 suture limb from an anchor was pulled until it slipped out of the anchor. To test the anchor pullout strength, both limbs of the suture anchor were loaded to failure. Mean load to anchor pullout ranged from 156 to 269 N. Mean load to suture slippage ranged from 66 to 109 N. Pullout load was 190% to 246% greater than the suture slippage load. The current study’s results showed a 160% higher failure load for the type II anchors that failed primarily by anchor pullout or tendon tearing than the type I anchor that failed primarily by suture slippage. The results of these 2 studies show the importance of a secure-locking mechanism in a knotless suture anchor to prevent premature failure of the repair.

Chu et al. compared 3 different double-row rotator cuff repair anchor systems in a human cadaver model. They used a completely knotless suture anchor system (SutureCross; KFx Medical, Carlsbad, California) and 2 commonly used hybrid anchor systems: BioCorkscrew/PushLock (Arthrex, Inc, Naples, Florida) and Spiralok/Versalok (DePuy Mitek). The repairs were loaded cyclically and then loaded to failure. The knotless suture anchors failed by the suture slipping out of the anchor in 11 of 14 specimens during cyclic loading. Only 1 specimen failed in cyclic loading in the

**DISCUSSION**

**Table 2**

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Type I Anchor</th>
<th>Type II Anchor</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Anterior</td>
<td>Posterior</td>
</tr>
<tr>
<td>Anchor pullout</td>
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<td>2</td>
</tr>
<tr>
<td>Suture slippage</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Tendon tearing</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Suture breakage</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*In 1 specimen, both anchors pulled out of the humerus between cycles 300 and 400.*

*In 1 specimen, the suture slipped through both anchors during the first cycle.*

![Figure 3: Graphs showing gap formation with the anterior (A) and posterior (B) anchors.](image)
other 2 groups due to the suture tearing through the tendon. The importance of a strong suture-locking mechanism was also demonstrated in their study. The other 2 anchor systems failed primarily by the suture pulling through the tendon in load to failure (12/14). Mean failure load was 310 and 337 N for the PullLock and Versalok, respectively. The failure load was 288 N in the current study when the failure mode was tendon tearing or anchor pullout. These failure loads were similar despite the different repair techniques because the failure was in the tissue and not the hardware.

The current study had some limitations. The repairs were performed using an arthroscopic technique and instruments but in an open manner. All of the soft tissue was removed except for the supraspinatus. This does not duplicate the conditions of a repair performed in the operating room. However, this made the repair more reproducible while potentially removing surgeon skill as a variable. Furthermore, this study was done on a cadaveric model and therefore cannot address the potential affects of biologic healing on the strength of a repair over time. In addition, only 2 different anchors were compared in this study. Several other knotless suture anchors are available that could have been compared to make this study more comprehensive. Finally, despite initial strength being proposed as a critical factor in clinical outcomes, little clinical evidence exists to support this claim except in the case of large rotator cuff tears.26

Conclusion
A knotless suture anchor with a ratcheting suture-retention mechanism was found to have significantly higher ultimate load than another anchor design with a suture-cinching mechanism in a single-row repair. However, no significant difference existed between the 2 anchors’ ability to limit gap formation during cyclic testing.

References