Original Article

All Suture Biceps Tenodesis Has Greater Biomechanical Strength Than Metal Button Fixation

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Purpose: To evaluate the maximal load to failure, cyclic displacement, stiffness, and modes of failure of onlay subpectoral biceps tenodesis with an intramedullary unicortical metal button (MB) versus an inlay, all-suture Caspari-Weber (CW) technique. **Methods:** Sixteen matched paired human cadaveric proximal humeri were randomly allocated for subpectoral BT with either CW or MB using a high-strength suture (N = 16; 8 male, 8 female, mean age = 82.5 years, range 62-99 years). Specimens were tested on a servohydraulic mechanical testing apparatus under cyclic load for 1,000 cycles and then loaded to failure. Maximal load to failure, displacement, construct stiffness, and mode of failure were compared. **Results:** There was no significant difference between groups when comparing construct stiffness, creep displacement, or displacement at ultimate load. The maximal load to failure for the CW technique was greater than the unicortical MB (588.36 ± 149.06 N vs 375.83 ± 131.4 N, $P = .014$). **Conclusions:** In this study, the all-suture CW biceps tenodesis technique had a greater maximal load to failure than the onlay unicortical MB technique while having similar construct displacement and stiffness. The CW subpectoral biceps tenodesis may offer a lower cost alternative with a mechanically robust fixation when performing an open subpectoral biceps tenodesis. **Clinical Relevance:** This cadaveric biomechanical study can help guide surgeons when selecting a fixation technique for biceps tenodesis.

The long head of the biceps brachii (LHB) is a common source of shoulder pain with surgical treatment options including both LHB tenotomy and tenodesis. LHB tenodesis reduces the risk of cosmetic deformity and cramping seen in tenotomy and preserves the length-tension relationship of the LHB.[1,2]

There are numerous arthroscopic and open techniques described for LHB tenodesis. Compared with open techniques, higher reoperation rates have been reported for arthroscopic LHB tenodesis.[1,3] Techniques for subpectoral biceps tenodesis include both onlay and inlay fixation options. Compared with onlay techniques, inlay techniques have evidence of increased pain, adverse reaction to the implant, and risk of humerus fracture.[4,5] Options for onlay fixation include suture anchor, metal button (MB), or all-suture button.[5,6] Differences in these techniques include fixation device composition, the size of the drill hole needed to introduce the device, and implant cost. All-suture devices are attractive alternatives because they require a smaller diameter drill hole for insertion and lack metal artifact on postoperative imaging.[5-7]

The Caspari-Weber (CW) technique is an open subpectoral inlay biceps tenodesis method using bone tunnels without an implant. It is a modification of the keyhole technique described in 1975.[7,8] This technique involves passing the tenotomized biceps tendon through a drill hole in the humerus and tying it over itself or over a bone bridge through a second distal drill hole. The CW technique, if biomechanically equivalent to modern onlay constructs, represents a potential

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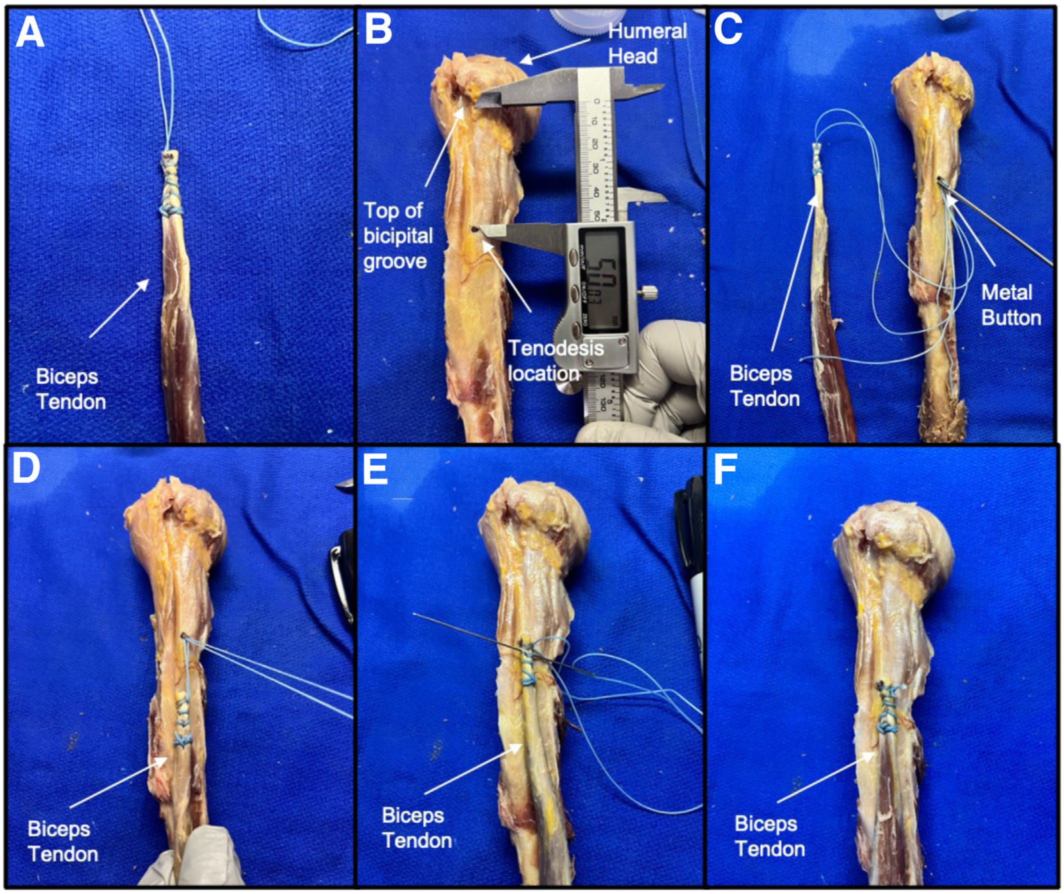

Fig 1. The metal button technique performed on a cadaveric right humerus specimen. (A) The biceps tendon is whip stitched with a No. 2 braided suture. (B) A drill hole is made 50 mm distal from the top of the bicipital groove. (C) Sutures securing the biceps tendon are placed into the metal button, which is inserted into the drill hole. (D) The biceps tendon is reduced to the drill hole by tensioning the sutures. (E) One limb of the suture is passed back through the tendon. (F) The tenodesis construct is secured with surgical knots.

cost-saving alternative that avoids reliance on implants.

The purpose of this study was to evaluate the maximal load to failure, cyclic displacement, stiffness, and modes of failure of onlay subpectoral biceps tenodesis with an intramedullary unicortical MB versus an inlay, all-suture CW technique. We hypothesized that both techniques would perform similarly in regard to ultimate load to failure, displacement, and stiffness.

Methods

Eight matched pairs of fresh-frozen cadaveric proximal arms (N = 16; 8 male, 8 female, mean age = 82.5, range 62-99 years) were procured and stored at −20°C. Within each matched pair, humeri were randomly assigned to onlay subpectoral biceps tenodesis using an intramedullary unicortical metal suspensory button (BicepsButton; Arthrex, Naples, FL; Fig 1A) or inlay tenodesis with the all-suture CW technique (Fig 1B). Bone mineral density (BMD) of each specimen was measured at the surgical neck via dual-energy X-ray absorptiometry (Discovery-A System; Hologic, Mississauga, Canada).

Specimens were thawed 12 hours before being dissected free of all soft tissue except for the biceps tendon. The biceps tendon was freed completely from the bicipital groove and wrapped in normal saline solution—soaked gauze and refrigerated before fixation. The bones were transected 14 cm proximal to the elbow joint. Specimens were then marked 50 mm below the palpable entrance of the bicipital groove, approximately at the midpoint of the pectoralis major tendon insertion, to mark the tenodesis point. This study was conducted after approval by our institutional review board.

Experimental Design

For the MB group, the tendon was secured using a single high tensile-strength suture (No. 2 FiberLoop; Arthrex) in a whip stitch running 5 passes over 2 cm proximal to the myotendinous junction. A unicortical

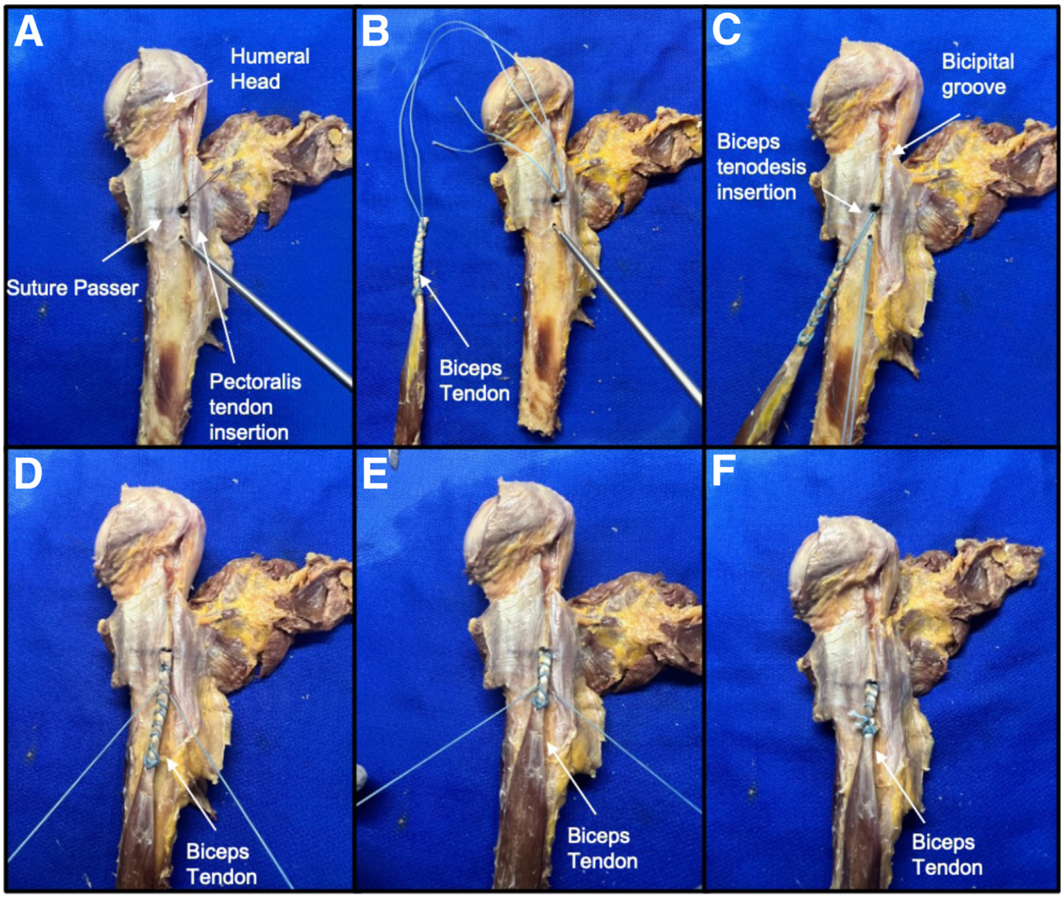

Fig 2. The Caspari-Weber technique performed on a cadaveric left humerus specimen. (A) The suture passer is placed through the distal drill hole and passed through the proximal hole, which has already been reamed to the appropriate size for the tendon. (B) Sutures securing the biceps tendon are placed in the suture passer. (C) Sutures are passed through the proximal and distal drill holes. The biceps tendon is introduced into the proximal hole (D) and then tensioned appropriately (E), and the tenodesis construct is secured with surgical knots (F).

drill hole was created at the marked location 50 mm distal to the bicipital groove with a reusable 3.2-mm drill pin. The suture was then loaded onto the suture button with one end threaded in one direction and then the other in the opposite direction. The button was inserted and one strand of the suture was used to tension the tendon to the bone, passed through the tendon, and then tied with 6 surgical knots positioned on top of the tendon (Fig 1).

For the CW repair, the tendon was whip stitched with the same No. 2 suture at the myotendinous junction and extending for a distance of 35 mm to the truncated tendon end. A guide pin was inserted 50 mm distal to the bicipital groove, and a reusable reamer up to 0.5 mm larger than the tendon diameter was used to create a unicortical socket. A second drill hole was then made 25 mm distal to the socket using a reusable 2.4-mm drill bit. A suture passing device was inserted in the distal hole and exited the proximal socket to retrieve the free suture ends from the tendon and pass the suture-tendon construct from proximal to distal through the bone tunnels. The sutures were tensioned until 25 mm of tendon was delivered into the bone, and the exiting suture limbs were tied over the biceps tendon to secure the construct (Fig 2).

Biomechanical Testing

The biomechanical testing protocol was modeled after previously published studies.[5-7,10] Repaired specimens were tested using a servohydraulic mechanical testing system (MTS 858 Mini Bionix II; MTS Systems Corp., Eden Prairie, MN). The humeral head was secured into a custom mounting jig with pins in line with the actuator. The biceps tendon was secured to the actuator and load cell through a custom sinusoidal clamp attached to the biceps tendon at the musculotendinous junction and in line with the actuator (Fig 3). A pin was inserted into the humerus just proximal to the repair site, and a

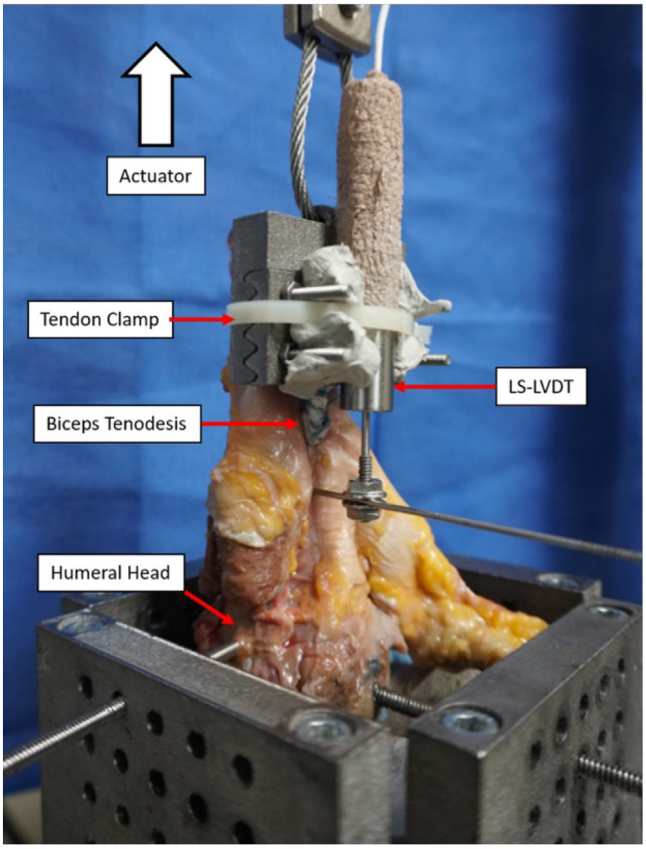

Fig 3. Proximal humerus specimen mounted to the servo-hydraulic testing system. The long head of the biceps underwent tenodesis 50 mm distal to the bicipital groove, and the distal end was affixed to the load cell and actuator via a custom sinusoidal tendon clamp. The long-stroke-linear variable differential transformer (LS-LVDT) sensor pin was attached to a bone pin placed just proximal to the tenodesis site, and the sensor body was secured to the tendon clamp using putty and a zip tie.

long-stroke linear variable differential transformer (LS-LVDT; LORD, Microstrain Sensing Systems, Cary, NC) was attached to the pin. Once mounted, the biceps tendon was preloaded to 5 N over 2 minutes, and the repairs were inspected to ensure that there was no premature failure.

Once the sensors and load were properly configured, the specimen was cycled from 5 to 70 N at 1 Hz for 1,000 cycles. After cyclic loading was completed, specimens were loaded to failure at a constant distraction rate of 1 mm/s until the construct failed. A specimen was deemed failed when the force across the construct dropped to 25% of the peak force achieved during testing. Force and displacement were continuously measured (102 Hz) by the MTS actuator and in-line load cell (Model 1500; Interface, Inc., Scottsdale, AZ) in addition to the long-stroke linear variable differential transformer throughout the cyclic loading and loading to failure testing procedures. All testing was conducted at room temperature, and the biceps tendon was periodically sprayed with 1% phosphate-buffered saline spray to maintain hydration.

Table 1. Modes of Failure for Each Specimen

Mode of Failure	Metal Button	Caspari Weber
Failure at button interface	4 (50%)	N/A
Suture cut out at tendon-suture interface	3 (37.5%)	3 (37.5%)
Tendon pulled through cortical hole	N/A	1 (12.5%)
Failure distal to tenodesis	1 (12.5%)	4 (50%)

Data Analysis

A power analysis was performed applying methods from previous studies. For load to failure, we applied a standard deviation (SD) of 64 N from a prior study with similar design.[9] A sample size of 8 per group will detect a 100 N difference in load to failure at 80% power with an alpha of 0.05. Force and displacement data were low-pass filtered at 6 Hz using a second-order zero-lag Butterworth filter with custom MATLAB scripts (version R2023a; MathWorks Inc., Natick, MA). Creep displacement during cyclic loading was calculated as the difference in displacement of the tendon at the initial 70 N load versus the 70 N load at cycle 1,000. After each specimen was loaded to failure, maximum load during failure, maximum displacement at failure, and mode of failure were recorded. Tendon stiffness was calculated based on the slope of the linear region of the load-displacement data from load-to-failure testing. Descriptive statistics (mean ± standard deviation) were calculated for creep displacement after 1,000 cycles, yield point displacement, maximum load to failure, and stiffness. A preliminary Shapiro-Wilk normality test demonstrated normally distributed data for parametric statistical analysis. Paired sample *t* tests were computed within matched samples to determine any statistical differences between the 2 surgical methods. Values less than the 25th percentile value minus 1.5 times the interquartile range (IQR; Q1 − 1.5 * IQR) or greater than the 75th percentile value plus 1.5 times the IQR [Q3 + 1.5 IQR] were identified as outliers for exclusion. An a priori significance of $P = .05$ was used.

Results

The mode of failure for each specimen is provided in Table 1. The most common method of failure for specimens with MB fixation was a failure at the interface with the button (4 of 8 specimens). The remaining specimens failed from suture cut out at the tendon suture interface (3 specimens) or tendon failure (1 specimen). For the CW fixation method, failure occurred most commonly through failure of the tendon distal to the tenodesis (4 of 8 specimens), with other failures occurring at the suture tendon interface (3

Table 2. Mean (Standard Deviation) and Resultant Statistical Analysis for Calculated Biomechanical Variables

	Caspari-Weber (n = 8)	Metal Button (n = 8)	*P*
Creep displacement (mm)	1.23 (0.29)	1.39 (0.47)	.673
Maximum failure load (N)	588.36 (149.06)	375.83 (131.40)	.014*
Maximum displacement at failure (mm)	11.62 (6.53)	10.33 (2.06)	.771
Stiffness (N/mm)	76.59 (28.77)	58.08 (23.81)	.323

*Statistically significant ($P < .05$).

specimens) and 1 failure from the tendon pulling through the bone. The mean BMD was 0.541 g/cm^3, with no significant difference between groups (MB 0.538 g/cm^3 vs ASB 0.544 g/cm^3, $P = .895$).

Descriptive Statistics

The resultant means and standard deviations for biomechanical variables of both surgical groups are displayed in Table 2. There was no significant difference between groups when comparing construct stiffness, creep displacement, or maximum displacement at failure. The maximum failure load for the CW technique was significantly larger than for the MB (588.36 ± 149.06 N vs 375.83 ± 131.4 N, $P = .014$).

Discussion

The most important finding of this study was that the inlay CW technique demonstrated a greater maximal load to failure than the onlay MB technique. The remainder of the mechanical properties are similar, which suggests that CW and MB are both viable techniques. Greater maximal load to failure for CW over MB suggests that CW may have an advantage in resistance to failure when significant loads are placed on the repair during the initial postoperative period.

Although the literature contains several comparisons of various techniques and implants for biceps tenodesis, there remains debate over the optimal implant for tendon fixation.[2,5,6,10,11] The MB technique remains popular, and several studies support its biomechanical strength as being similar to other options such as an all suture implant.[5,10,12,13] However, these contemporary techniques all share the same drawbacks inherent to using an implant to secure the biceps tendon. With rising surgical costs and increasing concerns of value-based care, the advantage of an implantless technique that removes the cost of an implant should be considered.[14,15] The MB technique also has the associated risk of metal artifact on magnetic resonance imaging, which may be obtained during future shoulder evaluation.

Previous biomechanical studies have compared the CW technique with other options for biceps tenodesis.[7,16] Sampatacos et al.[7] compared a novel suprapectoral intraosseous biceps tenodesis using an MB to the CW technique and found their novel technique to be biomechanically inferior with the cortical button pulling distally and suture cutting through cortical bone. Sampatacos et al.[16] also investigated an arthroscopic variation of the CW technique and compared it with an interference screw technique and found a 2.5 times greater load to failure for the CW compared with the screw. This is similar to our data showing the greater load to failure for the CW than the MB and suggests that the CW may be superior to both under high loads.

With regard to the cost of a biceps tenodesis procedure, the literature has some examples regarding implant choice. One study reported that the average cost of a biceps tenodesis was $4,209 in 2011, and a 2014 study reported open biceps tenodesis costs averaging $21,013.[17,18] Although there is clear variability in the cost of biceps tenodesis, these figures represent a cost-per-episode, which includes more variables than the implant. The cost of an MB will vary by institution, with a search returning costs ranging from $500 to $675 per kit. In light of continually rising costs of surgery, a technique with similar biomechanical properties but decreased overall cost such as the CW may provide an attractive alternative, improving value delivery to patients undergoing this procedure.

Additionally, although most biomechanical properties were similar between the MB and CW techniques, the CW technique had a greater maximal load to failure, with a difference of 212.53 N. For reference, 100 N is approximately the force at the biceps tendon generated by a hand holding a 1 kg load.[19] The literature shows that failures in biceps tenodesis is often caused by fixation failure, suggesting that increased load placed on the repair will increase failure risk.[20-22] If a greater maximal load to failure can be achieved with the CW technique, this suggests that it may be superior in rehabilitation protocols where an early load is placed on the repair. In a population where early return to activity is likely, such as athletes or military service members, there may be a benefit to choosing CW over other fixation methods.

Limitations

This study is limited by its nature as a biomechanical study, and thus the evaluation of fixation is done at time zero. The results do not take into account any in vivo tendon healing that may occur. This study demonstrates a superiority for CW in load to failure at time zero, where the construct is particularly vulnerable to failure. However, there may be differences in healing rates in the 2 techniques. Additionally, this is a cadaveric study on specimens with a mean age of 82.5 years and an average BMD of 0.541 g/cm^3. The specimens are older and likely have lower bone density than the patient population that is generally treated with a biceps tenodesis.

Conclusions

In this study, the all-suture CW biceps tenodesis technique had a greater maximal load to failure than the onlay unicortical MB technique while having similar construct displacement and stiffness. The CW subpectoral biceps tenodesis may offer a lower cost alternative with a mechanically robust fixation when performing an open subpectoral biceps tenodesis.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: M.A.D. serves on the editorial board of *Arthroscopy*. C.J.T. is a podcast editor for *Arthroscopy* and a committee member of the American Academy of Orthopaedic Surgeons, American Orthopaedic Society for Sports Medicine, AANA, and Society of Military Orthopaedic Surgeons. All other authors (M.J.K., J.D.T., S.D.V., D.F.C., T.P.M., P.K.M., M.D.H.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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