Partial Distal Biceps Avulsion Results in a Significant Loss of Supination Force

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Background: Partial avulsions of the short and/or long head of the distal biceps tendon cause pain and loss of strength. The goal of the present study was to quantify the loss of supination and flexion strength following a series of surgical releases designed to simulate partial and complete short and long head traumatic avulsions.

Methods: Mechanical testing was performed to measure supination moment arms and flexion force efficiency on 18 adult fresh-frozen specimens in pronation, neutral, and supination. The distal biceps footprint length was divided into 4 equal segments. In 9 specimens (the distal-first group), the tendon was partially cut starting distally by releasing 25%, 50%, and 75% of the insertion site. In the other 9 specimens (the proximal-first group), the releases started proximally. Mechanical testing was performed before and after each release.

Results: Significant decreases in the supination moment arm occurred after a 75% release in the distal-first release group; the decrease was 24% in pronation ($p = 0.003$) and 10% in neutral ($p = 0.043$). No significant differences in the supination moment arm ($p \geq 0.079$) or in flexion force efficiency ($p \geq 0.058$) occurred in the proximal-first group.

Conclusions: A simulated complete short head avulsion significantly decreased the supination moment arm and therefore supination strength.

Clinical Relevance: A mechanical case can be made for repair of partial distal biceps tendon avulsions when the rupture involves ≥75% of the distal insertion site.

Traumatic partial avulsion of the distal biceps tendon can cause activity-related pain and substantial loss of supination and flexion strength[1-14]. A majority of patients with this type of lesion require surgical treatment for the resolution of symptoms[1-15]. The precise anatomical lesion requiring surgical reattachment is unknown.

A number of investigators have pointed out the dramatic variation in biceps structure, ranging from a fused muscle with a highly interdigitated distal tendon to 2 distinct muscles with separate short and long-head tendons—that is, a bifurcated muscle[3,9-12,16-22]. In most cadaveric dissections, the distal biceps tendon is easily separated into its short and long-head components, with the short head attaching distal to the long head on the radial tuberosity (Fig. 1) and occupying 60% of the footprint area (Fig. 2)[16,17,19-22]. The short head generates a greater supination moment arm in neutral and pronated forearm positions, whereas the long head is a more powerful supinator in the supinated forearm[21]. Furthermore, the distal insertion of the short head allows it to generate more elbow flexion force[21].

Partial distal avulsions of the short and/or long head can occur as a result of both traumatic and atraumatic etiologies[9-14,23,24]. Traumatic avulsions commonly propagate in a distal-to-proximal direction, whereas in atraumatic tears the degeneration starts on the deep surface of the tendon and progresses superficially[9-14,23,24]. A large clinical series showed that a magnetic resonance imaging (MRI)-diagnosed partial tear of >50% was a predictor of the need for surgery to resolve the symptoms (odds ratio, 3.0; $p = 0.006$); however, the study failed to describe the tear location[5]. Tear location and size may be important factors in determining the need for surgery. The effects of partial short and long-head avulsions on forearm supination and elbow flexion strength are not known.

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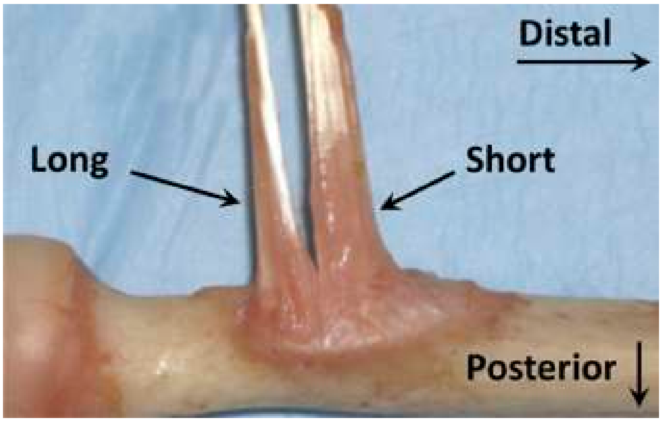

Fig. 1

Cadaveric dissection showing the distal attachment sites of the short and long heads on the posterior aspect of the radial tuberosity. The short head inserts distal to the long head. (Reprinted from J Shoulder Elbow Surg. 2012;21:942-8, Jarrett CD, Weir DM, Stuffmann ES, Jain S, Miller MC, Schmidt CC. Anatomic and biomechanical analysis of the short and long head components of the distal biceps tendon. With permission of Elsevier.)

The goal of the present study was to simulate partial and complete traumatic avulsions of the short and long heads with use of sequential surgical releases in a distal-to-proximal and a proximal-to-distal direction and to simultaneously measure the resultant forearm supination moment arm and elbow flexion force efficiency. Supination moment arm and elbow flexion force efficiency directly determine supination and flexion strength, respectively. We hypothesized that short-head releases would lead to a decrease in the supination moment arm in 60° of pronation and neutral forearm rotation and a reduction in elbow flexion force efficiency whereas partial long-head releases would result in a decrease in the supination moment arm in 60° of supination.

Materials and Methods

Eighteen fresh-frozen human shoulder-to-hand cadaveric specimens from male donors with an average age (and standard deviation) of 56.6 ± 13.6 years were used. All specimens had preservation of the proximal and distal biceps insertions and full forearm and elbow range of motion.

Mechanical tests were performed to measure isometric forearm supination moment arms in 60° of pronation, neutral, and 60° of forearm supination and elbow flexion force at 90° as previously reported[21,25-27]. After baseline testing, 9 specimens (the distal-first group) underwent a serial 25%, 50%, and 75% release of the biceps tendon from its insertion, starting distally (Figs. 3-A and 3-B). In the other 9 specimens (the proximal-first group), the biceps tendon was released in a similar manner, but starting proximally (Figs. 3-C and 3-D). The sequence of release (distal or proximal first) was randomized with use of a number generator. Mechanical testing was performed after each release.

Specimen Preparation

The lines of pull for the proximal short and long-head biceps tendons were anatomically replicated for each specimen[26]. Each cadaveric specimen was inspected for abnormalities and bifurcation.

The specimens were randomly assigned to either distal-first or proximal-first releases. The cut sequence (distal-first or proximal-first) defined the 2 conditions of the study. The humeri were osteotomized and the wrists were disarticulated to permit bolt fixation to the simulator. The soft tissue between the osteotomy and disarticulation sites, the interosseous membrane, and the distal radioulnar joint were preserved. A dorsal skin incision was made over the radial tuberosity, and the extensor carpi ulnaris and supinator muscles were split to expose the insertion of the distal biceps on the radial tuberosity. The biceps footprint length was measured with a scientific caliper (L.S. Starrett) with an accuracy of 0.01 mm and was divided into 4 equal segments (Figs. 3-A and 3-C). In 9 specimens (the distal-first group), the biceps tendon was partially cut from its attachment site starting distally by sequentially releasing 25%, 50%, and 75% of the insertion site (Fig. 3-B, 50% distal-first release). In the other 9 specimens (the proximal-first group), the biceps tendon was released starting proximally (Fig. 3-D, 50% proximal-first release). The releases were done under loupe magnification, with the specimens secured in the simulator, after native mechanical testing.

Elbow Simulator

The elbow simulator, forearm supination moment arm test, and elbow flexion force test have been previously validated[21,25-27]. The testing apparatus comprised an aluminum frame mounted to a material testing system (MTS) (MTS Systems) (Figs. 4 and 5). The humerus was bolted to the vertical limb of the frame. The elbow was placed in 90° of flexion, and

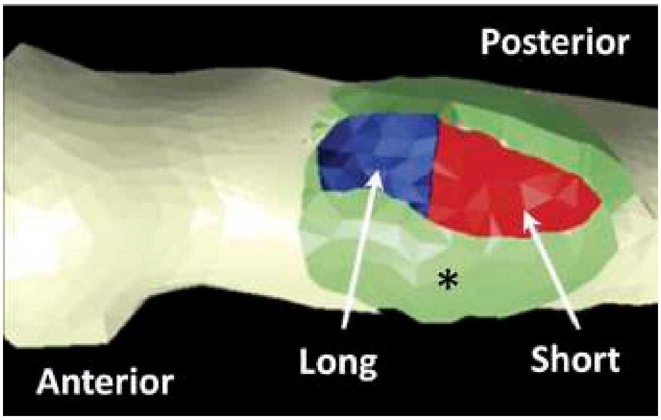

Fig. 2

Three-dimensional reconstruction of the radial tuberosity (green) with superimposed short (red) and long (blue) head footprints. The radial protuberance is marked by the asterisk. The forearm is pronated, and the tuberosity is visualized from a posterior approach. The short head occupies 60% of the total footprint area, whereas the long head occupies 40%. Note that the tendon attaches on the posterior aspect of the tuberosity. (Reprinted from J Shoulder Elbow Surg. 2012;21:942-8, Jarrett CD, Weir DM, Stuffmann ES, Jain S, Miller MC, Schmidt CC. Anatomic and biomechanical analysis of the short and long head components of the distal biceps tendon. With permission of Elsevier.)

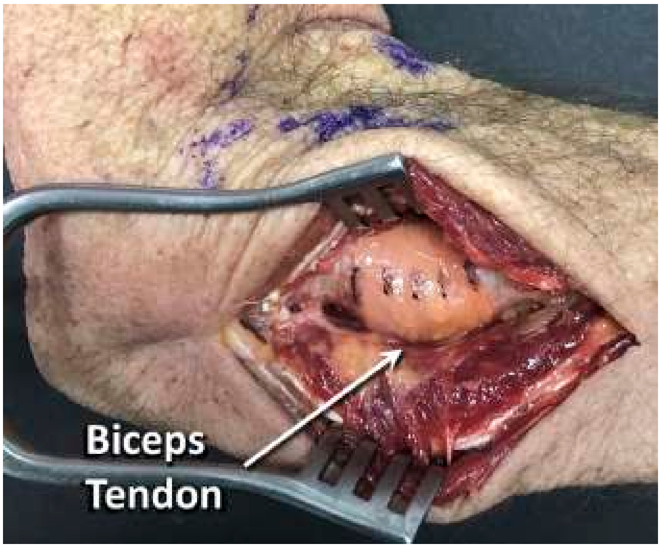

Fig. 3-A

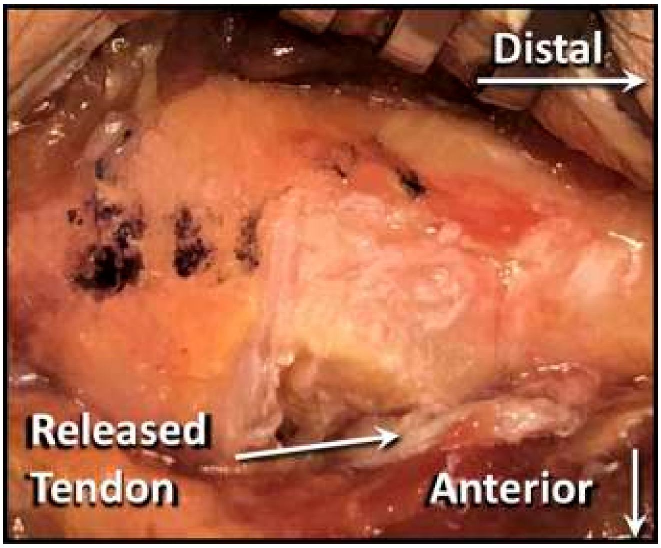

Fig. 3-B

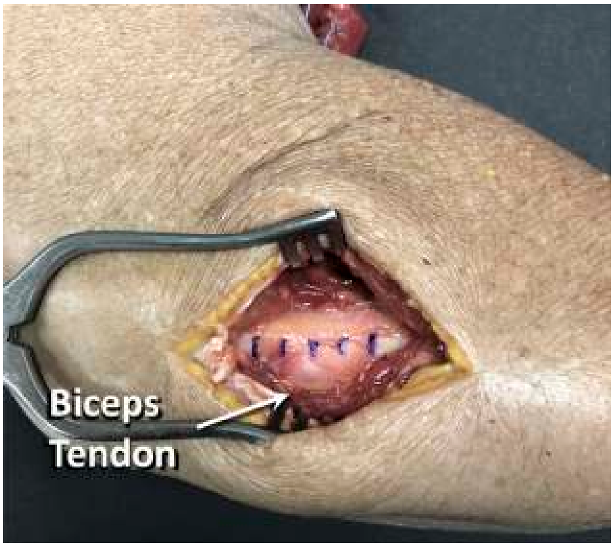

Fig. 3-C

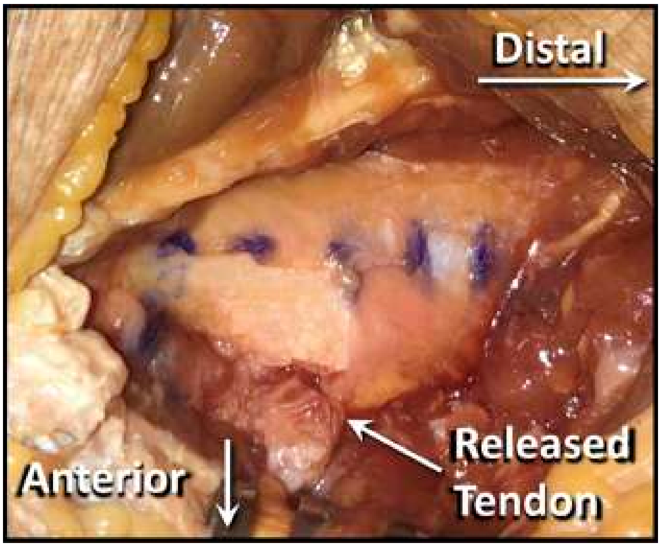

Fig. 3-D

Figs. 3-A through 3-D The biceps tendon was approached through the extensor carpi ulnaris/supinator window with the forearm in pronation. The length of the footprint was measured and divided into 4 equal segments. The biceps tendon was partially cut from its attachment starting distally (distal-first) or proximally (proximal-first) by sequentially releasing 25%, 50%, and 75% of the insertion site. Fig. 3-A Distal-first release specimen prior to release. **Fig. 3-B** A 50% distal-first release. **Fig. 3-C** Proximal-first release specimen prior to release. **Fig. 3-D** A 50% proximal-first release.

the radius was fixed to a mounting plate, which was attached to the torque sensor (Transducer Techniques) housed within the adjustable carriage. The torque sensor data were recorded with use of a data acquisition system (National Instruments). The adjustable shaft with universal joint and carriage were adjusted to recreate the anatomical axis of rotation for each specimen. The axis of rotation was found to be anatomical when the forearm easily rotated, without binding, from full pronation to supination. The anatomical lines of pull of the proximal short and long-head tendons were connected to a single actuator.

Mechanical Testing

Forearm supination moment arm and elbow flexion force tests were completed before and after each release for each specimen in a single session with use of a standard protocol[21,25-27]. To test the forearm supination moment arm, the specimens were mounted on the elbow simulator with the humerus and ulna fixed firmly to the frame at 90° of flexion (Fig. 4). The position was chosen on the basis of a previous report indicating that the maximum biceps supination moment arm occurs at 90° of elbow flexion[28]. The forearm was then rotated and locked into 3 positions: 60° of pronation, neutral, and 60° of supination. The

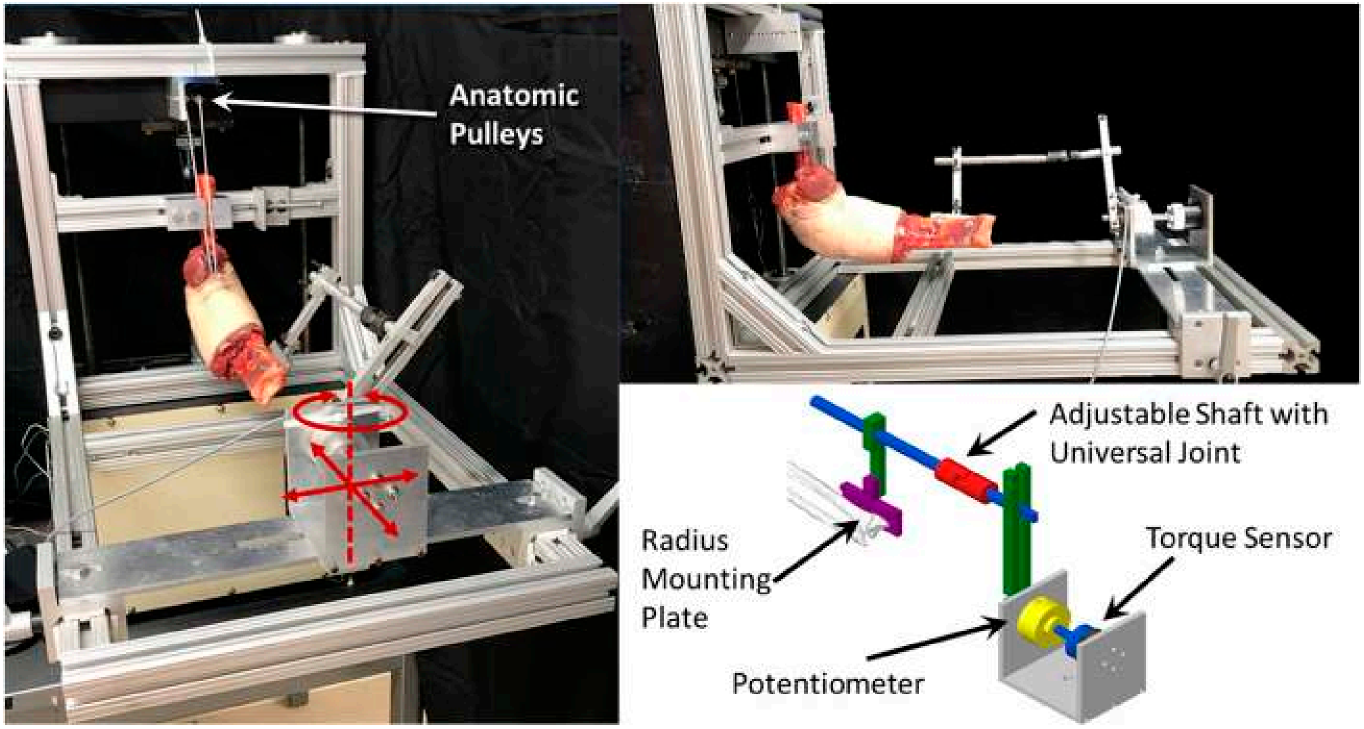

Fig. 4

Photographs and illustration showing an anatomical elbow simulator with a cadaveric elbow at 90° of flexion and the forearm in neutral position. This setup was utilized to conduct the forearm supination moment arm testing protocol. (The schematic is reprinted from JSES Open Access. 2019;3:225-231, Schmidt CC, Madonna TJ, Vandreuil N, Brown BT, Liu SY, Delserro S, Smolinski MP, Styron J, Smolinski PJ, Miller MC, et al. The effect of tendon rotation on distal biceps repair. With permission of Elsevier.)

neutral position was defined by a reference line drawn on the radius that bisected the scaphoid and lunate fossae by connecting the midpoints of the radial styloid and sigmoid notch[27]. The reference line was aligned vertically according to measurements read from a digital goniometer. The proximal short and long heads of the tendon were attached to the actuator with use of low-friction cables. The proximal biceps tendon was preloaded in each of the 3 forearm positions up to 10 N for 10 cycles and then was loaded up to 67 N at a rate of 1 cm/sec. The resulting supination torque was measured with the torque sensor. A least squares regression line was fitted to the curve of supination torque versus biceps load, and the slope of this regression line represented the supination moment arm. The test was repeated 3 times at each forearm position, and the values were averaged for each position tested. The sequence of the forearm positions was randomly assigned.

The elbow flexion force test measured the biceps flexion force efficiency, which is the ratio of flexion load to biceps load (Fig. 5)[21,25,26]. The torque device was removed while maintaining humeral fixation to the simulator. The radius and ulna were pinned in 60° of forearm supination, and the biceps was loaded until the elbow reached 90° of flexion. A cord attached to the distal part of the forearm was connected to a force sensor (Transducer Techniques), allowing a counterforce to maintain the elbow at 90° of flexion. The flexion force was recorded by preloading and loading the biceps as previously described for the supination test. Recorded flexion load versus applied load was used to calculate a least-squares regression line; the slope of this regression line was the elbow flexion force efficiency. The elbow flexion test was repeated 3 times, and the recorded values were averaged.

Statistical Analysis

A 1-factor repeated-measures analysis of variance (ANOVA) with partial tear size as the factor followed by post hoc analysis with use of Bonferroni correction was used for each forearm position to evaluate the effects of partial releases on the biceps tendon moment arm and elbow flexion force efficiency. For all statistical analyses, the level of significance was set at $p < 0.05$.

An a priori power analysis was performed to determine the minimum number of specimens that would be required to detect a 15% difference in the supination moment arm and flexion force. On the basis of the study data, a sample size of 8 specimens in each group would provide adequate power ($\alpha = 0.05$ and $\beta = 0.80$) to detect a 15% difference.

Results

No bifurcated biceps muscles were observed. Seventeen specimens were free of tendon abnormality, and 1 contained gouty crystals. The latter specimen was randomized into the proximal-first group and ruptured after a 75% release during force supination testing. The specimen was removed from mechanical analysis, leaving 9 specimens in the distal-first group and 8 specimens in the proximal-first group. The average footprint length as measured with the caliper was 22.1 ± 2.3 mm.

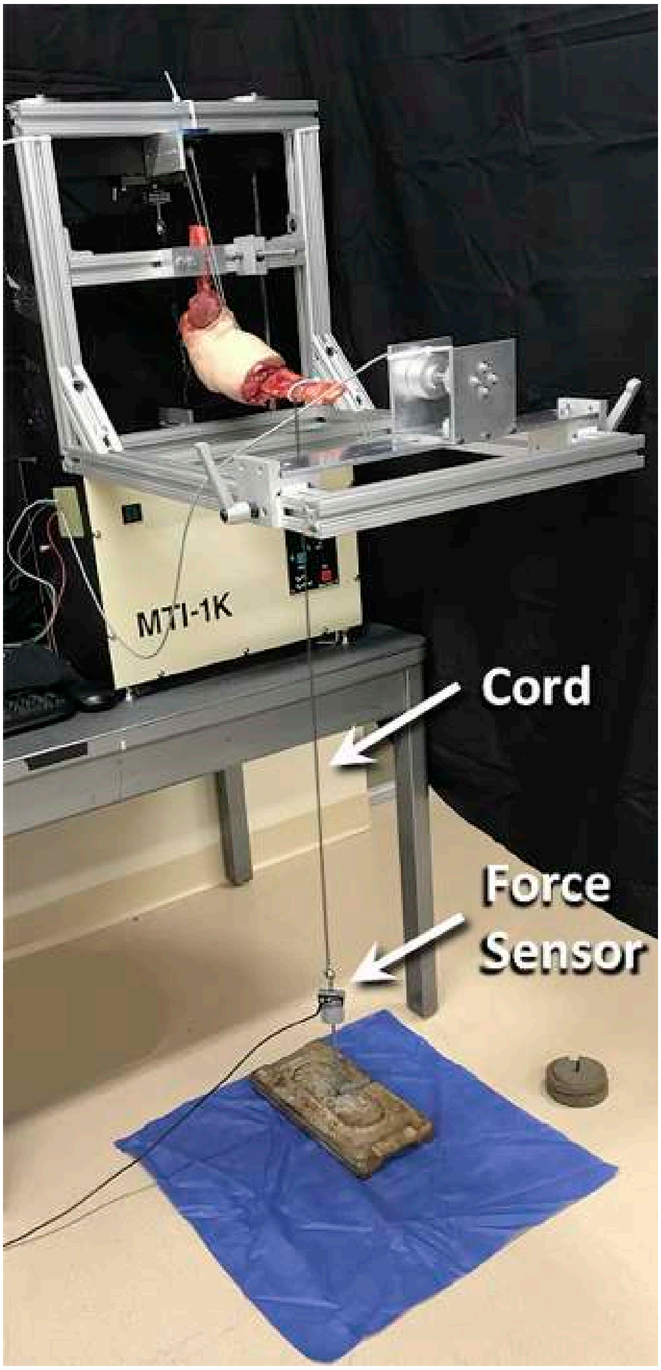

Fig. 5

Photograph showing an anatomical elbow simulator with corresponding force sensor. With use of this setup, a counterforce was applied to maintain the elbow at 90° of flexion, and the subsequent force generated during the flexion force efficiency test was recorded.

The supination moment arm results are summarized in Tables I and II (with the raw data shown in the Appendix). The native moment arm values were not significantly different from those in our previously published work ($p \geq 0.131$) (Appendix)[21,25-27].

In the distal-first group, the only significant decreases in the supination moment arm occurred in association with a 75% release ($p \leq 0.043$) (Table I). In pronation, the moment arm was 24% less than that in the intact state ($p = 0.003$), whereas in neutral, the moment arm was 10% less than that in the intact state ($p = 0.043$). Additionally, a 29% decrease occurred in supination ($p = 0.056$).

In the proximal-first group, there was no significant difference in the supination moment arm in association with 25%, 50%, and 75% releases in pronation, neutral, or supination ($p \geq 0.079$) (Table II). However, proximal-first releases of 50% and 75% reduced the supination moment arm in supination by 35% ($p = 0.079$) and 37% ($p = 0.131$), respectively.

The flexion force efficiency results are shown in Table III. Elbow flexion force did not significantly change relative to the intact state in any of the distal-first or proximal-first release

TABLE I Distal-First Release Supination Moment Arms

Release Comparison	Percent Change	P Value
60° pronation		
Native versus 25%	−10%	0.158
Native versus 50%	−12%	0.122
Native versus 75%	−24%	0.003*
Neutral		
Native versus 25%	−2%	0.999
Native versus 50%	−10%	0.377
Native versus 75%	−10%	0.043*
60° supination		
Native versus 25%	−7%	0.996
Native versus 50%	−18%	0.999
Native versus 75%	−29%	0.056

*Significant ($p < 0.05$).

TABLE II Proximal-First Release Supination Moment Arms

Release Comparison	Percent Change	P Value
60° pronation		
Native versus 25%	−4%	0.999
Native versus 50%	−13%	0.971
Native versus 75%	−1%	0.999
Neutral		
Native versus 25%	0%	0.999
Native versus 50%	−4%	0.999
Native versus 75%	−7%	0.999
60° supination		
Native versus 25%	−2%	0.999
Native versus 50%	−35%	0.079
Native versus 75%	−37%	0.131

TABLE III Flexion Force Efficiency

Release Comparison	Percent Change	P Value
Proximal-first		
Native versus 25%	1%	0.999
Native versus 50%	4%	0.482
Native versus 75%	5%	0.058
Distal-first		
Native versus 25%	3%	0.716
Native versus 50%	2%	0.999
Native versus 75%	−2%	0.999

groups following 25%, 50%, or 75% sectioning ($p \geq 0.058$). The proximal-first 75% release increased the flexion force efficiency by 5% ($p = 0.058$).

Discussion

Traumatic avulsion of the short head of the distal biceps tendon can result in a substantial loss of supination strength. In the present study, a 75% distal-first release, which simulates a complete short-head avulsion, decreased the supination moment arm by 24% in pronation ($p = 0.003$), 10% in neutral ($p = 0.043$), and 29% in supination ($p = 0.056$). The supination moment arm can be thought of as the efficiency of the biceps muscle to rotate the forearm; that is, the greater the moment arm, the greater the supination strength that can be generated by a given biceps contraction[27]. A drop in the moment arm value reduces the effectiveness of biceps force transmission, which could result in a clinically meaningful loss of supination strength, endurance, and/or power.

A recent clinical series showed that an MRI-diagnosed partial tear of >50% was a predictor of the need for surgery to resolve the symptoms (odds ratio, 3.0; $p = 0.006$)[5]. The mechanical results of the present study supported those clinical findings when the tear was distal and involved ≥75% of the insertion site. A simulated complete short-head avulsion was associated with a significant ($p \leq 0.043$) decrease in the supination moment arm in the pronated and neutral forearm positions. The authors of the clinical series did not address the location of the >50% tear[5]. In the future, using preoperative advanced imaging to clarify tear size and location may help to further define appropriate surgical indications.

The pathoanatomy of partial distal biceps avulsions can be divided into traumatic and atraumatic etiologies, and the understanding of this subject is still evolving[9-14,23,24]. The cutting sequence of distal-to-proximal (distal-first) or proximal-to-distal (proximal-first) instead of deep-to-superficial was designed to model a traumatic distal partial avulsion and not a chronic degenerative tear[4,14,23,24,29,30]. The merit of our cutting sequence is supported by the following clinical findings: (1) the most common mode of traumatic failure of bifurcated distal biceps tendons is a complete short-head rupture and (2) a recent MRI study demonstrated no significant difference in tear morphology between bifurcated and non-bifurcated tendons ($p = 0.32$) and showed that 20 (44%) of 45 patients with a traumatic partial distal biceps injury presented with a complete short-head avulsion (Fig. 6)[9-13,18,24,31]. The present study did not investigate atraumatic partial ruptures, which are believed to occur as a result of radial tuberosity impingement[4,14,23,24,29,30]. In degenerative tears, it is believed that the tendon first fails on its deep surface adjacent to osseous irregularities on the tuberosity and then progresses superficially[14,23]. However, we speculate that the mechanics would not be different from the uninjured state as long as the superficial fibers of both the short and long heads remain intact, given that force-transmission studies have shown that the supination moment arm does not change from the native state as long as the tendon is reattached posterior to its radial protuberance[27,32-34].

In a previous mechanical study, the short and long-head components were separated, tested individually, and compared with each other[21]. In that study, the short head was found to be a better supinator in pronation and neutral, whereas the long head was a better supinator in a supinated position because the shape of the radial protuberance maximized the moment arms for each head in their respective positions. The present study was different because the tendons were not separated but rather were released from the radius to simulate partial avulsions and subsequently were compared with the intact tendons. The significant decreases in the supination moment arm that were observed in association with a complete (75% distal-first) short-head release in pronation

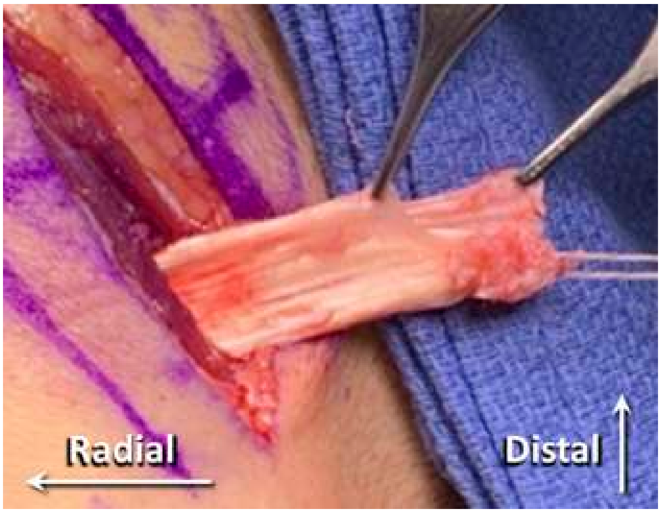

Fig. 6

Clinical photograph showing a short head tendon avulsion, after the entire tendon was detached to aid in repair. Prior to the photograph, a posterior extensor carpi ulnaris-slitting approach was used for exposure[32]. The short head was found avulsed, and the long head was found intact. The long head was then temporarily sutured for future traction. The long head was surgically detached at the insertion site. The entire tendon was retracted to gain exposure for permanent short and long-head suture placement. In this photograph, the avulsed short head is held by 2 forceps. The short and long heads were then reattached to their respective insertion sites with 2 single cortical buttons (not shown).

(24%; $p = 0.003$) and neutral (10%; $p = 0.043$) and the substantial decrease in the supination moment arm in association with a complete (50% proximal-first) long-head release in supination (35%; $p = 0.079$) are in agreement with the findings of the above-mentioned mechanical study[21] (Tables I and II). However, one would expect that proximal-first release would increase the supination moment in pronated and neutral positions because of increasing force transmission through the short head, and likewise, that distal-first release would increase the supination moment in a supinated position because of increasing force transmission through the long head. These findings were not observed in the present study as none of the supination moment arms increased after sectioning. Perhaps a proximal-first release of 25% shifts the long-head load to the short head, but in an asymmetrical manner, whereby the tendon fibers next to the release receive most of the load; this asymmetrical transmission shifts the resultant force vector off its apex on the protuberance toward the release and thereby fails to increase its expected moment arm. Proximal-first releases of >40% cut into the short-head tendon and also shift the resultant vector off its apex, away from the release. The overall moment arm fails to increase because the resultant force fails to act on the protuberance at its maximum point away from the forearm axis of rotation[20,25]. The above rationale also can be applied to distal-first release, but it is important to remember that the long head occupies 40% of the footprint[21].

It is surprising that partial releases, either distal-first or proximal-first, did not significantly affect the native flexion force efficiency ($p \geq 0.058$). Anatomical studies have clearly shown that the short head inserts further than the long head from the center of rotation of the elbow joint[16,19,21,22]. Intuition would suggest a complete short-head avulsion (distal-first 75% release) would substantially reduce the flexion force efficiency. Furthermore, a previous mechanical study demonstrated that the ratio of flexion load to biceps load was 15% higher ($p = 0.001$) in the short head as compared with the long head[21]. In that study, the short and long-head muscles and tendons were completely separated and any interconnections were released. In the present study, the interconnections between the short and long-head muscles and tendons were preserved, and these bridging structures could redistribute the flexion force after a partial release and thereby mechanically compensate for the loss of the distal attachment site[20]. Another explanation for the lack of significant findings could be the limited number of specimens that completed the mechanical analysis ($n = 17$, including 9 in the distal-first group and 8 in the proximal-first group). An a priori power analysis showed that 8 specimens were needed to detect a 15% difference in supination moment arm and flexion force efficiency.

The findings of the current study may not be clinically applicable, given the limitations of our injury model and the ability of the human body to adapt to a partial distal biceps avulsion. However, other mechanical studies on reattachment position have correlated with subsequent clinical findings[27,32-34]. In conclusion, the size and location of the partial distal biceps tear affect the supination moment arm. A partial distal biceps avulsion involving ≥75% of the distal footprint substantially decreases the supination moment arm, and therefore strength; a strong mechanical case can be made for surgical repair with the goal to restore full clinical function.

Appendix

Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/G325). ■

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