Original Research

Biomechanical Comparison of Subpectoral Biceps Tenodesis Onlay Techniques

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Background: Subpectoral biceps tenodesis can be performed with cortical fixation using different repair techniques. The goal of this technique is to obtain a strong and stable reduction of biceps tendon in an anatomic position.

Purpose/Hypothesis: The purpose of this study was to compare (1) displacement during cyclic loading, (2) ultimate load, (3) construct stiffness, and (4) failure mode of the biceps tenodesis fixation methods using onlay techniques with an all-suture anchor versus an intramedullary unicortical button. It was hypothesized that fixation with all-suture anchors using a Krackow stitch would exhibit biomechanical characteristics similar to those exhibited by fixation with unicortical buttons.

Study Design: Controlled laboratory study.

Methods: Ten pairs of fresh-frozen cadaveric shoulders (N = 20) were dissected to the humerus, leaving the biceps tendon-muscle unit intact for testing. A standardized subpectoral biceps cortical (onlay) tenodesis was performed using either an all-suture anchor or a unicortical button. The biceps tendon was initially cycled from 5 to 70 N at a frequency of 1.5 Hz. The force on the tendon was then returned to 5 N, and the tendon was pulled until ultimate failure of the construct. Displacement during cyclic loading, ultimate failure load, stiffness, and failure modes were assessed.

Results: Cyclic loading resulted in a mean displacement of 12.5 ± 2.5 mm for all-suture anchor fixation and 29.2 ± 9.4 mm for unicortical button fixation ($P = .005$). One all-suture anchor fixation and 2 unicortical button fixations failed during cyclic loading. The mean ultimate failure load was 170.4 ± 68.8 N for the all-suture anchor group and 125.4 ± 44.6 N for the unicortical button group ($P = .074$), with stiffness 59.3 ± 11.6 N/mm and 48.6 ± 6.8 N/mm ($P = .091$), respectively. For the unicortical button, failure occurred by suture tearing through tendon in 100% of the specimens. For the all-suture anchor, failure occurred by suture tearing through tendon in 56% and knot failure in 44% of the specimens.

Conclusion: The all-suture anchor fixation using a Krackow stitch for subpectoral biceps tenodesis provided ultimate load and stiffness similar to unicortical button fixation using a nonlocking whipstitch. The all-suture anchor fixation technique was shown to be superior in terms of displacement during cyclic loading when compared with the unicortical button fixation technique. However, the results of this study help to show that the fixation method used on the humeral side is less implicative of the overall construct strength than stitch location and technique, as the biceps tendon tissue and stitch configuration seem to be the limiting factor in subpectoral onlay tenodesis techniques.

Clinical Relevance: All-suture anchors have a smaller diameter than traditional suture anchors, can be inserted through curved guides, and preserve humeral bone stock without compromising postoperative imaging. This study supports use of the all-suture anchor fixation technique for subpectoral biceps tenodesis, with high biomechanical fixation strength and low displacement, as an alternative to the subpectoral onlay biceps tenodesis technique.

Keywords: subpectoral biceps tenodesis; all-suture anchor; unicortical button; onlay technique

The long head of the biceps is recognized as a common contributor to anterior shoulder pain and is often associated with other shoulder pathologies, including SLAP (superior labrum anterior and posterior) lesions, rotator cuff tears, and subacromial impingement.[13,22] Both tenotomy and tenodesis are effective in ameliorating pain associated with the long head of the biceps tendon. However, decreased muscle function and cosmetic defects are seen at a higher rate after tenotomy compared with tenodesis.[8,21,22,28,31] Lower reoperation rates are seen after subpectoral fixation when compared with suprapectoral fixation, and it is believed that releasing the tendon from its sheath and the bicipital groove relieves the patient of most associated pain.[16,22,25]

There is no clear consensus on whether bone tunnel or cortical surface (onlay) healing confers better outcomes. Clinical outcome studies comparing interference screw fixation (intramedullary) and suture anchor fixation

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techniques (onlay) for subpectoral biceps tenodesis found no significant difference in patient outcomes between the 2 techniques.[16,19] However, interference screws are found to be associated with various complications, including humeral fractures at the drill hole, persistent pain, and bioabsorbable screw reactions.[7,17,26] Subpectoral biceps tenodesis using an onlay fixation technique is a reasonable alternative to mitigate these risks.

Fixation using all-suture anchors in the shoulder has become more popular owing to increased preservation of bone stock with unicortical drilling of only 1.8 mm, improved postoperative imaging, easier revision surgery, potentially lower fracture risk, and similar biomechanical properties in comparison with suture anchors for labral repairs.[15,32] While most studies have reported the use of all-suture anchor onlay techniques in the glenoid, the all-suture anchor has only been presented as a fixation device for subpectoral tenodesis with bicortical drilling and intramedullary tendon fixation.[4] The purpose of this study was to compare the (1) displacement during cyclic loading, (2) ultimate load to failure, (3) construct stiffness, and (4) failure mode of the biceps tenodesis fixation methods using the all-suture anchor and unicortical button onlay techniques. It was hypothesized that fixation with all-suture anchors would exhibit biomechanical characteristics similar to those exhibited by fixation with unicortical buttons when used for an onlay biceps tenodesis.

METHODS

Specimen Preparation

Ten total pairs (N = 20) of male fresh-frozen cadaveric shoulders (mean age, 58.8 years [range, 51-64 years], body mass index, 18-35 kg/m^2) were used in this study. All specimens were devoid of any history of shoulder injury or surgery, osteoarthritis, degenerative joint disease, and osteoporosis. The shoulders from each pair were randomly allocated into 2 groups: one using a unicortical button fixation method for biceps tenodesis (n = 10) and the other using an all-suture anchor fixation (n = 10). Randomization was used to minimize the effects of anatomic differences between right and left shoulders. All specimens were dissected of all soft tissue and muscle to the level of the shoulder capsule, leaving only the biceps muscle and tendon and capsular structures intact. The humerus was then disarticulated from the glenoid, and the transverse humeral ligament was removed to release the biceps tendon from the intertubercular groove and sectioned 40 mm below the upper border of the pectoralis major insertion. The humerus was then inverted and the proximal aspect was potted in a cylindrical mold with polymethyl methacrylate (Fricke Dental International) to the level of the inferior border of the intertubercular groove while orienting the longitudinal axis of the humerus parallel to the longitudinal axis of the cylindrical mold. A saline spray was used throughout preparation and testing to keep the biceps tendon tissue superficially hydrated.

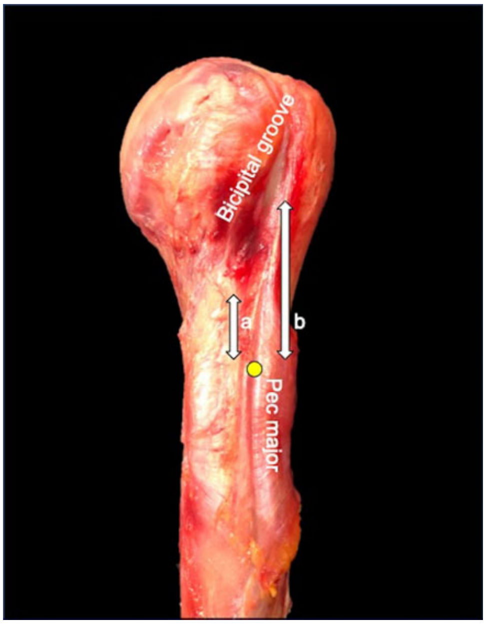

Figure 1. Entrance point of unicortical drilling (yellow dot), 50 mm below the distal entrance of the bicipital groove (*b*) approximately 20 mm below the proximal edge of the pectoralis major tendon (Pec major) (*a*) to ensure the anatomic length and tension of the biceps muscle.

Surgical Technique

For all repairs, the biceps tenodesis site on the humerus was marked 50 mm below the palpable entrance of the bicipital groove. This placement is approximately 20 mm distal to the proximal edge of the pectoralis major tendon, which is 10 mm proximal to the musculotendinous junction (MTJ) of the long head of the biceps (Figure 1).[9,12] The long head of the biceps tendon was cut 20 mm proximal to the MTJ and all tendons were sutured as described in the following “Fixation Technique” section 20 mm distally

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Ethical approval was not sought for the present study.

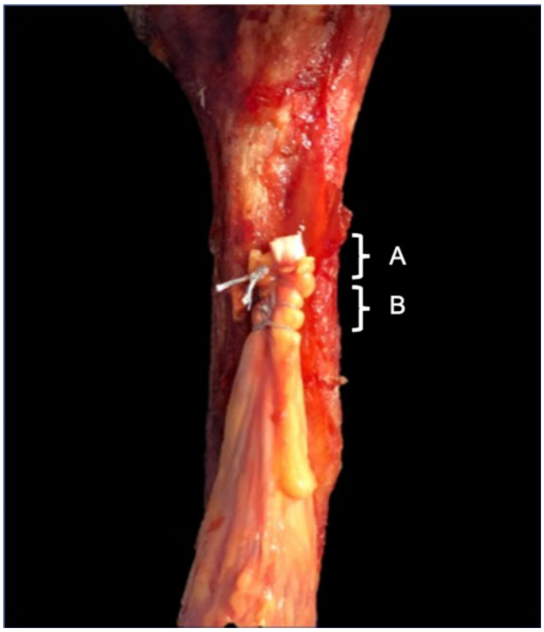

Figure 2. Final repair construct with whipstitched biceps tendon, beginning 10 mm proximal to (*A*) and including 10 mm of the musculotendinous junction (*B*).

beginning 10 mm proximal to the MTJ (Figure 2), as this is the location of the strongest fixation strength.[29]

Unicortical Button Fixation Technique

The unicortical button used in the study was an implantable titanium suture button of 2.6 × 12–mm size with 2 suture holes (BicepsButton; Arthrex). For intramedullary unicortical fixation, a 3.2-mm hole was drilled 50 mm distal from the entrance of the bicipital groove as previously described (Figure 3A).[3] A nonabsorbable high-strength suture loop (FiberLoop No. 2; Arthrex) was then placed in the MTJ with an initial locking stitch and a nonlocking whipstitch 20 mm proximally with a total of 8 throws. The free suture ends were manually pretensioned to seat the sutures, and both strands were passed through 1 button hole, then reshuttled through the opposite button hole in the reverse direction. The button was passed through the previously drilled hole in the anterior cortex of the humeral shaft according to the manufacturer's guide (Figure 3B). The button was released in an intramedullary manner and the shuttled strands were gently pulled, allowing the button to "flip" and be seated in contact with the anterior cortex of the humeral shaft (Figure 3C). The suture ends were pulled to tighten the biceps tendon against the bone. Subsequently, the shuttled strands were passed through the tendon and tied to each other by use of a knot pusher with an initial sliding Weston knot followed by 4 reverse half-hitches (Figure 3D).

All-Suture Anchor Fixation Technique

A modified all-suture anchor fixation technique was performed using a single-loaded all-suture soft anchor (1.8-mm FiberTak; Arthrex) with a braided high-strength suture (No. 2 FiberWire CL; Arthrex).[10] For unicortical fixation, a drill guide was placed 50 mm distal from the entrance of the bicipital groove and a 1.8-mm hole was drilled (Figure 4A). The all-suture anchor was inserted into the bone tunnel through the drill guide (Figure 4B) and seated by hand before it was impacted into its final position. The suture was then gently pulled to expand the anchor and seat it securely against the anterior cortex of the humeral shaft (Figure 4C). One suture limb was then used to make a locking Krackow stitch[11] about the proximal biceps tendon 20 mm distally and back, starting 10 mm proximal to the MTJ with 8 throws in total. After completion of the Krackow stitch, the suture was pretensioned manually to seat the sutures in the biceps tendon. The free suture limb was pulled to shuttle the biceps tendon to the bone and then was passed through the tendon. Both suture ends were tied by the use of a knot pusher with an initial sliding Weston knot followed by 4 reverse half-hitches (Figure 4D).

Biomechanical Testing

Following repair, the biceps tissue was secured by the use of a ribbed, custom soft tissue clamp to the actuator of the dynamic testing machine (ElectroPuls E10000; Instron Systems) 2 cm distal to the fixation site of the biceps tendon. The humerus was fixed to the base of the dynamic testing machine, allowing the biceps to be pulled vertically along the longitudinal axis of the humeral shaft. This was done to replicate anatomic force vectors on the biceps tendon. The setup for biomechanical testing is shown in Figure 5. The biceps tendon was initially cycled 500 times from 5 to 70 N at a frequency of 1.5 Hz.[3] The force on the tendon was then returned to 5 N and the tendon was pulled at a rate of 30 mm/min until ultimate failure of the construct. Displacement was determined by the displacement of the actuator, while force was recorded by the tensile testing machine's load cell (Dynacell Biaxial Dynamic Load Cell; maximum load capacity, ±10 kN; maximum torque capacity, ±100 N·m; manufacturer-reported accuracy, 0.5% of reading), throughout the testing. Ultimate load was defined as the highest load attained during testing. Stiffness was calculated by interpolating a line through the region of the force-displacement curve located between 30% and 70% of the yield load (yield load was defined as the first time the force dropped by over 5% of the ultimate load during testing). Following failure of the construct, failure mode was qualitatively reported.

Statistical Analysis

The statistical power of the analysis was calculated according to a prior study.[3] Paired t tests were used to assess the primary comparison of displacement during cyclic loading, ultimate load, and stiffness between the button and all-suture anchor fixation techniques. A Welch t test was used to compare the same measurements between failure mode. $P < .05$ was deemed statistically significant. The statistical software R version 3.5.0 was used for all plots and analyses (R Core Team, with additional package *ggplot2*).

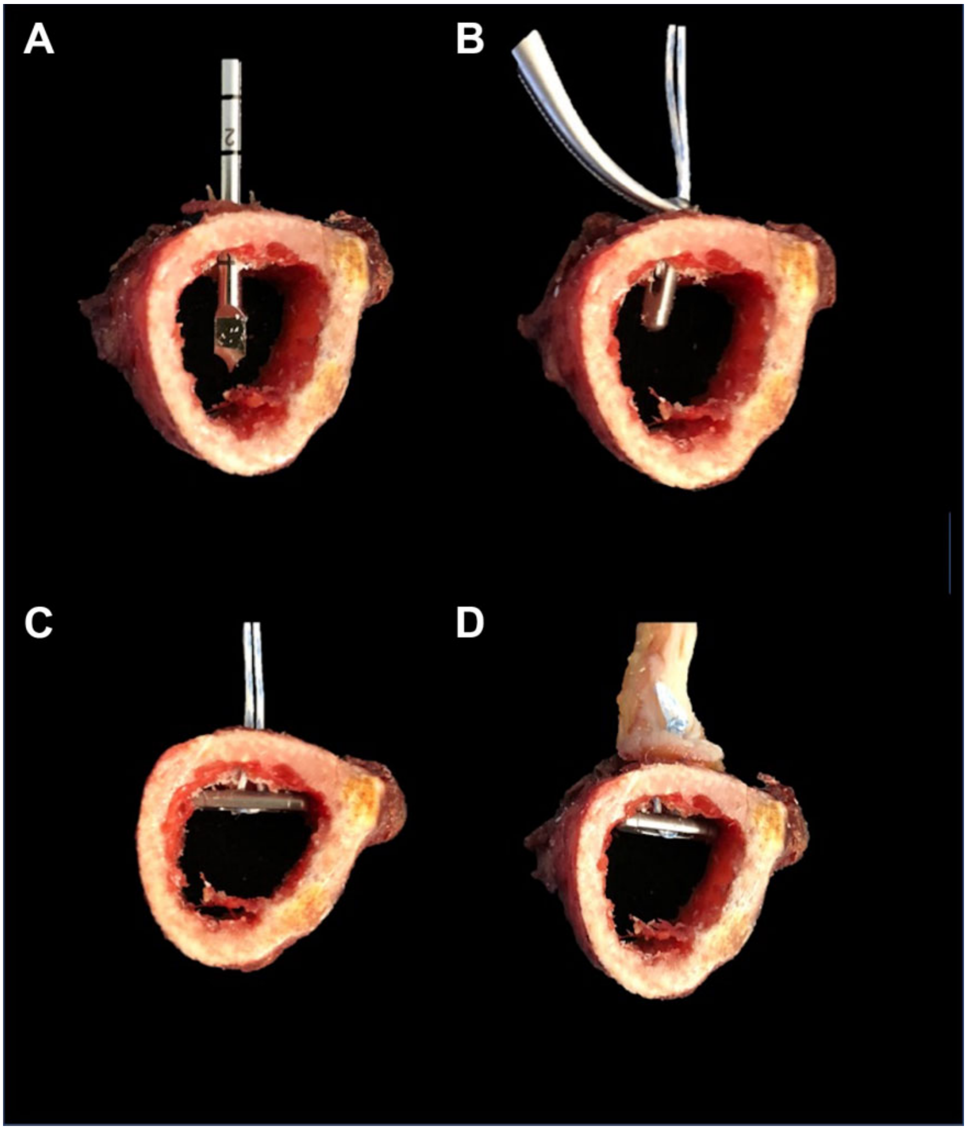

Figure 3. Unicortical button placement illustration: (A) unicortical 3.2-mm drilling of the anterior cortex of the humeral shaft; (B) insertion of the button; (C) one suture strand was gently pulled, allowing the button to "flip" and be seated to the anterior cortex; (D) final unicortical button fixation with biceps tendon.

RESULTS

Two specimens (1 from each group) were excluded for technical reasons (error in the load cell software, resulting in increased tension during cyclic loading) prior to testing. Data analysis was performed on the remaining 18 specimens. Two specimens in the cortical button group (suture pulled through tendon) and 1 specimen in the all-suture anchor group (knot failure) failed during cyclic loading prior to beginning the pull-to-failure portion of the test.

The mean displacement during cyclic loading was 29.2 ± 9.4 mm for the unicortical button fixation and 12.5 ± 2.5 mm for the all-suture anchor fixation. The all-suture anchor fixation had a significantly lower displacement when compared with the button fixation ($P = .005$).

The mean ultimate load for the unicortical button fixation was 125.4 ± 44.6 N and the mean stiffness was 48.6 ± 6.8 N/mm (Table 1 and Figure 6). The all-suture anchor fixation showed a mean load to failure of 170.4 ± 68.8 N and a mean stiffness of 59.3 ± 11.6 N/mm (Figure 6). The difference in ultimate load ($P = .074$) and stiffness ($P = .091$) for both fixation groups was not significant.

Failure Mode

In all unicortical button fixations, the construct failed on the tendon side with the suture cutting or tearing through the tendon (Figure 7). In 5 (55.6%) of the all-suture anchor fixation specimens, failure occurred by means of suture cutting or tearing through the tendon. In the remaining 4 (44.4%), knot failure was observed. No statistically

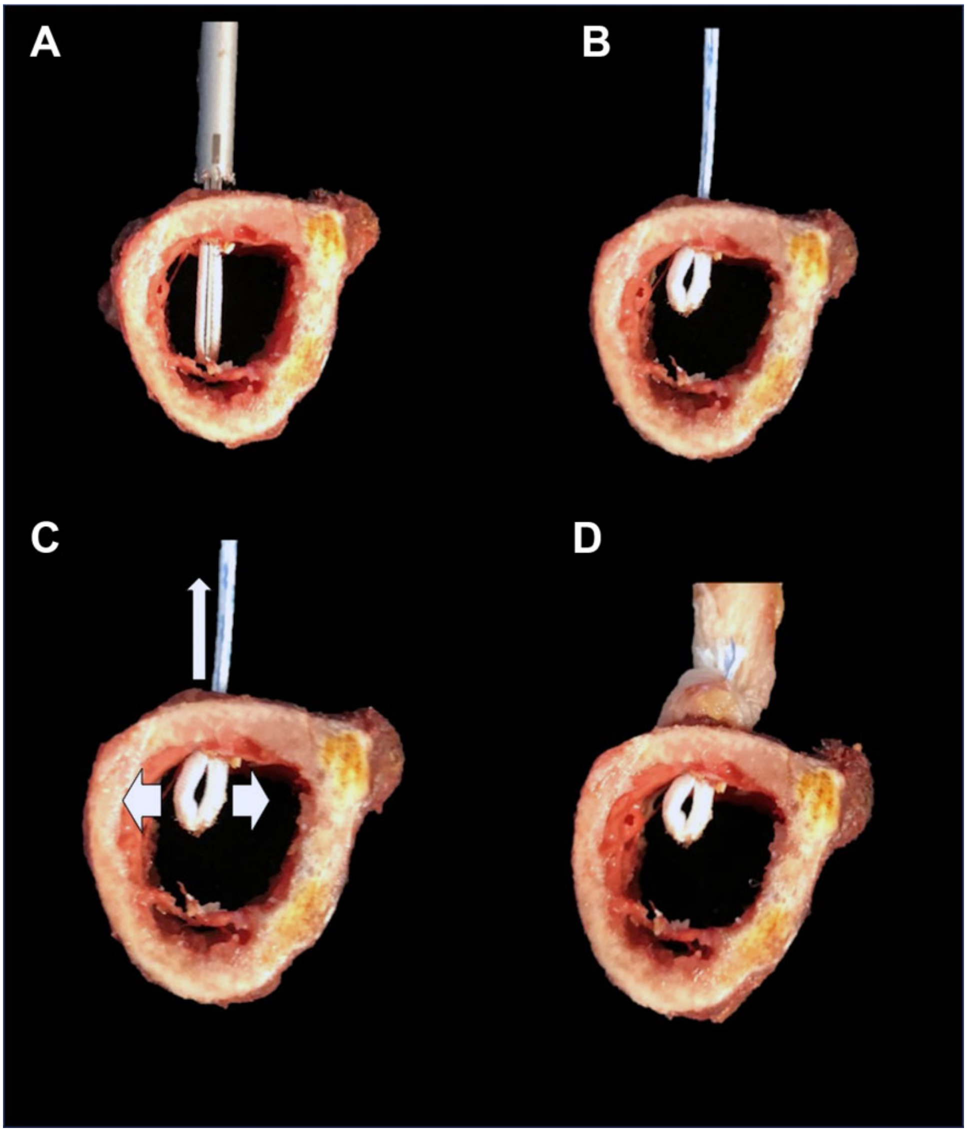

Figure 4. All-suture anchor placement illustration: (A) unicortical 1.8-mm drilling through the femoral shaft with a drill guide; (B) placed all-suture anchor; (C) gentle pulling of the suture ends to expand (arrows) and seat the all-suture anchor to the anterior cortex; (D) final all-suture anchor fixation with biceps tendon.

significant differences were seen in displacement (*P* = .285), ultimate load (*P* = .445), or stiffness (*P* = .699) between those specimens with all-suture anchor fixation that failed due to the knot versus those that failed due to tearing through the tendon. No failure of the bone (ie, fracture) or pullout of either the button or all-suture anchor occurred.

DISCUSSION

The most important finding of this study is that all-suture anchor fixation using a Krackow stitch for subpectoral biceps tenodesis provides ultimate load and stiffness similar to unicortical button fixation using a nonlocking whipstitch. The all-suture anchor fixation technique was shown to be superior in terms of displacement during cyclic loading when compared with the button fixation technique. When observing the failure mechanism, the unicortical button technique (without continuous locking stitches) showed an increased rate of suture cutting through the tendon, with significantly higher displacement (Figure 6) when compared with all-suture fixation technique (with continuous locking stitches). This finding supports the idea that stitch location and configuration is critical in subpectoral onlay biceps tenodesis, as the stitched tendon will not be pressed into the bone with an interference screw.[6,29]

There is no clear consensus on whether the bone tunnel or the cortical surface (onlay) healing confers better outcomes. In a rabbit model, Tan et al[30] compared tendon-to-bone healing for both the fixation techniques and found no significant difference between groups with respect to

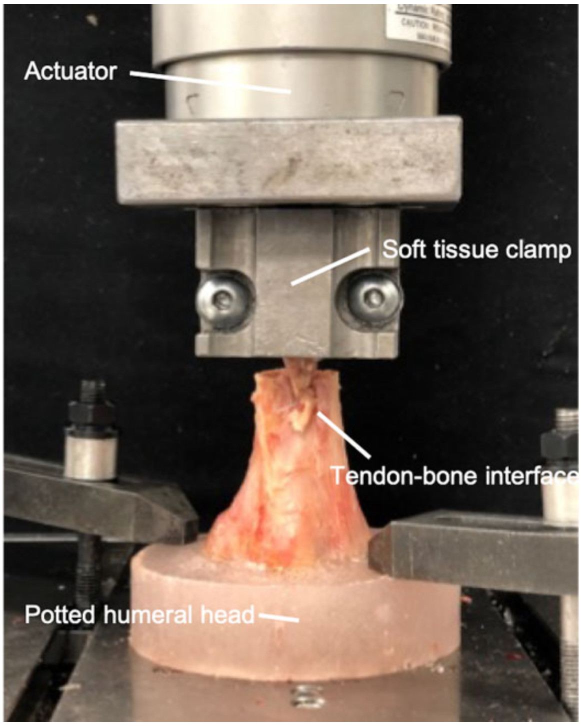

Figure 5. Setup for biomechanical testing.

TABLE 1
Summary of Biomechanical Strength for Both Fixation Groups[a]

Fixation Type	Cyclic Displacement (mm)	Stiffness (N/mm)	Ultimate Load (N)
Button	29.2 ± 9.4	48.6 ± 6.8	125.4 ± 44.6
All-suture anchor	12.5 ± 2.5	59.3 ± 11.6	170.4 ± 68.8

[a] Values are given as mean ± SD.

failure load, stiffness, and mean volume of newly formed bone. Histological analysis demonstrated direct tendon-to-bone healing on the outer cortical surface. In the intracortical fixation group, only 5% of the newly formed bone was located intramedullary, while 95% was present on the cortical surface.

Several cadaveric studies have reported on different supra- and subpectoral fixation techniques for biceps tenodesis, showing the interference screw to provide the strongest biomechanical stability.[14,18,20,23] However, complications have been reported, including implant failure, bioabsorbable screw reactions, and especially humeral fractures.[5,7,17,26] Sears et al[26] reported a case series of humeral fractures following subpectoral biceps tenodesis. They concluded that the potential stress riser effect created by the cortical defect, location, and depth of the drill hole may be reduced by limiting the size of the cortical defect. This stress riser effect and fracture risk may be increased especially in young overhead athletes with repetitive humeral torque.[24] Buchholz et al[3] introduced a bone-preserving onlay technique using unicortical button fixation for subpectoral biceps tenodesis. These authors showed that the unicortical button withstands similar loads when compared with the “gold standard” interference screw fixation, with ultimate loads of 218 ± 40 N and 212 ± 28 N for the button and screw, respectively.[3]

The present study used a similar testing protocol to compare the onlay unicortical button technique with an all-suture anchor onlay fixation technique for subpectoral biceps tenodesis. The all-suture technique requires only a 1.8-mm unicortical drill hole compared with 3.2 mm for the button technique. Results have confirmed the hypothesis that the all-suture anchor fixation is biomechanically similar to the button technique for subpectoral biceps tenodesis in terms of ultimate load, with means of 170.4 ± 68.8 N and 125.4 ± 44.6 N (ns) for the all-suture anchor and button fixations, respectively. Ultimate loads of both constructs exceeded 110 N, which is the force required to hold 1 kg at 90° of elbow flexion and has been proposed as a good estimate of force during daily activities.[3] Concerns exist of decreased construct stiffness due to the soft component of all-suture anchors; however, this study presented comparable results in terms of stiffness for all-suture anchor fixation (59.3 ± 11.6 N/mm) compared with titanium button fixation (48.6 ± 6.8 N/mm; ns).

While ultimate load and stiffness of both constructs are convincing, significantly higher displacement was observed during cyclic loading for unicortical button fixation at the MTJ (29.2 ± 9.4 mm) compared with the all-suture anchor fixation (12.5 ± 2.5 mm). However, there was no button failure observed at the humeral site, indicating that the tendon tissue and stitch configuration may be the limiting factors. While both techniques utilized 8 throws through the tendon, a locking Krackow stitch technique was used for tendon fixation of the all-suture anchor group, and a suture-loop system with only 1 locking stitch was used for the button group. We observed that, with the lack of a terminal locking stitch in the suture-loop system, the most proximal throws of the whipstitch pulled through the tendon and increased the overall displacement during cyclic testing. This phenomenon was not observed in the all-suture fixation group. Although the use of 2 different stitch techniques on the tendon may be construed as one of the study limitations, it reflects clinical reality. This study did not only compare 2 implants against each other, but 2 subpectoral biceps tenodesis techniques according to their daily clinical use. While Spiegl et al[29] emphasized the importance of suture location for proximal biceps tenodesis, biomechanical performance of stitch configurations and alternative sutures (ie, tape) should be addressed in future investigations of biceps tenodesis techniques.

The results of this study are in line with those of previously published studies. Arora et al[1] found ultimate loads of 174 ± 38 N with a stiffness of 73 ± 26 N/mm for unicortical button fixation, compared with 125.4 ± 44.6 N and 48.6 ± 6.8 N/mm in the present study. However, the displacement differed greatly: 9 mm in the Arora et al study compared with 29 mm in the present study. This disparity may be because Arora and colleagues used a locking suture-loop system, leading to a potentially stronger suture fixation

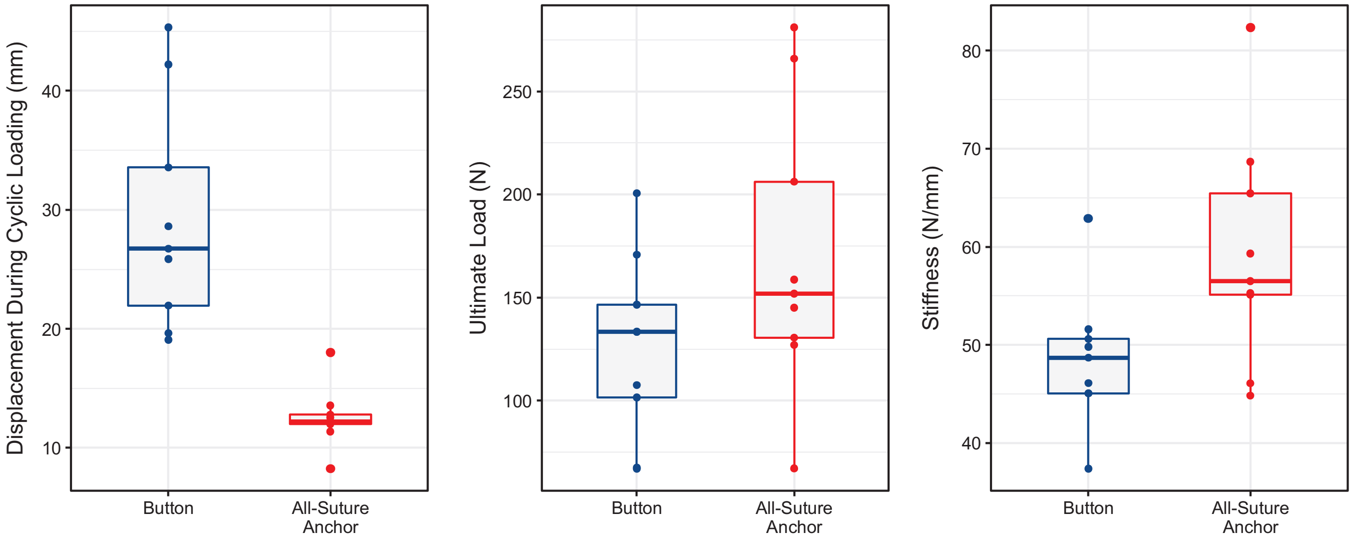

Figure 6. Boxplots comparing displacement during cyclic loading, ultimate load, and stiffness between groups, with the thick horizontal line representing the median and the box representing the interquartile range.

Figure 7. A right shoulder from the biceps button group during cyclic loading, showing large displacement after slipping and tearing of the suture through the tendon.

in the tendon tissue. Furthermore, Arora et al pretensioned the construct over a 2-minute period prior to measurement of cyclic displacement, which may have caused initial elongation to go undetected. The current study refrained from adding a preconditioning protocol, as there is no preconditioning in clinical practice. Sethi et al[27] biomechanically compared different interference screw fixations to unicortical button (with button placed at the posterior cortex) fixation for subpectoral biceps tenodesis. They found a mean ultimate load of 99 ± 17 N and a mean displacement of 15 ± 8 mm for the unicortical button group. The ultimate load was 43% lower than that observed by Arora et al, while the displacement was 40% greater. Similar to the current study, Sethi et al used a suture configuration without continuous locking stitches, resulting in uniform suture tearing through the tendon. These findings indicate that suture configuration may compromise the results of onlay subpectoral biceps tenodesis techniques.

To our knowledge, biomechanical performance of subpectoral biceps tenodesis onlay techniques using all-suture anchor fixation had not been evaluated prior to this study. Therefore, this study is the first to establish results comparing all-suture anchor fixation with an established onlay technique for subpectoral biceps tenodesis. The all-suture anchor onlay fixation technique proved to be biomechanically similar to the button technique in this cadaveric model.

Limitations

We acknowledge several limitations to this study. First, as mentioned previously, continuous locking stitches were not utilized in the unicortical button group, which may predispose the construct to greater displacement and decreased ultimate failure loads. However, the fixation technique used is consistent with the manufacturer's instructions[2] and reflects daily clinical practice. Second, as a time-zero cadaveric study, the evolution of biomechanical properties in vivo with potential healing of the tendon to the bone could not be studied. However, the results may provide an idea of the construct strength in the early postoperative phase when no advanced healing has occurred.

CONCLUSION

The all-suture anchor fixation using a Krackow stitch for subpectoral biceps tenodesis provides ultimate load and stiffness similar to unicortical button fixation using a nonlocking whipstitch. The all-suture anchor fixation technique was shown to be superior in terms of displacement during cyclic loading when compared with the unicortical button fixation technique. However, the results of this study help to show that the fixation method used on the humeral side is less implicative of the overall construct strength than the stitch location and technique, as the biceps tendon tissue and stitch configuration seem to be the limiting factors in subpectoral onlay tenodesis techniques.

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