Effect of Interference Screw Depth on Fixation Strength in Biceps Tenodesis

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Purpose: The purpose of this study was to assess the biomechanical performance of the long head of the biceps tenodesis with an interference screw with respect to screw depth. **Methods:** Twenty-one human cadaveric shoulders were randomized into 3 treatment groups (7 each): interference screw placed flush to the humeral cortex, 50% proud, or fully recessed. Bone density was determined, and subpectoral biceps tenodesis was performed with 8 × 12 mm Bio-Tenodesis screws (Arthrex, Naples, FL). Each construct was cyclically loaded from 5 to 70 N for 500 cycles at 1 Hz and then pulled to failure at 1 mm/s. Relative actuator displacement was calculated from cyclic testing. Maximum load, elongation, linear stiffness, and failure mode were recorded from pull-to-failure testing. Because of numerous failures during cyclic testing, the final load data from the fully recessed group were not statistically analyzed. The remaining groups were compared by use of a 2-tailed, Student unpaired *t* test and χ^2 analysis. **Results:** There was no significant difference in displacement among groups during cyclic testing. Five specimens in the recessed group failed during cyclic testing, whereas 2 specimens and 0 specimens failed in the proud and flush groups, respectively. The maximum loads sustained were 281.6 ± 77.8 N, 184.5 ± 56.3 N, and 209.1 ± 57.0 N for the flush group, 50% proud group, and recessed group (in those specimens surviving cyclical loading), respectively. **Conclusions:** Placement of a Bio-Tenodesis screw flush to the humeral cortex is preferred for maximum fixation strength in subpectoral biceps tenodesis. A screw placed to 50% depth may be effective in the laboratory setting, but recessed placement is more variable and requires additional fixation. The fully recessed group resulted in 5 of 7 failures during cyclical loading, with no specimens failing in the flush group. **Clinical Relevance:** This study shows the importance of determining the optimal depth of interference screw placement during biceps tenodesis to obtain optimal biomechanical performance and reduce the risk of fixation failure.

The function of the long head of the biceps tendon (LHBT) remains under intense debate.[1,2] It has been postulated as both a stabilizer within the glenohumeral joint and a vestigial structure assisting with proprioception.[3,4] Although the exact function of the LHBT remains unclear, it has long been recognized as a source of pain. Pathology of the LHBT has been associated with various shoulder pathologic conditions,[5] including arthritis, impingement syndrome, labral lesions,[6,7] and rotator cuff tears.[8-10] Examination of the proximal biceps during both open and arthroscopic surgery has provided significant information in the understanding of biceps pathology, which ranges from tendinitis to more complex pathologies such as instability and partial- or full-thickness tendon tears.

Biceps tenodesis has become a well recognized and effective treatment for pathology of the LHBT. Tenodesis screws have been introduced for secure fixation of the biceps tendon to the diaphyseal or metaphyseal area of the humerus.[11,12] However, because this procedure is often accomplished through a small incision without direct visualization of the screw-bone interface, precise screw depth placement can be

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problematic, often leaving the screw proud or even recessed beyond the near cortex of the humerus. To date, no study has determined the security of screw fixation in relation to overall screw depth relative to the humeral cortex.

The purpose of this study was to evaluate the biomechanical performance of LHBT tenodesis with interference screw fixation with respect to interference screw depth. Our hypothesis was that there is no difference in biomechanical strength and stiffness of a biceps tenodesis construct fixed with an interference screw regardless of the depth at which the screw is placed in relation to the anterior humeral cortex.

Methods

After we received approval by the Rush University Institutional Review Board, a total of 21 fresh-frozen human cadaveric shoulders were thawed at room temperature before dissection, repair, and testing. Each shoulder was dissected down to the glenohumeral joint, and any specimen noted to have biceps fraying or tears, fractures, or evidence of prior surgery was excluded. The LHBT was cut from its attachment to the superior labrum at the supraglenoid tubercle, and the proximal humerus was disarticulated from the glenoid. All soft tissue was removed from the humerus, leaving the proximal humerus, biceps tendon, and muscle as a free graft. Each specimen underwent computed tomography scanning (BrightSpeed; GE Medical Systems, Fairfield, CT) to calculate the bone mineral density (BMD). With the use of a Mimics 13.1 algorithm (Materialise, Leuven, Belgium), the BMD at the bicipital groove and at the proximal humerus was calculated. The specific locations (bicipital groove and proximal humerus) were marked digitally by a single fellow (K.C.M.) using our picture archiving and communication system. By use of the BMD values, the specimens were randomized and assigned to 1 of 3 test groups of similar mean BMD. The cortical thickness was also taken by use of Mimics at the approximate location of the repair.

An a priori power analysis based on our pilot data showed that 21 specimens (i.e., 7 per group) would provide 80% power to detect a significant difference in mean load to failure among the 3 groups with an effect size of 0.6 and significance level of $P < .05$. Therefore specimens were randomly divided into 3 groups with 7 specimens in each group as follows: screw placed flush to humeral cortex, 50% proud, and fully recessed (screw inserted 1 to 2 mm past the anterior humeral cortex).

All specimens were prepared by use of the same distal fixation surgical technique. This technique used a Bio-Tenodesis screw (Arthrex, Naples, FL) for fixation of the biceps tendon. The location of the interference screw for the distal fixation approach was 1 cm proximal to the inferior border of the pectoralis major tendon in the bicipital groove. A guidewire was placed through the anterior cortex and perpendicular to the surface of the bone, and an 8-mm reamer was used to create a 12-mm bone tunnel. A tap was then used to prepare the drill hole for interference screw insertion. One centimeter of the biceps tendon, beginning at the musculotendinous junction, was then whip-stitched with the use of a FiberLoop suture (Arthrex). The remainder of the biceps tendon was cut and discarded. The free suture limbs were then passed through the Bio-Tenodesis driver, and an 8 × 12 mm polyetheretherketone tenodesis screw was inserted by use of the driver until it was flush with the surrounding humeral cortex in 1 group. In the other groups the tendon and humerus were prepared in a similar fashion, but the tenodesis screw was placed either proud (only 50% of the screw length was inserted into the humerus) or recessed (the screw was inserted 1 to 2 mm past the anterior humeral cortex). A digital caliper was used to ensure standardization of the screw placement. The residual free ends of the suture were then tied with alternating half-hitch knots in all groups.

Biomechanical Testing

Each biceps tendon–proximal humerus repair construct was mounted in a materials testing system (MTS Insight 5; MTS Systems, Eden Prairie, MN) for biomechanical testing. A custom soft-tissue cryoclamp was used to secure the biceps muscle–tendon unit to the test actuator and inline 1,000-N load cell, and a custom-designed threaded jig was used to stabilize the humeral head to the platform of the MTS system.[13] The humerus and biceps tendon were aligned such that the tensile forces were applied parallel to the longitudinal axis of the humerus, thus approximating the in vivo biceps muscle–tendon force vector.

Dry ice was placed within the chutes of the cryoclamp (to freeze the grip on the tissue) just before testing to securely grasp the biceps muscle belly. The temperature of the tendon below the grip was monitored throughout testing to minimize potential thermal effects on tendon mechanical properties.[14] On the basis of previous studies,[13] each specimen was tested by use of the following parameters. The preload of 5 N was held for 2 minutes, followed by cyclic testing of 5 to 70 N at 1 Hz for 500 cycles. The construct then was loaded to failure at 1 mm/s. Load-to-failure testing was performed immediately after cyclical loading testing. The tendon was kept moist with room-temperature saline solution throughout testing.

Time, force, and actuator displacement were synchronously recorded at 48 Hz by use of the MTS software. For the cyclic test, displacement at the peak load of cycle 1 and cycle 500 was recorded. Cyclic displacement was calculated as the peak actuator displacement of cycle 500 relative to that of cycle 1. For

the pull-to-failure test, maximum load, displacement at maximum load, and stiffness were determined. Stiffness was calculated as the steepest slope spanning 30% of the data points from initial to maximum load during the failure test.[13] The timing (during cyclic or pull-to-failure testing) and mode of failure (screw, screw-tendon interface, or suture) were also recorded. Screw failure included breakage of the screw or the screw popping out, screw-tendon interface failure consisted of the screw tearing through the tendon, and suture failure included suture breakage or knot failure (resulting in failure of the repair).

Statistical analysis was performed with the GraphPad Prism 5 program (GraphPad Software, La Jolla, CA). A 2-tailed, Student unpaired *t* test was used to compare cyclic and failure data between the 2 remaining experimental groups. We used χ^2 analysis for the comparison of failure mode. Results were considered statistically significant at $P < .05$. Because specimens were distributed based on BMD in a randomized fashion, providing data in a normal distribution, parametric statistical analysis was deemed appropriate.

Results

There was no significant difference ($P = .12$) in cortical thickness of the specimens among the flush (4.0 ± 1.2 mm), 50% proud (4.6 ± 1.4 mm), and fully recessed (3.3 ± 0.6 mm) groups. There was no significant difference ($P = .80$) in BMD of the specimens among the flush (445.1 ± 35.5 Hounsfield units [HU]), 50% proud (452.2 ± 28.5 HU), and fully recessed (441.7 ± 25.3 HU) groups.

Cyclic Testing

The flush group had no failures during cyclic testing; however, there were 2 failures in the 50% proud group and 5 failures in the fully recessed group. In the 50% proud group, 1 specimen failed at the screw-tendon interface and the other failed at the screw-bone interface by screw pullout. In the fully recessed group, 2 specimens failed by suture failure and the other 3 failed at the suture-tendon junction. Among specimens that completed cyclic testing, there was no statistical difference in the crosshead displacement between the flush group (2.49 ± 1.65 mm) and 50% proud group (2.95 ± 2.07 mm). Because of the failures during cyclic testing in the fully recessed group (5 of 7), the load data for this group were not statistically analyzed. Statistical analysis of the timing of failure (during cyclical loading *v* during ultimate load-to-failure testing) showed significant differences among the 3 groups ($P < .0001$).

Failure Testing

Because of the failures during cyclic testing, only 14 specimens were tested during pull-to-failure testing (7 in the flush group, 5 in the 50% proud group, and 2 in the fully recessed group). There was no significant difference ($P = .122$) between the flush and 50% proud groups in the crosshead displacement at maximum load (10.08 ± 1.98 mm and 8.25 ± 3.57 mm, respectively). Maximum load showed a significant difference ($P = .025$) between the flush group (281.6 ± 77.8 N) and 50% proud group (175.2 ± 53.0 N). For stiffness, there was no significant difference ($P = .50$) between the flush group (59.0 ± 10.3 N/mm) and 50% proud group (54.5 ± 11.9 N/mm). The stiffness of the 2 remaining specimens in the fully recessed group was 85.0 ± 6.4 N/mm on average, but again, these data were not statistically analyzed because of the small sample size. All failures occurred at the screw-tendon interface (Table 1).

Discussion

Overall, this study was designed to provide important clinical information regarding the depth of interference screw placement relative to the humeral cortex during biceps tenodesis to obtain optimal biomechanical performance and reduce the risk of fixation failure. The primary finding of this study is that flush interference screw placement offers improved biomechanical performance compared with proud or recessed placement during LHBT tenodesis with interference screw fixation in a subpectoral location. In addition, the study shows that proud fixation does offer adequate load to failure similar to that reported previously for suture anchor constructs but is inferior to flush placement.[15-18] Finally, recessed placement should be avoided because most of the specimens in this study failed during cyclic loading with a recessed screw. Testing of more proximal tenodesis locations was not performed, and therefore no conclusion can be drawn in this regard.

Table 1. Data From Pull-to-Failure Test

	No. of Specimens Surviving Cyclical Loading	No. of Specimens Failing Cyclical Loading	Maximum Load (N)	Displacement (mm)	Stiffness (N/mm)
Flush (n = 7)	7	0	281.6 ± 77.8*	10.08 ± 1.98	59.0 ± 10.3
50% proud (n = 5)	5	2	175.2 ± 53.0*	8.25 ± 3.57	54.5 ± 11.9
Fully recessed (n = 2)†	2	5	238.8 ± 9.0	4.57 ± 0.13	85.0 ± 6.4

*Maximum load was significantly different between the flush and 50% proud groups.
†The fully recessed group was not statistically analyzed because of the small sample size (n = 2).

Interestingly, although cortical thickness was not statistically different among the 3 groups, the fully recessed group did have the smallest overall thickness. Nevertheless, given the very small differences among the groups, as well as the substantial number of specimens failing during cyclical loading in this group, we did not believe that the difference in cortical thickness was clinically significant.

Biceps tenodesis to the metadiaphyseal or proximal diaphyseal region of the humerus has become a well-accepted procedure for fixation of a biceps tenodesis.[10,19-26] The technique of subpectoral tenodesis allows a small cosmetic incision, an inter-nervous tissue plane, and fixation of the tendon at the musculotendinous junction, eliminating all potential diseased tendon. Multiple studies have focused on the biomechanical properties of various fixation devices such as bone tunnels, suture anchors, interference screws, keyholes, and ligament washers.[13,17,19-22,27] Although some variations exist, the literature suggests that interference screw fixation through a mini-open subpectoral approach is a safe, effective method for repairing cosmetics, form, and function and provides maximum fixation strength.[24,28,29]

Slabaugh et al.[13] studied the effect of interference screw length and diameter on the properties of biceps tenodesis in both proximal and distal positions. Interestingly, they showed no difference in the ultimate load to failure, displacement at peak loads, or stiffness of biceps tenodesis at either the proximal or distal position. Their recommendation was to use the smallest screw size available to minimize the risk of stress fracture at the tenodesis site. In their study all screws were placed flush to the surrounding cortex. Of note, their study used 15-mm-long screws whereas our study used 12-mm-long screws (from different manufacturers).

Although no prior studies have examined the effect of screw depth on fixation strength with biceps tenodesis, Phillips et al.[30] did report on the correlation of interference screw insertion torque with depth of placement in the tibial tunnel in anterior cruciate ligament reconstruction. In their biomechanical study, they examined the insertion torques of interference screw fixation of quadrupled hamstring tendon grafts at 3 depths in the tibial tunnel: the outer cortex, the articular surface, and a position between these 2 points. They found significantly lower insertional torque with the deeper screw placement, resulting in lower peak load or pullout strength.

To our knowledge, there have been no studies evaluating the biomechanical performance of interference screw fixation of subpectoral biceps tenodesis in relation to screw depth. Our study shows the importance of placing the tenodesis screw at the optimal level, flush to the humeral cortex, to maximize the fixation strength of this device. Although screw placement at 50% depth did result in a lower ultimate load to failure and greater elongation during cyclic loading, the maximum force sustained at construct failure compares favorably with previously published data on dual–suture anchor fixation.[17] The fully recessed group was much more variable, with 5 of the 7 constructs (71%) failing before completion of the cyclic loading.

Limitations

The limitations of this study are similar to those of most cadaveric biomechanical studies: The results are relevant to the immediate (time 0) post-repair period, in the absence of biologic healing of the tendon within the bone. Furthermore, in vivo biceps tendon forces are not known. As with prior studies from our institution, our biomechanical testing used 500 cycles between 5 and 70 N to replicate the theoretical forces on the biceps observed during the first 2 postoperative weeks when the patient is relatively immobilized.[31] In addition, we tested only 1 screw diameter, choosing an 8 × 12 mm screw. Previous work has shown no difference in biomechanical properties among different screw diameters for biceps tenodesis.[13] We standardized the screw for all groups by using only the 8-mm-diameter screw, and 12 mm was the length option offered by the manufacturer. We also standardized the tunnel size to avoid adding additional variables that may have confounded the results. This study analyzed only the subpectoral tenodesis location; testing of more proximal tenodesis locations was not performed, and therefore no conclusion can be drawn with regard to more proximal fixation. Finally, as noted in detail earlier, certain interesting outcomes, including the mode of failure during cyclical loading, as well as ultimate load to failure in the fully recessed group, were not statistically analyzed because of the small sample size. Because our power analysis intended to include 7 specimens per group, the sample size determined by the power analysis was not achieved, and there is a possibility of a type II error. Future study with a larger number of specimens may be helpful to better interpret these data.

Conclusions

Placement of a Bio-Tenodesis screw flush to the humeral cortex is preferred for maximum fixation strength in subpectoral biceps tenodesis. A screw placed to 50% depth may be effective in the laboratory setting, but recessed placement is more variable and requires additional fixation. The fully recessed group resulted in 5 of 7 failures during cyclical loading, with no specimens failing in the flush group.

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