

Biceps Tenodesis With Interference Screw Fixation: A Biomechanical Comparison of Screw Length and Diameter

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Purpose: To evaluate the effect of screw length and diameter on the mechanical properties of biceps tenodesis (BT) with an interference screw in 2 different locations (proximal and distal). **Methods:** We randomized 42 fresh-frozen human cadaveric shoulders (mean age, 65 ± 8 years) into 6 groups ($n = 7$): arthroscopic proximal BT using 7×15 -, 7×25 -, 8×15 -, or 8×25 -mm interference screws or distal subpectoral BT with 7×15 - or 8×15 -mm interference screws. Each repaired specimen was mounted onto a materials testing machine, preloaded to 5 N for 2 minutes, cycled from 5 to 70 N for 500 cycles (1 Hz), and loaded to failure (1 mm/s). Displacement during cyclical loading, pullout stiffness, and ultimate load to failure were computed, and the mechanism of failure was noted. **Results:** All failures occurred at the tendon-screw interface. There was no statistically significant difference in ultimate displacement among all groups in the ultimate load to failure, displacement at peak load, and stiffness. **Conclusions:** There is no difference in ultimate load to failure, displacement at peak load, and stiffness of BT with regard to screw length or diameter at both proximal and distal tenodesis locations. These data would support use of a smaller-diameter and shorter implant for BT both proximally and distally. **Clinical Relevance:** The results may serve as a guide to the orthopaedic surgeon performing proximal BT in selecting the appropriate interference screw. When possible, we recommend using the smallest screw size available to minimize risk of stress fracture at the tenodesis site.

Numerous surgical procedures have been suggested to address pathology associated with the long head of the biceps tendon. Techniques range

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The specimens and implants were provided by Smith & Nephew, Andover, Massachusetts. N.N.V. is a consultant and receives research support from Smith & Nephew. A.A.R. is a consultant and receives research support from Arthrex, Naples, Florida. The other authors report no conflict of interest.

The views expressed in this article are those of the authors and do not reflect the official policy or position of the United States Navy, Department of Defense, or the US Government.

Received October 16, 2009; accepted July 1, 2010.

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0749-8063/9617/\$36.00

doi:10.1016/j.arthro.2010.07.004

from simple debridement to tenotomy or tenodesis. Currently, there is no consensus as to whether tenotomy or tenodesis is most appropriate,¹ and biomechanical²⁻⁷ and clinical⁸⁻¹⁰ studies have shown both procedures to be effective. Tenodesis might be preferred over tenotomy for several reasons, including improved cosmetic appearance, maintenance of elbow flexion and supination strength, and maintenance of the biceps muscle length-tension relation, as described by Mazzocca et al.¹¹

Although several biomechanical studies have been published on different biceps tenodesis fixation techniques,^{3-7,11-13} there are no studies that specifically evaluate the fixation stability of biceps tenodesis either proximally or distally in relation to screw diameter or length. The purpose of this study was to analyze the biomechanical behavior of the bone-tendon-screw complex of polyetheretherketone (PEEK) interference screws of different size and length used for biceps tenodesis at both proximal and distal fixation sites. Our hypothesis was that longer screws in the proximal location may provide improved biomechanical performance. In addition, we

hypothesized that screw diameter would not affect overall fixation stability.

METHODS

A total of 60 fresh-frozen human cadaveric shoulders were thawed at room temperature before dissection, repair, and testing, from which 42 were ultimately chosen. Each shoulder was dissected down to the glenohumeral joint, and any specimen noted to have significant soft-tissue pathology, biceps fraying or tear, fractures, or evidence of prior surgery was excluded. We deemed 42 shoulders (22 left and 20 right shoulders, 16 male and 26 female cadavers), with a mean age of 65 ± 9 years, appropriate for inclusion in the study. The long head of the biceps tendon was cut from its attachment to the superior labrum at the supraglenoid tubercle, and the humerus was disarticulated from the glenoid. All soft tissue was removed from the humerus, leaving the proximal humerus, biceps tendon, and biceps muscle as a free graft.

Each specimen then underwent dual energy X-ray absorptiometry testing (Lunar, Madison, WI) to determine bone mineral density (BMD) at the bicipital groove and at the proximal humeral diaphysis (site of mini-open screw placement) such that specimens could be assigned to experimental groups of similar BMD (between groups, not within groups), thereby minimizing the potential influence of BMD on mechanical characteristics. The tendon width of each specimen was also measured with digital calipers (Dura-cal IP65; Brown & Sharpe, North Kingston, RI) (resolution, 0.01 mm). For those specimens receiving proximal tenodesis (arthroscopic), the tendon width was measured at the hiatus to the bicipital groove, at the approximate location of the tunnel-screw aperture site during tenodesis. For specimens undergoing distal (mini-open) fixation, the biceps tendon width was measured 2 cm proximal to the musculotendinous junction, again allowing for 1 cm of tendon to be inserted into the tenodesis socket.

An a priori power analysis¹⁴ based on our pilot data showed that 42 specimens (i.e., 7 per group) would provide 80% power to detect a significant difference in mean ultimate load to failure between the 6 groups with an effect size of 0.6 and significance level of $P = .05$. Therefore specimens were randomly divided into 6 groups of similar BMD between groups, with 7 specimens in each group as follows:

- Group 1: Proximal interference screw technique with 7×15 -mm screw

- Group 2: Proximal interference screw technique with 7×25 -mm screw
- Group 3: Proximal interference screw technique with 8×15 -mm screw
- Group 4: Proximal interference screw technique with 8×25 -mm screw
- Group 5: Distal interference screw technique with 7×15 -mm screw
- Group 6: Distal interference screw technique with 8×15 -mm screw

Surgical Technique for Groups 1 to 4: Proximal Fixation (Arthroscopic Approach)

All specimens in groups 1 to 4 were prepared by use of the same proximal fixation surgical technique, with the screw size differing depending on the group. This technique used a PEEK soft-tissue interference screw (Biceptor; Smith & Nephew, Andover, MA) for fixation of the biceps tendon. A guidewire was placed through the anterior cortex and perpendicular to the surface of the bone, 1 cm distal to the most proximal aspect of the bicipital groove (Fig 1). Then, a 7-mm

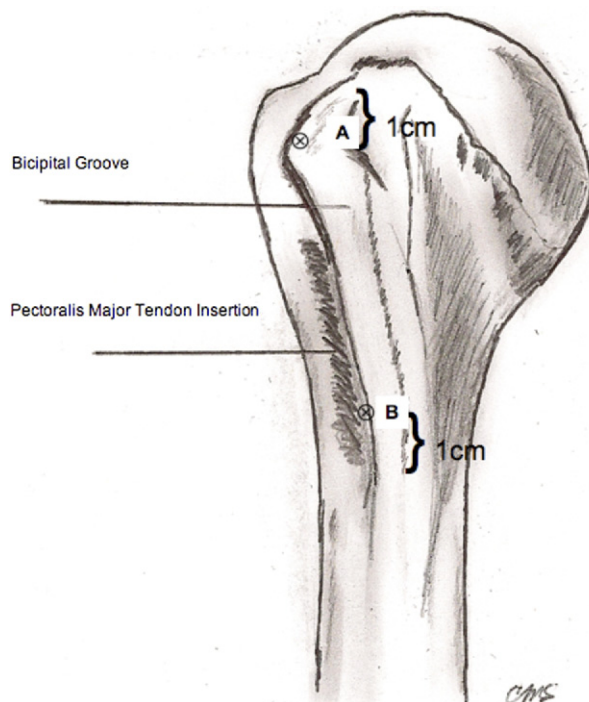


FIGURE 1. Proximal humerus with bicipital groove and insertion of pectoralis major tendon emphasized. The insertion of the proximal group of screws was 1 cm distal to the superior-most aspect of the bicipital groove (A). The insertion of the distal group of screws was 1 cm proximal to the inferior border of the pectoralis tendon in the bicipital groove (B).

reamer (groups 1 and 2) or 8-mm reamer (groups 3 and 4) was used to create a 25-mm bone tunnel (groups 2 and 4) or 15-mm bone tunnel (groups 1 and 3). A tap was then used to prepare the drill hole for interference screw insertion. Next, a tendon fork was used to capture the tendon over the prepared hole and drive it completely to the base of the hole. A 1.5-mm drill pin was then placed through the cannulated tendon fork. The PEEK interference screw (the size of which corresponded to the width of the drill hole) was then inserted by use of the driver until it was flush with the surrounding humeral cortex. If any proximal tendon remained, it was transected and removed.

Surgical Technique for Groups 5 and 6: Distal Fixation (Mini-Open Approach)

This technique used the same interference screw (Biceptor; Smith & Nephew) as groups 1 to 4. However, 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 (Fig 1). In contrast to the proximal fixation location for biceps tenodesis, the subpectoral location does not accommodate a 25-mm interference screw because of the limited width of the humeral medullary space. Therefore only the 15-mm interference screws were used in the distal fixation location. The technique for screw insertion was identical to the previously listed procedure, with the exception that 8-mm drill holes were used for both the 7×15 -mm and 8×15 -mm interference screws to accommodate the thicker distal biceps.

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 cryo-clamp 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. The humerus and biceps tendon were aligned such that the tensile forces throughout the protocol were applied parallel to the longitudinal axis of the humerus, thus approximating the *in vivo* biceps muscle/tendon force vector (Fig 2).

Dry ice was placed within the chutes of the cryo-clamp just before testing to securely grasp the biceps muscle belly. Then, using a previous study¹¹ as a model with the specific testing parameters modified



FIGURE 2. Setup of biomechanical testing of biceps tenodesis model (proximal group). The proximal humerus is inferior and the biceps tendon and muscle are superior, held by a clamp in the MTS machine. The MTS machine tested the biceps longitudinally in line with the normal pull of the biceps muscle.

based our own pilot data, we applied the following test parameters to each specimen: preload at 5 N (constant load) for 2 minutes, followed by cyclical loading for 500 cycles from 5 to 70 N (50% of the mean failure load for our pilot specimens) at 1 Hz, followed by a pull-to-failure test at 1 mm/s. The tendon graft was regularly moistened with a saline solution spray throughout testing.

By use of MTS TestWorks 4 software (MTS Systems) interfaced with the materials testing system, time, force, and actuator displacement data were continuously recorded throughout testing.

Cyclical displacement (i.e., gapping) was calculated as the peak actuator displacement of cycle 500 relative to that of cycle 1. Data computed from the failure test included ultimate load to failure, displacement (elongation) at peak (failure) load, displacement after cycle 500 (from the initial starting-position load after preconditioning to 5 N), and method/location of graft failure.

As previously described, the statistical power of the analysis was computed a priori from a pilot study of 4 unpaired shoulders. By use of an effect size of 0.6 and 80% power, the sample size needed is 7 specimens. For Cohen *d*, an effect size of 0.6 is considered a

medium effect. Power was calculated by use of G*Power 3 (Erdfelder, Faul, & Buchner, 1996, Düsseldorf, Germany).¹⁴

Statistical analysis was performed by use of GraphPad Prism 5 (GraphPad Software, La Jolla, CA). Univariate analysis of variance was used to compare the age, BMD, tendon width, cyclical testing, and failure data among the 6 experimental groups, followed by Tukey post hoc analysis for multiple comparisons between each of the groups, when appropriate. Results were considered statistically significant at $P < .05$.

RESULTS

Randomization into the 6 groups resulted in no statistical difference ($P = .97$ for proximal humerus and $P = .84$ for proximal diaphysis) in the BMD at either the proximal humerus ($0.50 \pm 0.14 \text{ g/cm}^2$) or proximal diaphysis ($0.55 \pm 0.15 \text{ g/cm}^2$).

There were 7 specimens that failed during the cyclical testing: 2 in the proximal 7×15 -mm group (cycles 120 and 410), 2 in the distal 8×15 -mm group (cycles 30 and 119), and 1 each in the proximal 8×15 -mm group (cycle 22), proximal 8×25 -mm group (cycle 497), and distal 7×15 -mm group (cycle 210). Each of these samples failed at the tendon-screw interface. Because these specimens failed during cyclical testing, data for ultimate load to failure, stiffness, and displacement could not be reported for these specimens.

The results of this study are summarized in Table 1. There was no statistically significant difference among any of the screw lengths, sizes, or sites of insertion in ultimate load to failure. In addition, stiffness and displacement at peak load were shown to have no significant differences among any of the groups. Displacement during cyclical loading was measured, and there was a statistically significant difference in the

displacement between the proximal 8×15 -mm group relative to that of the proximal 7×25 -mm group ($P = .008$), proximal 8×25 -mm group ($P = .002$), and distal 8×15 -mm group ($P = .004$). Displacement during cyclical loading showed no significant difference between the proximal 7×15 - and 7×25 -mm screws and the distal 2 screws ($P > .05$). All failures occurred at the tendon-screw interface. There were no humeral fractures or failures of the biceps tendon.

DISCUSSION

The principal findings of this study showed that there is no significant difference in ultimate load to failure, stiffness, and displacement at peak load with screws of different sizes and lengths inserted either proximally or distally. Even though there was 1 screw size (proximal 8×15 mm) that showed increased displacement with cyclical loading compared with longer screws (7×25 and 8×25 mm), we believe this is not clinically relevant, given the overall length of the tendon and the natural tendon excursion that occurs with flexion and extension.

The numerous techniques described for biceps tenodesis include both distal (open) and proximal (arthroscopic) approaches. Suture anchor fixation according to Gartsman and Hammerman¹⁵ is commonly used as an arthroscopic technique in the fixation of the biceps tendon. In addition, arthroscopic techniques for biceps tenodesis using interference screw fixation have also been described.^{4,7,8,11,16,17} Finally, interference screw fixation with a mini-open subpectoral approach is also widely utilized.^{4,10,11,18-22}

Despite differences in loading parameters, the available literature suggests superior properties for interference screw fixation^{3,4,7} relative to suture anchor fixation. To our knowledge, there are no studies eval-

TABLE 1. Results for All Testing Parameters

Repair Location	Screw Size (mm)	Age (yr)	BMD (g/cm ²)	Tendon Size (mm)	Peak Load (N)	Displacement at Peak Load (mm)	Stiffness (N/mm)
Proximal	7×15	66 ± 9	0.49 ± 0.11	5.66 ± 1.25	154.49 ± 26.4	7.1 ± 3.6	51.7 ± 8.1
Proximal	7×25	59 ± 8	0.52 ± 0.12	5.43 ± 1.23	143.83 ± 39.2	14.2 ± 17.4	55.5 ± 18.7
Proximal	8×15	67 ± 7	0.49 ± 0.18	5.79 ± 0.43	135.79 ± 25.2	13.7 ± 9.6	44.22 ± 10.7
Proximal	8×25	67 ± 10	0.51 ± 0.21	5.26 ± 0.41	176.76 ± 30.6	9.7 ± 4.8	54.3 ± 18.6
Distal	7×15	66 ± 11	0.55 ± 0.16	6.72 ± 1.11	181.55 ± 53.9	10.1 ± 13.2	66.0 ± 18.6
Distal	8×15	63 ± 8	0.54 ± 0.14	6.62 ± 1.09	165.59 ± 80.1	5.0 ± 3.8	71.6 ± 20.8
Mean		65 ± 9	0.52 ± 0.14	5.98 ± 1.17	158.68 ± 44.9	10.4 ± 10.3	56.9 ± 17.6

NOTE. The differences in all of the data, including screw size, age, BMD, tendon size, peak load, displacement, and stiffness, were nonsignificant ($P > .05$) among all groups.

uating the fixation of different interference screw sizes and lengths for biceps tenodesis. There are, however, several reports of fixation strengths of different constructs for biceps tenodesis using a cyclical loading protocol. Currently, different screw lengths have been advocated for proximal and distal tenodesis, with longer screws being used in a proximal location.

Mazzocca et al.⁵ describe 4 fixation techniques, 2 of which are similar to the proximal and distal fixation methods used in our study, with the exception that 1 single screw size was used in their study. As in our study, they found no significant difference between fixation methods with regard to ultimate pullout strength after cyclical loading between proximal and distal fixation sites. In addition, they did not find a difference in gap formation between interference screw fixation either proximally or distally. Their study only used an 8-mm screw diameter both proximally (8×23 mm) and distally (8×12 mm). This is in contrast to our study, where a screw with a shorter length (8×15 mm) had more gap formation than longer screws (8×25 and 7×25 mm). We postulate that the longer screws have more intraosseous tendon-screw interface, which may lead to decreased slippage with cyclical loading.

In a sheep model that simulated proximal tenodesis, Jayamoorthy et al.¹² found that there was a significant difference between biceps fixation using a keyhole technique compared with 7-mm interference screw fixation but not compared with an 8-mm screw. In our study there was a trend toward increased pullout strength with longer screw size with the 8-mm proximal tunnel, although this difference did not reach statistical significance. There was no difference in the 7-mm group regardless of screw length. We postulate that given no difference in tendon width between the 2 groups, the larger 8-mm tunnel may result in decreased load to failure associated with shorter screw lengths, which decrease the area of fixation. This hypothesis would be consistent with findings of interference screw fixation of soft-tissue grafts in the knee where fixation strength has been related to screw length.^{23,24}

Kusma et al.³ studied 5 different proximal tenodesis techniques in a porcine model. They compared suture anchor, bone tunnel, keyhole, interference screw, and ligament washer fixation after 200 cycles. Interference screw fixation was shown to be superior in both ultimate load to failure and gap formation compared with the other fixation methods. Their study reported a higher ultimate load to failure (398 N) for proximal screw fixation (8×23 mm) than our study (177 N).

However, this finding is most likely related to testing with a porcine bone substrate rather than human cadavers.²⁵ The authors did not provide the BMD of the porcine bone models used in this study, and thus it is difficult to compare the results from the human cadaveric bone models in our study with those in the study of Kusma et al. In addition, they only used 200 cycles before testing ultimate load to failure. They did report increased gap formation for their interference screw fixation group (4.28 mm) that was greater than our displacement of only 2.16 mm for the proximal 8×25 -mm screw, despite our specimens undergoing more cycles (500) compared with those in their study.

Limitations of this study include the use of older human cadavers with decreased BMD compared with the typical patient in whom biceps tenodesis would be performed. However, no significant differences in BMD were noted among the 6 groups, suggesting that this parameter did not confound the reported results. Furthermore, this was a time 0 study in a cadaveric model with simulated cyclical loading. This model cannot account for postoperative healing of the tenodesis site and the biological changes that occur over time. In addition, in vivo biceps tendon forces are not known. We chose 500 cycles and 70 N to replicate what would theoretically be seen in the first 2 postoperative weeks when patients are kept relatively immobilized to allow for tendon healing.²⁶ Finally, the large standard deviation associated with the peak load to failure was another limitation to this study, accounting for a wide range of failure values among the specimens. An additional limitation of this study is the unknown effect of the necessary larger hole needed to accommodate a larger screw. Theoretically, a larger screw hole could lead to a larger risk of postoperative fracture.

CONCLUSIONS

There is no difference in ultimate load to failure, displacement at peak load, and stiffness of biceps tenodesis with regard to screw length or diameter at both proximal and distal tenodesis locations. These data would support use of a smaller-diameter and shorter implant for biceps tenodesis both proximally and distally.

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