The effect of biceps reattachment site

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Background: We hypothesize that an anatomic repair of the distal biceps tendon would recreate native tendon moment arm and forearm rotation, while a nonanatomic insertion would compromise moment arm and forearm rotation.

Methods: Isometric supination torque was measured at 60° of pronation, neutral, and 60° of supination for the native distal biceps tendon and 4 repair points in 6 cadaveric specimens using a computer controlled elbow simulator. The slope of the regression line fitted to the torque versus biceps load data was used to define the moment arm for each attachment location. Range of motion testing was performed by incrementally loading the biceps, while measuring the supination motion generated using a digital goniometer.

Results: Tendon location and forearm position significantly affected the moment arm of the biceps ($P < .05$). Anatomic repair in all forearm positions showed no significant difference from the native insertion. Moment arm for an anterior center repair was significantly lower in supination (-97%) and neutral (-27%) and also produced significantly less supination motion. No difference was observed between all tendon locations in pronation.

Conclusions: Reattachment of the biceps to its anatomic location, as opposed to a more anterior central position, is critical in reestablishing native tendon biomechanics. Clinically, these findings would suggest that patients with a biceps repair might experience the most weakness in a supinated position without experiencing a deficit in the pronated forearm.

Level of evidence: Basic Science Study.

Keywords: Distal biceps tendon; supination torque; supination moment arm; tendon attachment location; biceps rupture; biceps tendon repair

Rupture of the distal biceps tendon is not an uncommon occurrence in middle-aged men.\textsuperscript{1,3,32,42} The avulsion of the tendon from the tuberosity usually results from eccentric loading of the supinated forearm, such as occurs during lifting activities or when braking one’s fall.\textsuperscript{3,32,38,42} When nonoperative treatment is chosen, supination strength decreases by 22-50% and flexion strength is reduced by 12-40%.\textsuperscript{3,24,34,38} While some controversy continues to exist over the need for repair of an acute distal biceps tendon, surgical repair has been shown to be a better alternative in patients with higher physical activity than nonoperative treatment for restoration of strength and endurance.\textsuperscript{3,8,12,15,24}
Current surgical methods have focused on approaches to the biceps tuberosity and initial attachment strength.\textsuperscript{2,5,13,20,27,28,38} There are numerous in vitro biomechanical studies discussing attachment of the tendon either with sutures, suture anchors, interference screws, or a cortical button.\textsuperscript{2,17,18,22,33} Although these studies have examined the fixation strength of repairs, little has been done to examine the effect that attachment location has on functional outcome of the repair.

To our knowledge, only 1 study has attempted to quantify the effect of insertion location on the ability of the biceps to act in its primary role as a forearm supinator. Henry et al reconstructed the biceps using either a 1-incision anterior or 2-incision posterior position via transosseous suture fixation in matched cadaveric upper extremities.\textsuperscript{23} The forearms were mounted in neutral rotation and supination torque was measured via a load cell. A trend towards loss of supination torque was found with anterior fixation; however, this did not reach statistical significance. While this study provided some information to compare these 2 fixation points, it fell short of providing a comprehensive evaluation of the effect of reattachment location on supination torque.\textsuperscript{35,39}

Forearm supination torque is a function of both the biceps muscle load and the moment arm. The supination moment arm can be thought of as the efficiency of the biceps to rotate the radius, i.e., a larger moment arm can generate a greater supination torque for a given biceps load. The moment arm is found by analyzing the supination torque per muscle force relationship.\textsuperscript{21}

A biomechanical cadaveric study was designed to compare biceps supination moment arm and forearm range of motion generated by the native biceps and 4 repaired tendon positions. Our hypothesis was that an anatomic repair would most closely recreate native tendon torques and forearm motion, while anterior, posterior, and proximal repairs would deviate from the native. Furthermore, we felt that different forearm rotational positions would influence the amount of deviation found between the native and repaired tendon.

**Materials and methods**

A total of 6 frozen upper extremity cadaveric specimens (5 male), with an average age of 60 years (range, 36-83), were used. The specimens included the full forearm from the hand to the mid-humerus proximally. Specimens with medical histories of rheumatoid arthritis, degenerative joint disease, or any orthopaedic anomaly were excluded. Prior to the day of testing, each specimen was allowed to thaw overnight at room temperature and kept moist with normal saline.

**Tendon attachment locations**

With the arm fully supinated, the borders of the radial tuberosity were identified and the proximal and distal border lines of the insertion were drawn (Figure 1). The borders were defined at the point where the bone geometry of the radius begins to exhibit slightly concave curvature. The lengths of the tuberosity borders were measured and their midpoints were marked. A line connecting the 2 midpoints was used to define the center axis line. The highest point (apex) on the tuberosity at the tendon-bone interface was identified using calipers. A medial to lateral line, parallel to the tuberosity borderlines, was drawn to define the apex diameter line.

Using these markings as a guide, 3 drill holes (2.25-mm diameter) were systematically placed in the radius. Location anatomic (A) was placed on the apex diameter line at the native tendon insertion. Location anterior center axis (ACA) was placed at the intersection of the center axis and apex diameter lines. Location posterior center axis (PCA) uses the same drill hole as ACA, but the tendon was wrapped around the tuberosity on the posterior side of the radius. Location proximal anatomic (PA) was attached at the most ulnar point on the proximal borderline.
A device capable of measuring isometric forearm torque generated by cadaveric elbows was mounted to the front of a previously developed elbow simulator (Figure 2). A clamp on the front frame of the simulator holds the humerus of a cadaveric elbow stationary. Computer controlled actuators exert known loads through a line routed through a series of pulleys and sutured into the biceps tendon. The pulleys ensure the proper line of action of the applied load.

An adjustable shaft on the torque measurement device attached to a plate mounted on the distal radius. The other end of the shaft transmitted load to a torque sensor (Transducer Techniques, Temecula, CA), which was wired into a computer data acquisition system. The torque sensor was attached to a carriage placed on a track mounted to the front of the simulator. The assembly permitted the carriage to translate and rotate to allow proper alignment of the forearm rotational axis with the sensor axis (Figure 2). After alignment, the carriage was locked into position.

**Testing apparatus**

Each specimen was mounted in the elbow simulator with the humerus and ulna fixed firmly to the frame at 90° of flexion, as shown in Figure 2. Bremer et al provided experimental evidence that the biceps supination moment arm was greater in 90° of flexion compared to 0° and 45°. The specimens were placed at 90° of flexion for all testing in an effort to maximize the torque measurement. The proximal end of the distal biceps tendon was attached to an actuator using 80lb test line. The adjustable shaft was attached to the distal radius plate. The forearm was then rotated and locked into 3 positions: 60° of supination, neutral, and 60° of pronation. Forearm position measurements were made in a systematic manner for all specimens. A reference line was drawn on the radius that bisected the scaphoid and lunate fossas by connecting the midpoints of the radial styloid and sigmoid notch (Figure 3). Neutral was defined by the collaborating orthopaedic fellow as the position when the reference line was aligned vertically according to measurements read from a digital goniometer. The biceps tendon was gradually loaded to 67 N and the torque was measured for the native tendon attachment. It has been shown that the mean biceps force needed to flex cadaver arms to 130° was 67 N. For this reason, 67 N was determined to be a reasonable approximation of the physiological loading that could occur.

For each forearm position, the test was repeated 3 times. The distal biceps tendon was then transected, surgically reattached using an Endobutton (Smith and Nephew, Andover, MA), and tested at 4 different locations: A, ACA, PCA, and PA. Cortical button fixation was chosen, because it allowed testing of all locations without compromising the radial geometry.

For this study, the magnitudes of the supination torque and biceps load were measured simultaneously. We tested all tendon attachment locations at the same forearm rotational positions under the same biceps muscle loading profile. By comparing the moment arms for each attachment location at a given forearm rotation position, the effect of the attachment location could be determined. Therefore, any change in the torque generated was due to a change in the muscle moment arm resulting from varying the attachment location.

A linear regression line was fitted to the supination torque versus biceps load data for each torque test, as shown by Figure 4. The moment arm for each tendon attachment was defined as the slope of
the regression line. The moment arm was averaged over the 3 repeated tests taken at each forearm position. A positive moment arm value indicated that the biceps generated a supination torque.

Supination motion test

The humerus and ulna were firmly fixed at 90° of flexion. Only forearm rotation was allowed. Forearm position was defined in the same manner performed during torque testing. With no load on the biceps tendon, the arm was placed in pronation. The biceps was then loaded incrementally from 0 N to 22.25 N, 44.50 N, and 66.75 N, and the forearm position was measured at each load increment. The test was repeated 3 times for each biceps tendon attachment location.

Statistical analysis

A two-way repeated measures analysis of variance was used to determine if tendon location and forearm position significantly affect the moment arm of the biceps (P < .05). Tukey’s post-hoc testing was used to compare the mean moment arm of each repair to the native tendon.

Another two-way repeated measures analysis of variance was used to determine if tendon location and biceps load significantly affected supination motion of the biceps (P < .05). Tukey’s post-hoc testing was used to compare the mean rotation generated by each repair to the native.

Results

Gross observations

The native biceps tendon appeared to insert normally in all specimens. Each native tendon inserted slightly posterior of the most ulnar edge of the tuberosity in a ribbon-like fashion (Figure 5). At 60° of supination, minimal wrapping of the tendon around the apex of the tuberosity was noted. As the forearm was pronated, an increase in tendon wrapping was observed with definitive wrapping occurring just before neutral. Location A exhibited a similar wrapping behavior to the native tendon. In contrast to the anatomic (A) repair, location ACA showed minimal tendon wrapping. Furthermore, no wrapping was observed at 60° of supination. This limited wrapping was due to the centralized placement of the repair. For PCA, tendon wrapping was observed at all 3 forearm positions. At this location, the tendon was acting over the apex of the tuberosity at all times. Location PA demonstrated some wrapping at 60° of supination. However, in contrast with the 3 distal locations, the tendon did not wrap around the tuberosity, but wrapped around the proximal junction of the tuberosity and radial shaft.

Moment arm

The supination torque versus biceps load data clearly exhibited a linear relationship by gross observation, as shown by
The best-fit lines from the linear regression analysis had an average $R^2 = .980$ confirming a linear relationship.

Analysis showed that tendon location and forearm position significantly affected the moment arm of the biceps ($P < .05$) (Figure 6). Reattachment to location A in all forearm positions showed no significant difference from the native insertion. Location ACA had a moment arm that was significantly lower in supination (-97%) and neutral (-27%) compared to the native insertion, while no difference was found in pronation. In 2 specimens, this position created a pronation torque at 60° of forearm supination. Location PCA was significantly higher in supination (+27%) compared to the native; however, no differences were found in neutral and pronated positions. Location PA showed a trend to a lower moment arm than the native tendon insertion in all 3 forearm positions, but the difference was only statistically significant in neutral (-15%). In supination, location PA moment arm was significantly higher (97%) than ACA. No difference was observed between all tendon locations in pronation.

**Supination motion**

Tendon location and biceps load significantly affected the supination motion of the biceps ($P < .05$) (Figure 7). Location A was not significantly different than the native tendon. At 44.50 N and 66.75 N, location ACA was significantly lower than the native tendon producing 13% and 15% less rotation at each load, respectively. At 22.25 N, 44.50 N, and 66.75 N, location PCA was significantly higher than the native tendon producing 9%, 10%, and 10% more rotation at each load, respectively. Location PA was not significantly different than the native tendon.

**Discussion**

The contractile force of the biceps muscle and the tendon’s moment arm determines its ability to generate a supination torque. The surgeon cannot control the patient’s innate biceps muscle mass, but he/she can influence tendon’s moment arm during repair. This study showed that reattaching the distal biceps back to its anatomic position (A) did not statistically change its moment arm. However, radializing the attachment to the ACA location resulted in a significantly lower moment arm than the native insertion in neutral (-27%) and 60° of supination (-97%). With a compromised supination moment arm, the patient would require greater muscle contraction to produce the same torque prior to injury. The need to produce stronger contraction could explain the reported loss of endurance. Based on our findings, a patient with an ACA repair could potentially have decreased supination endurance, as well as peak torque, due to the reduction in moment arm. In order to optimize supination strength, the native biceps tendon’s moment arm needs to be reestablished by an anatomic repair.

We believe less tendon wrapping around the tuberosity and failure to use the apex of the tuberosity caused the lower moment arm seen in the ACA location. As the forearm was pronated, the tendon was observed to only wrap around portions of the tuberosity that were radial to its insertion site (Figure 8). There was less wrapping in the ACA position compared to the A position. When we simulated biceps contraction, the ACA position became unwound between neutral and 60° of supination. The A position was still wound at 60° supination and always generated a supination torque. Furthermore, a tendon repaired at the ACA never acted over the added height provided by the apex of the tuberosity. This finding provides evidence that the radial tuberosity functions as a cam that increases the biceps moment arm.

We also observed that in 2 specimens, the biceps acted as a pronator instead of a supinator at 60° supination for the ACA attachment location. For this to occur, the biceps must apply a force to a point on the radius located on the radial side of the axis of forearm rotation. Compared to the native insertion, the ACA insertion is positioned more radially on the anterior radius. In 2 specimens, this radial movement
was sufficient to allow the insertion to cross to the radial side of the forearm axis at 60° supination. However, as the forearm pronated, the insertion crossed back over to the ulnar side of the axis and acted as a supinator in neutral and 60° of pronation. In theory, the surgeon in repairing the biceps to the center of the radius could inadvertently decrease the patient’s ability to supinate with the forearm in a supinated position.

Henry et al measured the resultant supination force generated by 11 pairs of cadaveric arms in neutral forearm position using both an anterior and posterior repair method. For the anterior group, the biceps was sutured to the anterior tuberosity using a cortical bone bridge on the posterior tuberosity. Posterior reattachment was done using the modified Boyd-Anderson approach. An incision along posterolateral aspect of the elbow exposed the posterior aspect of the radial tuberosity. The tendon was passed between the ulna and radius while the forearm was pronated, and a cortical window was burred into the tuberosity. The tendon was seated into a bone tunnel and sutured into place using a bone bridge.

Henry et al showed no significant difference between the 2 repairs. Some limitations of the study were that the arms were only tested in neutral and that muscle moment arms were not measured. Studies have shown that the biceps moment arm can change nonlinearly with forearm position, making it difficult to draw conclusions about how the biceps tendon behaves throughout the entire range of motion based on measurements from 1 discrete position. Additionally, both surgical techniques that were compared required burring of the tuberosity to create a bone tunnel. This burring could have significantly altered the geometry of the radial tuberosity, thus making it difficult to isolate just the effect of attachment location alone.

The cortical button technique used in this study allowed examination of the effect of attachment location without drastically changing the native proximal radius morphology, and provided insight into the significance of the geometry. The creation of a cortical window in the tuberosity during a 2-incision Boyd-Anderson repair has been previously suggested to decrease the moment arm due to tuberosity height reduction. Our results support the importance of maintaining the tuberosity height and show that the ideal surgical repair for distal biceps ruptures would be one that required minimal change to the geometry of the radius. This would allow the tendon to wrap around of the anterior tuberosity, thereby, in effect, maximizing the muscle moment arm.

Our study further showed that tendon location had no impact on the moment arm at 60° of pronation. As the radius pronates, there is a certain point at which the tendon begins to wrap around the radius. For each tendon location, this will occur at a different angle of forearm rotation. However, at the angle where all of the tendon repairs begin to experience wrapping, the moment arms should be almost equivalent. At this angle, the tendon will wrap around the radial side of the radius, which typically has only small geometric variation over the length of the tuberosity. At 60° of forearm pronation, we believe this critical angle was surpassed, resulting in no difference in moment arms across all locations. Based on these findings, patients with a distal biceps repair might experience the most weakness in supination strength at a supinated forearm position, while experiencing minimal weakness in the pronated forearm.

Most of the strength testing in the literature has been performed using commercial dynamometers for isokinetic testing of the biceps, with comparisons of peak strength values usually defined as the maximal torque produced during the range of motion. One study found that peak supination torque occurred at 12° of forearm supination during isokinetic testing of a normal population, leading us to believe that the peak strength measurements in the literature might not be representative of the entire function of the repair. Isokinetic testing does not typically involve comparisons of peak supination strength.
differences at different forearm positions, other than positions of maximum torque. Thus, for isokinetic testing, it may be difficult to find isolated supination weakness due to the dynamic nature of the testing.

Isometric testing of supination strength in patients with distal biceps repairs has been reported, but patients are most commonly tested at neutral forearm rotation.\(^7,10,15,29,36,38,40\) Isometric testing has shown that after surgical repair the injured arm regains 87-93% of the supination strength of the uninjured arm.\(^7,10,36\) We believe that a larger deficit is most likely to be found in the supinated forearm during isometric testing, and that this deficit is likely to be even greater with nonanatomic repair. Based on previous supination strength testing protocols in the literature, the authors feel that a strength deficit in the supinated forearm might be under-reported.

We hypothesized that the effect of tendon location would manifest itself not only in the moment arm differences, but also in comparing the amount of supination motion generated for a given biceps load. The higher the moment arm, the more supination motion we expected it to generate. The findings from our supination motion test confirmed that location ACA was at a mechanical disadvantage compared to the other locations: for the same biceps input, it produced less supination motion. The opposite was true for location PCA, which had the greatest mechanical advantage and produced the most motion out of all of the tendon locations. This lends further support for the importance of tendon wrapping.

In chronic or delayed cases of the ruptured distal biceps, tendon/muscle shortening and adhesion formation can make anatomic repairs difficult.\(^10,44\) For these cases, the surgeon must choose whether to attempt anatomic repair or to

**Figure 8** Axial view of right forearm outline. ACA (blue), A (red), and PCA (green). A, Schematic of tendon wrapping during pronation. The biceps tendon will only wrap around portions of the tuberosity that are radial to the attachment point as shown. Note how ACA never acts over the whole tuberosity during forearm rotation, while the A and PCA wrap around the entire anterior tuberosity. B, Illustration of tendon unwrapping during supination. The ACA repair unwinds between neutral and 60° of supination, while A and PCA are still partially wrapped and thus can generate a greater supination torque.
reconstruct the biceps tendon with a graft. In our study, a PA location represented the scenario where proximal repair was chosen after the tendon was shortened due to retraction. The PA location trended to have a lower moment arm than the native in all forearm positions, but was only significantly different in neutral. At this position, only part of the tendon wraps around the proximal half of the tuberosity, and the repair is not able to take full advantage of wrapping effect seen with the native insertion; however, this position could provide more wrapping of the tendon over the tuberosity than the ACA location. Clinically, these findings would suggest that if the muscle was contracted and the tendon could not be inserted to its native position, then a proximal anatomic position would be better than a more central anterior one.

This study is a time zero look at the effect the reattachment location has on the ability of the tendon to generate a supination torque. The cadaveric biceps repair may not fully simulate a patient’s repaired tendon. The live tendon may respond to environmental stress by healing to its native position. A limitation of this study was that observations were made with only the biceps muscle loaded. This in vitro design may not recreate the in vivo condition when multiple muscles are working simultaneously to provide stability to the elbow joint. Removal of the hand at the wrist was required for testing and could have also affected the stability of the radius and ulna. However, this study provides strong biomechanical evidence in support of an anatomic repair.

Conclusion

Reattachment of the biceps tendon to an anatomic position could play a critical role in maximizing supination torque, especially when the forearm is positioned in neutral to supination. The study also provides data that shows supination strength testing at multiple positions throughout the range of motion might be required to evaluate the overall effectiveness of distal biceps tendon repair methods.

Disclaimer

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