Biomechanical Comparison of Transosseous Knotless Rotator Cuff Repair Versus Transosseous Equivalent Repair: Half The Anchors With Equivalent Biomechanics?

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**Purpose:** To compare the biomechanics of a transosseous equivalent (TOE) repair using medial and lateral anchors with tape to a transosseous knotless (TOK) tape repair with only laterally placed intraosseous anchors. **Methods:** One of 2 different repairs were performed on 8 paired specimens: (1) transosseous equivalent (TOE) tape repair or (2) transosseous knotless (TOK) tape repair. Specimens were mounted on a materials testing machine and loaded in uniaxial tension to measure cyclic construct gap formation, followed by failure testing. Paired t tests were used to compare gapping, ultimate stiffness, and failure loads. Fisher exact test was used to compare modes of failure (soft tissue failure vs construct failure). **Results:** Peak cyclic gapping, failure stiffness, and ultimate failure loads did not differ between TOE and TOK repairs ($P = .140$ for gapping, $P = .106$ for stiffness, and $P = .672$ for peak failure loads). All TOK repairs failed via soft tissue failure medial to the medial suture line, with no construct failures. TOE repairs failed more often through construct failure (anchor migration or suture-bone interface cut through) than TOK repairs ($P = .026$). **Conclusion:** TOK repairs only failed through soft tissue whereas TOE repairs failed through both soft tissue and the repair construct. Despite 50% fewer suture anchors in the TOK repairs than the TOE repairs, cyclic gapping and ultimate stiffness and failure loads were not significantly different. **Clinical Relevance:** The transosseous knotless construct presented is a 2-anchor construct that is equivalent in biomechanical function to a traditional 4-anchor construct, reducing anchor load in the tuberosity.

A variety of double-row rotator cuff repair techniques exist, including the transosseous equivalent repair initially described by Park. Numerous studies have shown that this pattern of repair provides increased failure loads, reduced gap formation, improved footprint restoration, increased tendon-bone contact, and a more watertight environment than other single- or double-row repairs. Unfortunately, the improvements noted in the healing and biomechanics of a double-row repair compared with a single-row repair come at the cost of double the overall number of required suture anchors.

Arthroscopic transosseous repairs are an alternative to transosseous equivalent repairs that potentially provide...
a similar “double-row” type of repair without the requirement of anchors. There is conflicting biomechanical data comparing transosseous equivalent repairs and transosseous repairs, with some studies suggesting equivalent mechanics whereas others report that transosseous equivalent repairs are mechanically superior to an arthroscopic transosseous repair.6,7 An arthroscopic transosseous repair that is knotless, has reduced mechanical dependence on bone quality, and does not require as many suture anchors as a transosseous equivalent repair, could provide a significant improvement in lowering cost without compromising overall construct strength.

The purpose of this study was to compare the biomechanics of a transosseous equivalent (TOE) repair using medial and lateral anchors with tape to a transosseous knotless (TOK) tape repair with only laterally placed intraosseous anchors. The hypothesis was that there would be no differences in structural properties between the TOE and TOK repairs.

Methods

Specimen Preparation
Fresh-frozen human cadaveric shoulders (8 pairs; 2 male, 6 female; mean age 63 years; range 55-72) were thawed for 24 hours at room temperature before dissection. No investigational board approval is required at our institution to perform cadaveric studies. No specimens were excluded. The primary surgeons performing the operations (R.Z.T., R.T.B.) assessed the specimens to confirm they did not have rotator cuff tearing or deformity precluding use in the study. Shoulders with gross evidence of supraspinatus tendon tears were excluded from the study. No differences in tissue quality or bony morphology were noted between shoulders within pairs. Specimens were dissected down to the glenohumeral joint, leaving the supraspinatus footprint on the humerus intact. The muscle belly was finely dissected and released from the scapula. After isolating the humerus, the entire rotator cuff was removed from the proximal humerus by releasing it directly off the bone. The supraspinatus tendon and muscle was then separated from the remainder of the rotator cuff for reattachment through the repair.

Repair Constructs
Two different constructs were created—a transosseous equivalent construct and a transosseous construct. Construct types were randomly assigned to each side of a matched pair using a fair coin toss method. It was also required that each construct type have an equivalent number of left and right specimens.

The TOE with tape repair was created using two 5.5-mm knotless anchors (SwiveLock PEEK; Arthrex) and two 5.5-mm knotless anchors in the lateral row. The medial-row anchors were placed at $45^\circ$ with respect to the articular margin, with the anterior anchor 5 mm posterior to the bicipital groove. The posterior anchor was placed 12 mm posterior to the first anchor. Lateral-row anchors were placed 10 mm distal to the proximal edge of the greater tuberosity with the same anterior/posterior spacing as that of the medial-row anchors. A total of 4 limbs of the suture tape were passed through the supraspinatus tendon, 2 from the anteromedial anchor and 2 from the posteromedial anchor. The limbs were passed 5 mm medial to the musculotendinous junction, with 5 mm separating the limbs from the same anchor. One limb from the anteromedial anchor and one limb from the posteromedial anchor were then brought to an anterolateral row anchor, tensioned, and then the anchor was inserted. Finally, the second limb from the anteromedial anchor and the second limb from the posteromedial anchor were brought to a posterolateral anchor, tensioned, and then the anchor was inserted (Fig 1).

The TOK with tape repair was performed using a custom guide that created a medial tunnel linked to a lateral tunnel (KATOR LLC, Logan, UT) (Fig 2). The medial (vertical) entrance of the tunnel was placed at the most medial aspect of the greater tuberosity, and the lateral exit of the tunnel was 10 mm distal to the proximal aspect of the greater tuberosity. Two tunnels were created, with the first 5 mm posterior to the bicipital groove in the greater tuberosity and the second 12 mm posterior to the anterior tunnel. Two 2-mm high-strength tapes (KATOR LLC) were passed through each tunnel using the tunnel guide. One limb of each tape was then passed 5 mm lateral to the musculotendinous junction, 2 limbs from the anterior tunnel and 2 from the posterior tunnel separated by 5 mm. The most anterior limb and the third-most anterior limb passed through the tendon were then

**Fig 1.** Transosseous equivalent (TOE) with tape repair with 2 medial knotless anchors each loaded with 1 suture tape and 2 lateral knotless anchors.
brought to an anterolateral 5.0-mm knotless anchor (KATOR Suture Anchor) along with the 2 limbs exiting the anterolateral tunnel. The largest KATOR anchor is of 5.0 mm diameter. The tapes were tightened and the anchor seated into the anterolateral tunnel. The steps were repeated taking the second and fourth-most anterior limbs passed through tendon. These were brought to a second lateral 5.0-mm knotless anchor along with the 2 limbs exiting the posterolateral tunnel. The tapes were tightened and the anchor seated into the posterolateral tunnel (Fig 3). Both anchors are manufactured from ASTM F 2026-compliant PEEK (polyetheretherketone) (Fig 4).

**Experimental Protocol**

A protocol modified from previous studies was used. A servohydraulic test frame (Instron 1331 Load Frame, Model 8800 controller; Instron Corp) with a 1-kN axial load cell (Dynacell Model 2527-130; Instron Corp) was used to apply dynamic cyclic and failure loading to the test specimens. The humeral shaft of each specimen was secured in a clamp that held the long axis of the humerus at 135° with respect to the natural axis of tendon pull. A custom cryoclamp was fixed to the muscle belly 25 mm above the medial row of suture passes (Fig 5).

Nine 2-mm-diameter fiducial markers, used to measure construct gapping, were affixed to the bone, tendon, and muscle belly with cyanoacrylate. High-resolution video tracking software (DMAS v6.5, accuracy of marker centroid tracking: ± 0.005 mm; Spica Technology Corp) and a Prosilica GC1350 Gigabit Ethernet camera (1360 × 1024-pixel resolution; Allied Vision Technologies) were used to measure marker motion. A calibration frame with markers of known spatial dimension was used to calibrate the tracking field of view. The difference in displacement of the markers on the bone and tendon was defined as construct gap formation. Construct gapping in excess of 10 mm was considered failure during cyclic testing. Gapping was also recorded during failure testing.

Soft tissues were kept hydrated throughout testing with 0.9% saline spray. A preload of 10 N was applied to each construct for 1 minute before commencing cyclic testing. Constructs then underwent 200 cycles of displacement between 10 and 100 N at 1 Hz using a triangle displacement waveform. The final 10-N load from cyclic testing was held for 1 minute before loading to failure at 1 mm/s.

Force and fiducial marker displacement were recorded continuously throughout testing and gapping was measured from the dynamic data at cycle 200. Failure load and fiducial marker displacement were also measured throughout the failure test, with failure defined as the point of highest load before abrupt loss of load support. The steepest slope of the load-displacement curve spanning at least 10% of data points up to the failure load was defined as the stiffness.

The mode of failure was defined for each specimen. Two primary modes of failure existed—soft tissue (tendon/muscle) failure or construct (bone/anchor) failure. Sutures were noted to pull through the tendon tissue, with the construct remaining intact for the tendon failure. The muscle would pull apart with the construct remaining intact for muscle failure. The anchors would either migrate or pull out or the suture would slip through the anchor for anchor failure. Finally, the suture would cut through the proximal humerus for bone failure.

**Data Analysis**

Sample size estimates for the present study were based on the literature, where prior studies evaluating transosseous equivalent repairs using suture and tape used 6 to 9 pairs of specimens. Paired t tests were used to compare gapping, ultimate stiffness, and failure loads. Fisher exact test was used to compare modes of failure.
failure (soft tissue failure vs construct failure). Comparisons with \( P < .05 \) were considered significant.

**Results**

In comparing the TOK and TOE repairs, cyclic gapping, stiffness, and ultimate failure loads did not differ significantly between repairs (Table 1). In the TOE repairs, 5 of 8 failed through construct failures (Table 1). Three of 8 repairs failed with suture cutting through bone and anchors migrating or pulling out. All anchor failure was through the lateral row anchors. In 2 of 8 repairs, failure occurred with suture cutting through bone and pulling through the tendon. Finally, 3 of 8 specimens failed with suture pulling through the tendon and muscle failure. All TOK repairs failed through soft tissue failure. Five of 8 repairs failed through suture cutting through tendon and muscle failure, 1 of 8 specimens failed with suture cutting through tendon, and 2 of 8 specimens failed with muscle failure only. In 63% of TOE repairs, the failure was at least partially via construct failures as opposed to 0% of TOK repairs (\( P = .026 \)).

**Discussion**

The current data support that a transosseous knotless anchor repair provides equivalent biomechanical strength in both cyclic gapping, failure stiffness, and ultimate failure loads compared with a transosseous equivalent repair, with half the number of anchors supporting the hypothesis. This reduction in anchor burden has multiple advantages, including potentially lower surgical costs and fewer anchors in the tuberosity, allowing more bony surface area of the rotator cuff footprint for tendon healing. Reduced anchor burden may also improve the ability to perform revision surgery in cases of healing failure.

Looking at the modes of failure, all transosseous knotless repairs failed through the soft tissue of the cadaver (tendon/muscle), whereas 63% of the transosseous equivalent repairs failed partially or completely through the fixation construct (anchors/bone). Consequently, the transosseous knotless construct is unlikely to have the limitations of a traditional transosseous repair in terms of reliance on bone quality. It also appears that the chance for anchor-related complications are lower with the transosseous knotless repair compared with the transosseous equivalent repair based on the failure modes. The anchor complications were potentially more common with the TOE repair as opposed to the TOK because the lateral TOE anchors have the potential to backout whereas the TOK anchors are locked in place. The only mechanism for the TOK anchors to fail is superiorly through the entire greater tuberosity whereas the TOE anchors can fail by backing out laterally, with no bone resisting this process.

Few studies have compared the biomechanical properties transosseous equivalent and transosseous repairs in cadaveric shoulders.\(^2\),\(^6\),\(^7\) Kummer et al.\(^5\) compared transosseous equivalent and transosseous repairs using suture in human cadaveric shoulders. They performed cyclic loading as well as load to failure testing and found ultimate failure loads of 309 N for the transosseous equivalent repairs and 339 N for the transosseous repairs (\( P = .22 \)) after 10,000 cycles at 150 N. Salata et al.\(^7\) also compared transosseous equivalent and transosseous repairs using suture in cadaveric shoulders. They performed cyclic loading and load to failure but only performed 100 cycles to 160 N using an identical TOE construct, but only 2 stitches per tunnel for the transosseous repair compared with 3 stitches per tunnel used by Kummer et al.\(^5\),\(^7\) They reported a failure load of 558 N for the TOE repair and 325 N for the transosseous repair (\( P < .05 \)). The difference in the findings of the Kummer and the Salata studies (TOE better than TO\(^7\); TOE similar to TO\(^6\)) may be due to different loading parameters as well as the number of sutures placed per tunnel in the
TO repairs. Similarly, the differences between the current data and the Salata data are likely due to differences in loading parameters and differences in transosseous constructs. The Salata et al. study used half the number of cycles and this may result in higher load to failures compared with the current data using double the number of cycling. Variations in the TOE load to failures between the Salata et al. and the current study could also be a result of Salata et al. using suture and the current study using tape. The differences in the transosseous repair load to failures between the Salata et al. and the current study are likely a result of the addition of the knotless anchor. This addition eliminates the effect of bone quality on construct strength, likely resulting in the higher load to failure in the TOK repairs.

Limited data are available on biomechanical properties of suture tape repairs. Spang et al. compared TOE repairs with suture versus tape and found no differences in gap formation or failure loads, reporting 408 N ultimate load for the tape construct and 421 N for the suture construct (P = .31). Barber et al. also reported on the biomechanical properties of a TOE repair with tape and reported 586 N ultimate failure load and 2.5 mm of gapping after 200 cycles. The repair construct in the Barber study differed from the current TOE repair as they included a second No. 2 "rip-stop" stitch placed in a mattress fashion from both medial anchors as well as the tape. Nevertheless, the gapping and failure loads are very comparable to those seen in the current study of the TOE technique. The current data further support the utility of tape with comparable data to prior reports of TOE repairs using tape as well as the utility of the TOK repairs using tape with comparability to TOE repairs with tape.

### Table 1. Specimen Demographics, Peak Failure Load, Stiffness, Gap Formation, and Failure Mode

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Donor ID</th>
<th>Side</th>
<th>Age</th>
<th>Gender</th>
<th>Peak Load, N</th>
<th>Stiffness, N/mm</th>
<th>Gap Formation at 200 Cycles, mm</th>
<th>Failure Mode</th>
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<td>TOE repair</td>
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<td></td>
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<tr>
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<td>R</td>
<td>62</td>
<td>F</td>
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<td>56</td>
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<tr>
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<td>378.9</td>
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<td>3.31</td>
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<td>Mean (SD)</td>
<td>62.8 (6.2)</td>
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<td>478.4 (81.0)</td>
<td>60.9 (28.8)</td>
<td>4.4 (2.5)</td>
<td></td>
<td>Frequency of construct fixation failure 5 (63%)</td>
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<tr>
<td>TOK repair</td>
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<td>504.8</td>
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<td>606.8</td>
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<td>680.2</td>
<td>124.3</td>
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<td>M</td>
<td>413.9</td>
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<td>Muscle failure</td>
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<td>M</td>
<td>368.7</td>
<td>49.3</td>
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<td>Muscle failure</td>
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<tr>
<td>Mean (SD)</td>
<td>62.8 (6.2)</td>
<td></td>
<td>497.5 (106.7)</td>
<td>77.2 (29.1)</td>
<td>3.1 (1.0)</td>
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<td>Frequency of construct fixation failure 0 (0%)</td>
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</table>

Statistical analysis, P value

| | .672 | .106 | .140 | <.026 |

NOTE. All P values are for a confidence interval of 95%. SD, standard deviation; TOE, transosseous equivalent; TOK, transosseous knotless.
Limitations

There are several limitations of the study. First, a biomechanical study only evaluates initial biomechanical properties of the repair construct in simulated tears, and consequently it is impossible to predict how these comparisons would perform in vivo in degenerative tears. Second, the tape materials were not identical as each manufacturer pairs its anchors for use with their specific tape. Nevertheless, the tape sizes were identical. Also, both the TOK and the TOE repairs had 4 passes of tape through the tendon. Consequently the constructs were as similar as possible without using the same material, and the tape materials never themselves failed. Third, the surgical technique for the TOK repair requires a guide and transosseous tape passage that may be clinically more challenging than a traditional TOE repair. Fourth, the current study only evaluated single tendon tears, and the results and technique may not be equivalent for larger more complex tears. Finally, all specimens were relatively young with an average age in the low 60s; therefore, the results may not be applicable in osteoporotic bone. Nevertheless, even in good bone, the TOE repairs failed at a significantly higher rate through anchor migration or bone cutout compared with the TOK repairs; therefore, it is likely these same patterns would hold in more osteoporotic bone.

Conclusion

TOK repairs only failed through soft tissue, whereas TOE repairs failed through both soft tissue and the repair construct. Despite 50% fewer suture anchors in the TOK repairs than the TOE repairs, cyclic gapping and ultimate stiffness and failure loads were not significantly different.

References