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A biomechanical comparison of two arthroscopic suture techniques in biceps tenodesis: whip-stitch vs. simple suture techniques

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Background: The aim of this study was to compare the biomechanical performance of whip-stitch (WS) and simple suture techniques (SST) of the long head of the biceps tendon in suprapectoral intraosseous tenodesis with interference screw fixation.
Methods: A total of 10 paired cadavers (61.1 ± 4.6 years) were randomized to receive WS or SST biceps tenodesis beginning at the musculotendinous junction. Both groups implemented a No. 2 FiberLoop wire and underwent suprapectoral fixation with a polyetheretherketone interference screw at the bicipital grove. A Materials Testing System performed cyclic testing (500 cycles), followed by load to failure at 1 mm/s. Load, displacement, and time were recorded during cyclic and failure testing. A 2-tailed Student's *t*-test and χ^2 analysis were performed for failure load and mode of failure, respectively.
Results: Two SST specimens and 1 WS specimen failed during cyclic loading via tendon rupture at the screw-tendon interface. There was no significant statistical difference in the cyclic displacement after 500 cycles between the WS (12.9 mm ± 4.4 mm) and SST groups (14.0 mm ± 3.8 mm, $P = .2$); cyclic strain, defined as the peak displacement at the 500th cycle divided by the initial gauge length, between the WS (0.4 ± 0.2) and SST groups (0.7 ± 0.7, $P = .3$); maximal load (162.7 N ± 56.8 N vs. 153.1 N ± 39.3 N, respectively, $P = .6$); and stiffness (50.5 N/mm ± 17.7 N/mm vs. 43.3 N/mm ± 10.9 N/mm, respectively, $P = .3$). All specimens ruptured at the screw-tendon interface.
Conclusion: The WS technique can provide equivalent biomechanical performance to the SST in suprapectoral intraosseous biceps tenodesis with interference screw fixation.
Level of evidence: Basic Science Study; Biomechanics
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Keywords: Whip-stitch; biceps tenodesis; arthroscopic; simple suture; long head of biceps; biomechanics

Rush University Medical Center Institutional Review Board provided an exempt status to this investigation due to its cadaveric nature.

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The biceps brachii muscle primarily functions in supination of the forearm and flexion at the elbow; however, the exact contribution of the long head of the biceps (LHB) at the shoulder remains controversial.[2] Despite the

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ambiguity regarding the role of the biceps muscle at the shoulder joint, the LHB tendon (LHBT) has been identified as a source of pain and is often a concomitant injury in a myriad of pathologies, such as labral injuries and rotator cuff tears.[3,4,6,12,15] Management of LHBT lesions typically involves biceps tenodesis. Although biceps tenotomy is an alternative treatment option that has shown to provide equivalent functional outcomes,[33] it is associated with a higher incidence of cosmetic defect.[25,27] Clinical outcomes after biceps tenodesis have been favorable regardless of location (suprapectoral or subpectoral), technique (open or arthroscopic), fixation (soft tissue-to-soft tissue or soft tissue-to-bone), type of osseous fixation (onlay vs. intraosseous),[8] or fixation device (interference screw or suture anchor).[1,7,11,19,20,31] To elucidate the optimal biceps tenodesis technique, previous investigations have examined the biomechanical behavior of biceps tenodesis with regard to fixation location,[16,32] suture technique,[10,14] type of fixation device,[13,18,26,28] depth of fixation screw,[24] and fracture risk after tenodesis.[17]

Werner et al[32] demonstrated that arthroscopic suprapectoral biceps tenodesis results in lower ultimate failure load than the open subpectoral biceps tenodesis. Despite the differences in strength of arthroscopic and open biceps tenodesis, both techniques provide adequate functional outcomes.[1] Thus, surgeons employ tenodesis techniques based on personal preference. In arthroscopic suprapectoral biceps tenodesis, options for the suture technique are limited due to spatial constraints within the joint. A simple suture technique has previously been used as it provides an adequate biomechanical profile while enabling the procedure to be performed entirely arthroscopically.[14] Although the Krackow suture technique demonstrates superior biomechanical properties, it cannot easily be performed arthroscopically.[10,14] Gigi et al[10] demonstrated that the triple-loop technique provided superior strength and integrity to the simple suture technique, while allowing the technique to be performed arthroscopically. The use of a whip-stitch locking suture mechanism has recently been implemented into arthroscopic suprapectoral biceps tenodesis; however, the biomechanical advantage of incorporating the whip-stitch suture with this technique has yet to be elucidated.

The purpose of this study was to compare the biomechanical performance of the whip-stitch and simple suture techniques used on suprapectoral biceps tenodesis with interference screw fixation. Although the whip-stitch technique provides additional points of fixation along the biceps tendon, we hypothesize that the simple suture technique is an appropriate alternative to provide equivalent strength and integrity in maintaining the bone-screw-tendon interface in suprapectoral intraosseous biceps tenodesis with interference screw fixation.

Methods

Ten paired human cadaveric shoulders were obtained. Cadaveric samples did not have a history of trauma or surgery to the shoulder joint, no history of cancer or related treatments, or chronic diseases that caused the patient to be bedridden. Before dissection, each sample underwent computer tomography scanning (BrightSpeed; GE Medical Systems, Fairfield, CT, USA) to calculate bone mineral density (BMD) and cortical thickness at the bicipital groove. Corresponding to the size of the bone socket used for tenodesis, a 7-mm region of interest was used to calculate BMD and cortical thickness along the midline of the bicipital groove with our institutions' PACS system (Konica Minolta Healthcare Systems, Wayne, NJ, USA). Ten matched pairs of fresh frozen human cadavers were thawed at room temperature before dissection, tenodesis repair, and mechanical testing. The cutaneous and subcutaneous tissues were removed to the level of the glenohumeral joint, and each specimen was then inspected for destruction of the LHBT or evidence of previous shoulder surgery. Any specimen that demonstrated evidence of previous shoulder surgery or pathology of the LHBT was removed from the study. The LHBT was cut from its attachment to the superior labrum and removed from the shoulder, keeping the proximal two-thirds of the LHB muscle belly attached. The total length of the tendon and the tendon width and thickness at the musculocutaneous junction were measured using an electronic caliper (Brown & Sharpe, Providence, RI, USA). All remaining tendons and ligaments were cut to allow for disarticulation of the proximal humerus from the glenohumeral joint.

Paired specimens underwent randomization to assign the stitching technique based on laterality. Fixation of the biceps tendon used a 6.25-mm polyetheretherketone interference screw (Arthrex, Naples, FL, USA). All tenodeses occurred in the bicipital groove and were performed by a sports-medicine fellowship-trained orthopedic surgeon (N.L.L.). A guidewire was placed perpendicular to the surface of the bone through the anterior cortex, and then a 6.5-mm reamer was used to create a 15-mm deep bone socket, followed by a 7-mm tap to prepare the drill hole for the interference screw. Beginning at the musculotendinous junction, 5 Krackow whip-stitches were placed in the LHBT using a No. 2 FiberLoop wire (Arthrex). The tendon remaining proximally was then cut and discarded. A second 2-0 FiberWire (Arthrex) was then placed just proximal from the free end of the tendon, which ensured that a part of the tissue could be advanced into the bone socket later. The tendon was then loaded onto the 6.25-mm polyetheretherketone interference screw (Arthrex). Both free limbs of the 2-0 FiberWire, and a single limb of the No. 2 FiberLoop were passed through the screw, thus creating a closed loop and locking the tendon to the tip of the screw. With the tip of the tendon positioned close to the screw tip, the complex was maneuvered to the bone socket. Care was taken to ensure that the tendon was completely inserted into the bone socket with the tenodesis screw, so that only the most distal whip-stitch could be visualized near the rim of the cortex (Fig. 1, *a*). The tails of the sutures were then tied using 5 alternating half hitches, and cut.[9] In the simple suture technique group, the humerus and bone socket were prepared in the same fashion. A single simple suture was placed at the musculotendinous junction of the LHBT using a No. 2 FiberLoop wire (Arthrex). Next, the screw-tendon complex was placed into

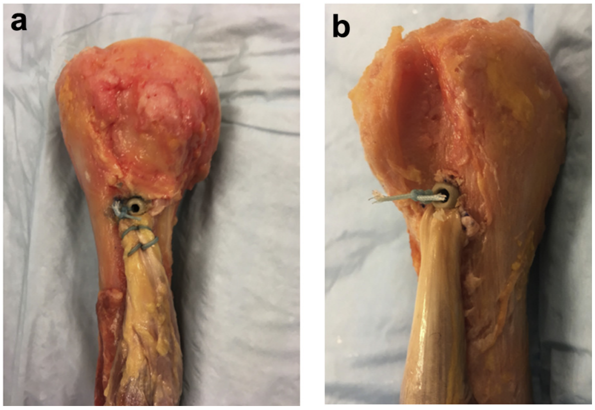

Figure 1 (**a**) Whip-stitch and (**b**) simple suture technique of the long head of the biceps tendon.

the bone socket, again ensuring complete insertion of the tendon (Fig. 1, *b*). After fixation, the length of the tendon from the fixation site to the musculocutaneous junction and the humeral diameter were measured with an electronic caliper (Brown & Sharpe).

Before mechanical testing, each humerus was cut 3 cm below the tenodesis fixation. Each biceps-humerus unit was then mounted on a Materials Testing System (Insight 5; MTS Systems, Eden Prairie, MN, USA) by attaching the humeral head to the base of the MTS machine using a custom-constructed fixation jig.[24] A custom cryoclamp was used to securely fasten the biceps muscle belly to the test actuator (Fig. 2). As dry ice was applied to the muscle belly, the tendon was warmed with saline to prevent the tendon from freezing. The actuator-tendon-bone unit was aligned such that the tensile force was near parallel to the shaft of the humeral bone, mirroring the muscle-tendon force vector of the biceps muscle (Fig. 3).

A preload of 5 N was applied to each specimen for 2 minutes, followed by cyclic testing of 5 to 70 N at 1 Hz for 500 cycles.[24,26] During cyclic and failure testing, force and actuator displacements were synchronously recorded as a function of time via the MTS software. Outcome measures from cyclic testing included cyclic displacement, which was calculated as the peak displacement at cycle 500 relative to the peak displacement after the first cycle, and cyclic strain, which was the cyclic strain

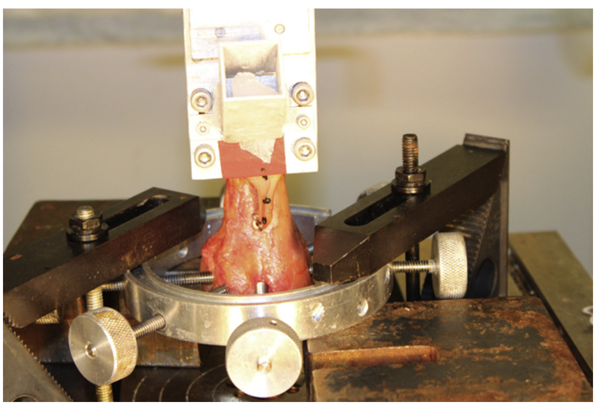

Figure 2 A dry-ice soft-tissue cryoclamp was used to grasp the muscle belly for biomechanical testing.

Figure 3 A custom fixation jig was used to secure the humeral head and a freeze clamp attached to the muscle belly allowed connection to the MTS testing apparatus.

divided by the initial gauge length. Displacement was calculated through the MTS machine. After cyclic testing, the specimen was allowed to rest for 5 minutes before maximum failure load testing as dry ice was applied to the cryoclamp to ensure that the muscle belly was frozen. The muscle-tendon-bone construct was loaded to failure at 1 mm/s. Outcome measures from the failure testing included maximum load, construct stiffness, and mode of failure (screw failure, suture pullout, or rupture of tendon). Screw failure was defined as screw breakage or the screw pulling-out from the fixation site, whereas suture pullout was defined as suture rupture or knot failure, and tendon rupture was defined as tendon shearing.

Statistical analysis

Based on the investigation by Gigi et al,[10] a power analysis was performed with maximal load to failure as the primary outcome. To achieve a clinically significant difference, a 25% increase in ultimate failure load was implemented into the power analysis.[14] To achieve a power of 80% at $\alpha = 0.05$, 10 paired cadavers were needed for this investigation. Power analysis was performed via R Studio software version 1.0.143 (R Foundation for Statistical Computing, Vienna, Austria). A 2-tailed paired Student's *t*-test was performed to compare the baseline characteristics of included specimens. Because of construct failures throughout testing, a nonpaired *t*-test was performed to compare cyclic displacement and maximum load between groups. χ^2 analysis was used to compare failure sites between the 2 comparator groups. Statistical analysis was performed using

Table I Data from cyclic loading and ultimate load to failure testing

	Number of specimens failed during cyclic testing	Displacement (mm)	Cyclic strain	Maximum load (N)	Stiffness (N/mm)
Whip-stitch	1	12.90 ± 4.42	0.43 ± 0.23	162.70 ± 56.83	50.50 ± 17.70
Simple suture technique	2	14.03 ± 3.84	0.65 ± 0.65	153.06 ± 39.34	43.26 ± 10.94

Microsoft Excel (Seattle, WA, USA). Results were considered statistically significant with $P < 05$.

Results

Ten paired fresh frozen specimens (total 20) were dissected and included in the investigation. The average age was 61.1 ± 4.6 years (range, 52-65 years), and the average cross-sectional area of the tendons in the whip-stitch group was 22.5 mm^2 ± 11.6 mm^2 and 29.7 mm^2 ± 14.4 mm^2 in the simple suture technique ($P = .05$). There was no statistical difference ($P = .1$) in cortical thickness of the specimens in the whip-stitch group (2.4 mm ± 0.5 mm) and simple suture technique (2.8 mm ± 0.4 mm). In addition, there was no statistical difference ($P = .8$) in BMD of the specimens within the whip-stitch group (1338.2 ± 312.1 Hounsfield units) or the simple suture technique (1366.6 ± 277.5 Hounsfield units).

Cyclic testing

During cyclic testing, there were 2 failures in the simple suture technique and 1 failure in the whip-stitch group, which occurred through tendon rupture at the screw-tendon interface. All failed specimens experienced tendon rupture at the screw-tendon interface. Among the specimens that completed cyclic testing, there was no statistical difference in the cyclic displacement between the whip-stitch group (12.9 mm ± 4.4 mm) and the simple suture technique (14.0 mm ± 3.8 mm) (Table I, $P = .18$). Cyclic strain, defined as the peak displacement at the final (500th) cycle divided by the initial gauge length, exhibited no statistical difference between the whip-stitch group (0.4 ± 0.2) and the simple suture technique (0.65 ± 0.65, $P = .3$). Lastly, there was no statistical difference in the timing of failure (during cyclic loading vs. maximum load testing) between both groups ($P = .53$).

Failure testing

Because of the failures during cyclic testing, 9 specimens in the whip-stitch group and 8 specimens in the simple suture technique were included for maximum load testing. The whip-stitch group exhibited a 6.2% increase in maximum load in comparison with the simple suture technique (162.7 N ± 56.8 N vs. 153.1 N ± 39.3 N, respectively, $P = .6$) (Table I). In addition, the whip-stitch group exhibited a 16.7% increase in stiffness in comparison with the simple suture technique (50.50 N/mm ± 17.70 N/mm vs. 43.26 N/mm ± 10.94 N/mm, respectively, $P = .33$). All specimens failed at the screw-tendon interface.

Discussion

In this investigation, the incorporation of the whip-stitch technique in suprapectoral biceps tenodesis with interference screw fixation resulted in a statistically equivalent biomechanical profile to the simple suture technique. The whip-stitch technique demonstrated a 6.2% increase in maximum load, a 16.7% increase in stiffness, and an 8.4% decrease in displacement of the overall construct after cyclic loading; however, none of these results were found to be statistically significant. In both suture techniques, all specimens failed because of tendon rupture at the screw-tendon interface. This finding is indicative that regardless of the suture technique implemented in suprapectoral biceps tenodesis, the junction between the tenodesis screw and the biceps tendon may prove to be the limiting factor in maintaining the integrity of the interference screw construct.

The construct of the biceps tenodesis is dependent on several factors such as technique, fixation location, anchor type, surrounding tissue involvement, and suture type.[30] Werner et al[32] illustrated that subpectoral biceps tenodesis provides superior maximum load and restores the length-tension relationship to a greater degree than suprapectoral biceps tenodesis. The difference in the biomechanical behavior of the tenodesis structures may be due to the location of the fixation site as the proximal suprapectoral technique is incorporated in weaker metaphyseal bone, whereas the distal subpectoral approach has more diaphyseal bone fixation. In addition, these findings may be attributed to the implementation of the whip-stich technique in the open biceps tenodesis group, but not in the arthroscopic group.

In performing biceps tenodesis, it is imperative to restore a normal length-tension relationship. Undertensioning the LHBT may result in discomfort, fatigue, cramping, and abnormal aesthetics with the development of a Popeye deformity.[29] Over-tensioning the LHBT increases the stress on the tenodesis construct;[32] however, over-tensioning the fixation construct results in fewer clinical manifestations, and is less of a concern.[29] Thus, it is imperative to maximize the biomechanical performance of each component of the tenodesis construct. Although various components of biceps tenodesis construct have been investigated, biomechanical assessment of suture techniques used in biceps tenodesis has been limited. The biomechanical behavior of the whip-stitch technique has previously been examined in a single investigation comparing its properties with the grasping suture modality in ovine flexor tendons. The maximum load of the whip-stitch technique was found to be significantly greater than the grasping suture modality.[5] This study concluded that the whip-stitch technique is a stronger option for fixation of tendon autograft compared with the needle-free suture grasping technique. However, this finding may not be applicable for all forms of tendon fixation as the use of an interference screw to compress the tendon may alter force distribution causing the whip-stitch and to add little mechanical advantage in comparison with other components of the fixation construct.

Although there was no significant difference in maximum load, the whip-stitch technique provides a sufficient amount of strength at time zero to maintain activities of daily living.[21] A load of approximately 112 N is required to maintain the weight of the arm at 90° of flexion while holding a 1 kg weight, whereas 75 N is exerted by the biceps to support the weight of the forearm against gravity.[13,23] After biceps tenodesis, the process of tendon-to-bone healing lasts 12 weeks, with the most significant improvement occurring within the first month.[22] Although no postoperative rehabilitation protocol has been established after biceps tenodesis, the current recommendation for rotator cuff tears is inclusive of biceps tendinopathy as patients are advised to be immobile for the first 6 weeks.[12,23] Both the whip-stitch and simple suture techniques provide sufficient strength to maintain the tenodesis construct in the immediate postoperative period. However, after tendon-to-bone healing, the whip-stitch technique potentially offers additional stability by providing additional points of fixation via its multiple passes through the tendon.

Previous studies found that compared with the simple suture technique, the triple loop suture and Krackow suture increased strength by 165% and 45%, respectively.[10,14] In the current investigation, the whip-stitch represented only a 6.2% increase in maximum load. Although the increase in maximum load is not on the same order of magnitude as previous investigations, this current study implemented interference screws in the tenodesis fixation, whereas Gigi et al[10] and Kaback et al[14] used knotless fixation implants. In addition to interference screw fixation at the screw-tendon interface, sutures from the tendon are tied around the interference screw, which provides further support to the construct. In addition, the amount of whip-stitched tendon that remains outside of the socket may impact biomechanical behavior as the suture may constrain the tendon until it fails. Increasing the amount of sutured tendon within the socket may reduce the risk of suture cutting into the tendon, thus maximizing the biomechanical efficacy of the tenodesis construct. Lastly, the cross-sectional area of the tendon with the simple suture technique cohort was nearly statistically greater ($P = .05$) than the whip-stitch cohort. A larger cross-sectional area allows for the exerted force to be distributed over a greater area, thus reducing the stress placed on the tendon and construct. Because failure was observed at the screw-tendon interface for all specimens, clear evaluation of the efficacy of suture techniques may be limited. The present study investigates the influence of the suture technique in biceps tenodesis with interference screw fixation. Future investigations are needed to assess the clinical outcomes of patients undergoing biceps tenodesis with various suture techniques.

Despite the results of this investigation, this study possesses limitations. Results from this cadaveric study must be interpreted with caution as results from ex vivo cadaveric studies may not reflect the in vivo system, particularly when considering the differences in quality of bone and soft tissue between cadaveric specimens and live patients. Particularly, in vivo systems allow for tendon-to-bone healing, which may improve the strength of the tenodesis construct. All cadaveric specimens represented an older population and may not be representative of findings in younger patients. Likewise, this biomechanical analysis does not account biological processes of tendon-bone healing, or the more dynamic biomechanical forces experienced by the biceps when other muscles are present and active. We also used a single screw size in all tenodesis constructs, 6.25 mm × 15 mm; however, previous investigations have shown no difference in the biomechanical properties of interference screws of various diameters.[26] Although an a priori power analysis demonstrated adequate power, there was a lack of statistical significance in this investigation. Thus, the results of this study may lack clinical utility.

Conclusion

The whip-stitch and simple suture technique can be performed in suprapectoral intraosseous biceps tenodesis with interference screw fixation and provides an equivalent biomechanical profile.

Disclaimer

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