J Shoulder Elbow Surg (2010) 19, 1157-1165

ELSEVIER

JOURNAL OF SHOULDER AND ELBOW SURGERY

www.elsevier.com/locate/ymse

The effect of biceps reattachment site

Christopher C. Schmidt, MD[a,b,*], David M. Weir, MS[b,e], Andrew S. Wong, MD[c], Michael Howard, MD[d], Mark Carl Miller, PhD[b,e]

[a]*Division of Upper Extremity Surgery, Department of Orthopaedics, Allegheny General Hospital, Pittsburgh, PA, USA*
[b]*Allegheny General Biomechanics Lab, Pittsburgh, PA, USA*
[c]*Loma Linda University Medical Center, Redlands, CA, USA*
[d]*Department of Orthopaedics, David Grant Medical Center, Travis AFB, CA, USA*
[e]*Swanson School of Engineering, University of Pittsburgh, Pittsburgh, PA, USA*

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.[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.[3,32,38,42] When nonoperative treatment is chosen, supination strength decreases by 22-50% and flexion strength is reduced by 12-40%.[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.[3,8,12,15,24]

This biomechanical study did not involve the participation of live subjects; therefore, approval from an Institutional Review Board was not applicable.

*Reprint requests: Christopher C. Schmidt, MD, Federal North Building, 1307 Federal Street, Second Floor, Pittsburgh, PA 15212.
E-mail address: cschmidthand@comcast.net (C.C. Schmidt).

1058-2746/$ - see front matter © 2010 Journal of Shoulder and Elbow Surgery Board of Trustees.
doi:10.1016/j.jse.2010.05.027

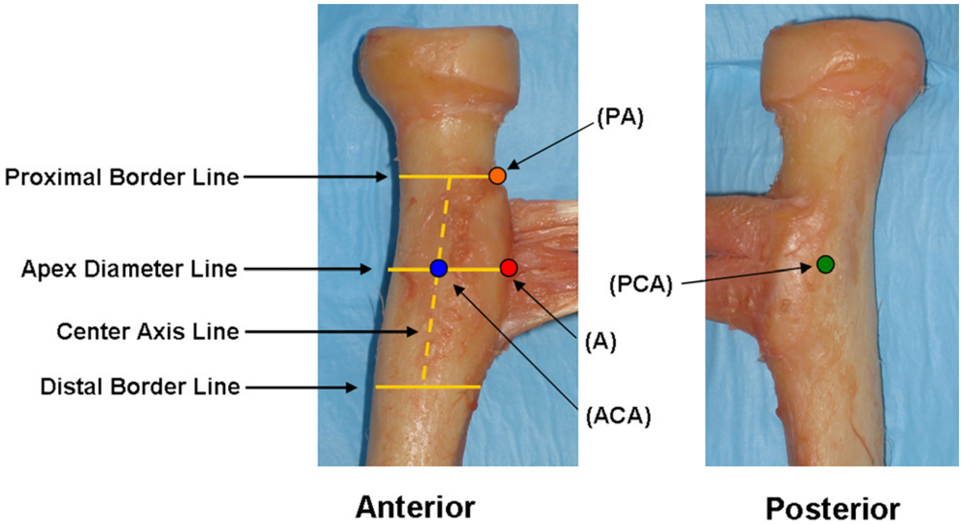

Figure 1 Diagram of distal biceps tendon reattachment locations. (*A*, anatomic [red], *ACA*, anterior center axis [blue]; *PCA*, posterior center axis [green]; *PA*, proximal anatomic [orange].)

Current surgical methods have focused on approaches to the biceps tuberosity and initial attachment strength.[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.[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.[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. The study failed to test the specimens in varying degrees of forearm rotation, which has been shown to be an important factor in measuring supination torque.[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, ie, 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.[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.

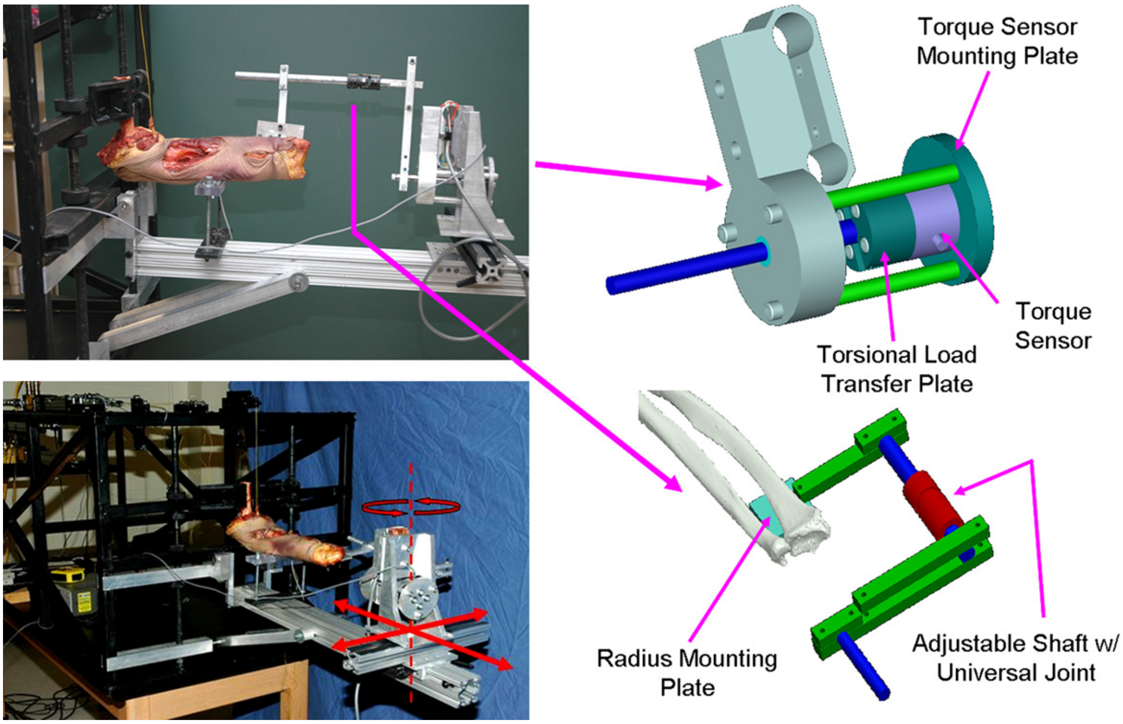

Figure 2 Assembly view of the device used to measure isometric forearm torque. The humerus and ulna are fixed to the frame at 90°, while the radius is attached to an adjustable shaft connected to a torque sensor. An actuator on the simulator loads the distal biceps tendon generating a torque which is measured by the sensor.

Testing apparatus

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).[31] 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.

Forearm supination torque test

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°.[6] 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.[17] 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

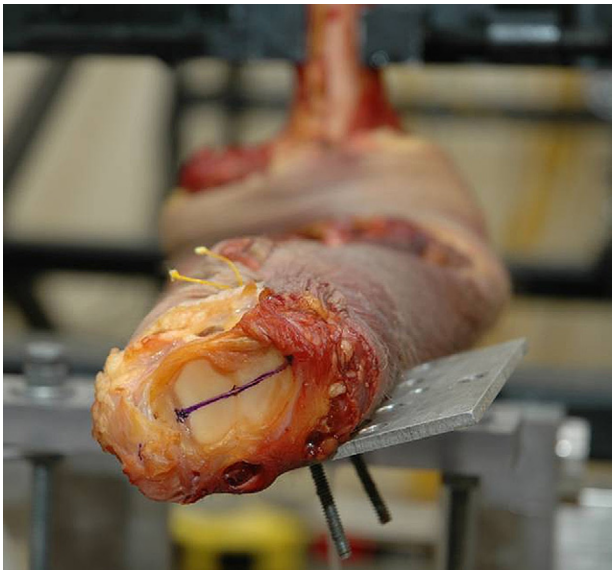

Figure 3 A reference line drawn on the radius that bisected the scaphoid and lunate fossas by connecting the midpoints of the radial styloid and sigmoid notch was used to define forearm rotational position.

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.

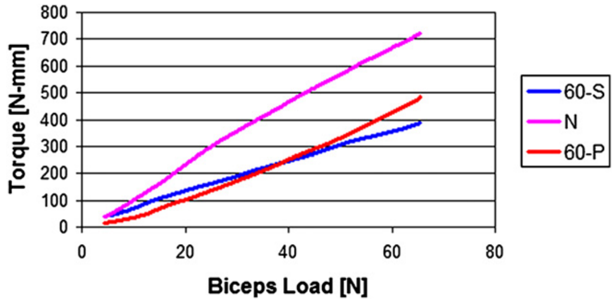

Figure 4 Example of torque vs. biceps load relationship for native tendon for specimen #3

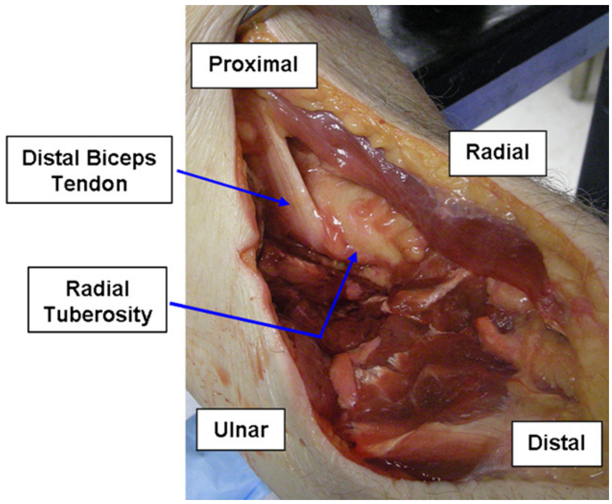

Figure 5 Native distal biceps tendon insertion on posterior ulnar tuberosity.

Moment arm

The supination torque versus biceps load data clearly exhibited a linear relationship by gross observation, as shown by

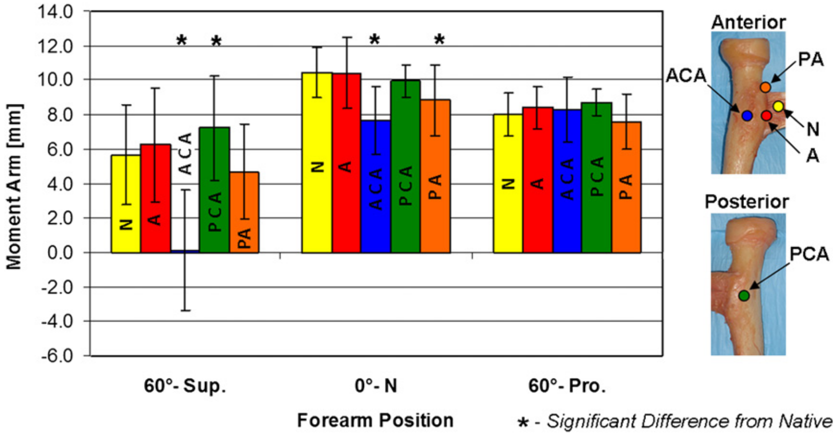

Figure 6 Average moment arm for native tendon and four biceps tendon repairs at three forearm positions. (N, Native [yellow]; *A*, anatomic [red], *ACA*, anterior center axis [blue]; *PCA*, posterior center axis [green]; *PA*, proximal anatomic [orange].) Asterisk (*) indicates significant difference from native tendon.

Figure 4. 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.[11,24,26,30,34,37] 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

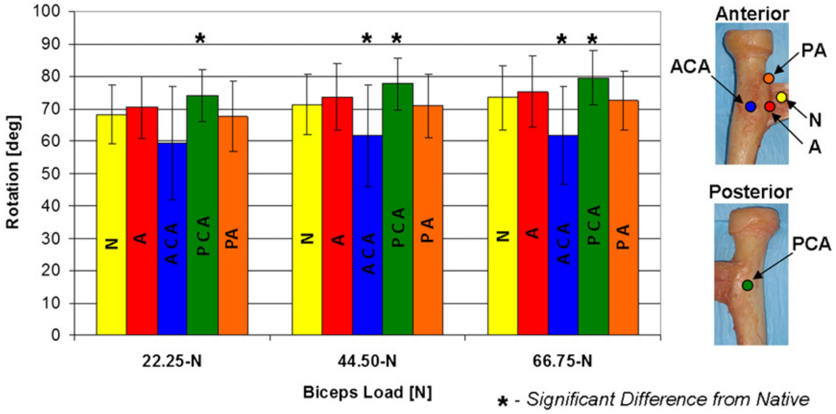

Figure 7 Average supination motion for native tendon and four biceps tendon repairs at 3 different biceps loads. (N, Native [yellow]; *A*, anatomic [red], *ACA*, anterior center axis [blue]; *PCA*, posterior center axis [green]; *PA*, proximal anatomic [orange].) Asterisk (∗) indicates significant difference from native tendon.

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.[23] For the anterior group, the biceps was sutured to the anterior tuberosity using a cortical bone bridge on the posterior tuberosity.[25] Posterior reattachment was done using the modified Boyd-Anderson approach.[38] 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.[14] 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.[3,4,9,11,12,16,24,26,30,32,34,37,40,41,43,44] 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.[16] Isokinetic testing does not typically involve comparisons of peak supination strength

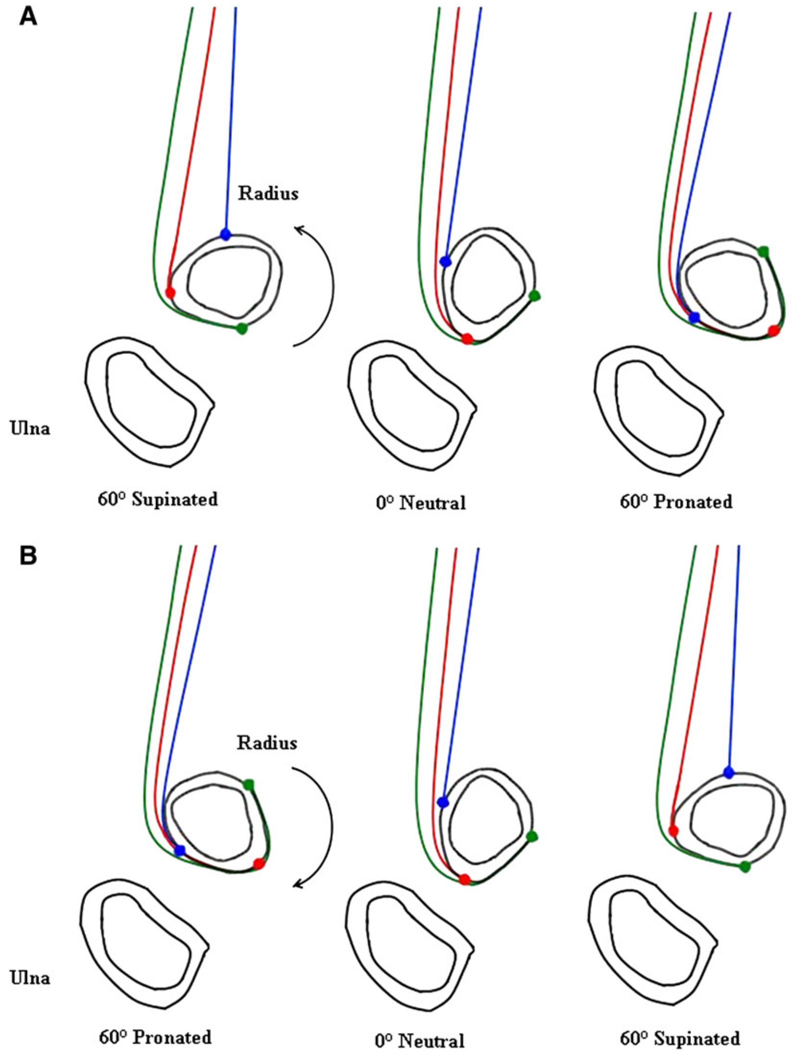

Figure 8 Axial view of right forearm outline. *ACA* (blue), *A* (red), and *PCA* (green). **A,** Schematic of tendon wrapping during pronation. The biceps tendon will only wrap around portions of the tuberosity that are radial to the attachment point as shown. Note how *ACA* never acts over the whole 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.

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 reconstruct the biceps tendon with a graft.[10,19,44] 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

The authors, their immediate families, and any research foundations with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Agins HJ, Chess JL, Hoekstra DV, Teitge RA. Rupture of the distal insertion of the biceps brachii tendon. Clin Orthop Relat Res 1988:34-8.
2. Bain GI, Prem H, Heptinstall RJ, Verhellen R, Paix D. Repair of distal biceps tendon rupture: a new technique using the Endobutton. J Shoulder Elbow Surg 2000;9:120-6. doi:10.1067/2000.102581
3. Baker BE, Bierwagen D. Rupture of the distal tendon of the biceps brachii. Operative versus non-operative treatment. J Bone Joint Surg Am 1985;67:414-7.
4. Balabaud L, Ruiz C, Nonnenmacher J, Seynaeve P, Kehr P, Rapp E. Repair of distal biceps tendon ruptures using a suture anchor and an anterior approach. J Hand Surg [Br] 2004;29:178-82. doi:10.1016/j.jhsb.2003.07.002
5. Boyd JB, Anderson LD. A method for the reinsertion of the distal biceps tendon. J Bone Joint Surg Am 1961;43:1041-3.
6. Bremer AK, Sennwald GR, Favre P, Jacob HA. Moment arms of forearm rotators. Clin Biomech (Bristol, Avon) 2006;21:683-91.
7. Cheung EV, Lazarus M, Taranta M. Immediate range of motion after distal biceps tendon repair. J Shoulder Elbow Surg 2005;14:516-8. doi:10.1016/j.jse.2004.12.003
8. Chillemi C, Marinelli M, De Cupis V. Rupture of the distal biceps brachii tendon: conservative treatment versus anatomic reinsertion—clinical and radiological evaluation after 2 years. Arch Orthop Trauma Surg 2007;127:705-8. doi:10.1007/s00402-007-0326-7
9. D'Arco P, Sitler M, Kelly J, Moyer R, Marchetto P, Kimura I, et al. Clinical, functional, and radiographic assessments of the conventional and modified Boyd-Anderson surgical procedures for repair of distal biceps tendon ruptures. Am J Sports Med 1998;26:254-61.
10. Darlis NA, Sotereanos DG. Distal biceps tendon reconstruction in chronic ruptures. J Shoulder Elbow Surg 2006;15:614-9. doi:10.1016/j.jse.2005.10.004
11. Davison BL, Engber WD, Tigert LJ. Long term evaluation of repaired distal biceps brachii tendon ruptures. Clin Orthop Relat Res 1996;333:186-91.
12. De Carli A, Zanzotto E, Vadala AP, Luzon D, Di Salvo M, Ferretti A. Surgical repair of the distal biceps brachii tendon: clinical and isokinetic long-term follow-up. Knee Surg Sports Traumatol Arthrosc 2009;17:850-6. doi:10.1007/s00167-008-0705-9
13. Eardley WG, Odak S, Adesina TS, Jeavons RP, McVie JL. Bioabsorbable interference screw fixation of distal biceps ruptures through a single anterior incision: a single-surgeon case series and review of the literature. Arch Orthop Trauma Surg 2009;130:875-81.
14. Forthman CL, Zimmerman RM, Sullivan MJ, Gabel GT. Cross-sectional anatomy of the bicipital tuberosity and biceps brachii tendon insertion: relevance to anatomic tendon repair. J Shoulder Elbow Surg 2008;17:522-6. doi:10.1016/j.jse.2007.11.002
15. Freeman CR, McCormick KR, Mahoney D, Baratz M, Lubahn JD. Nonoperative treatment of distal biceps tendon ruptures compared with a historical control group. J Bone Joint Surg Am 2009;91:2329-34. doi:10.2106/JBJS.H.01150
16. Gallagher MA, Cuomo F, Polonsky L, Berliner K, Zuckerman JD. Effects of age, testing speed, and arm dominance on isokinetic strength of the elbow. J Shoulder Elbow Surg 1997;6:340-6.
17. Greenberg JA, Fernandez JJ, Wang T, Turner C. EndoButton-assisted repair of distal biceps tendon ruptures. J Shoulder Elbow Surg 2003;12:484-90. doi:10.1016/S1058-2746(03)00173-3
18. Gregory T, Roure P, Fontes D. Repair of distal biceps tendon rupture using a suture anchor: description of a new endoscopic procedure. Am J Sports Med 2009;37:506-11. doi:10.1177/0363546508326985
19. Hallam P, Bain GI. Repair of chronic distal biceps tendon ruptures using autologous hamstring graft and the Endobutton. J Shoulder Elbow Surg 2004;13:648-51. doi:10.1016/j.jse.2004.01.032
20. Hartman MW, Merten SM, Steinmann SP. Mini-open 2-incision technique for repair of distal biceps tendon ruptures. J Shoulder Elbow Surg 2007;16:616-20. doi:10.1016/j.jse.2006.10.021
21. Haugstvedt JR, Berger RA, Berglund LJ. A mechanical study of the moment-forces of the supinators and pronators of the forearm. Acta Orthop Scand 2001;72:629-34.
22. Heinzelmann AD, Savoie FH III, Ramsey JR, Field LD, Mazzocca AD. A combined technique for distal biceps repair using a soft tissue button

and biotenodesis interference screw. Am J Sports Med 2009;37:989-94. doi:10.1177/0363546508330130

23. Henry J, Feinblatt J, Kaeding CC, Latshaw J, Litsky A, Sibel R, et al. Biomechanical analysis of distal biceps tendon repair methods. Am J Sports Med 2007;35:1950-4. doi:10.1177/0363546507305009
24. Hetsroni I, Pilz-Burstein R, Nyska M, Back Z, Barchilon V, Mann G. Avulsion of the distal biceps brachii tendon in middle-aged population: is surgical repair advisable? A comparative study of 22 patients treated with either nonoperative management or early anatomical repair. Injury 2008;39:753-60. doi:10.1016/j.injury.2007.11.287
25. Kaeding C, Fischer R, Anderson T. Modified distal biceps tendon repair. J Orthop Tech 1996;4:29-32.
26. Karunakar MA, Cha P, Stern PJ. Distal biceps ruptures. A follow-up of Boyd and Anderson repair. Clin Orthop Relat Res 1999:100-7.
27. Kettler M, Lunger J, Kuhn V, Mutschler W, Tingart MJ. Failure strengths in distal biceps tendon repair. Am J Sports Med 2007;35: 1544-8. doi:10.1177/0363546507300690
28. Kettler M, Tingart MJ, Lunger J, Kuhn V. Reattachment of the distal tendon of biceps: factors affecting the failure strength of the repair. J Bone Joint Surg Br 2008;90:103-6.
29. Khan AD, Penna S, Yin Q, Sinopidis C, Brownson P, Frostick SP. Repair of distal biceps tendon ruptures using suture anchors through a single anterior incision. Arthroscopy 2008;24:39-45. doi:10.1016/j.arthro.2007.06.019
30. Klonz A, Loitz D, Wohler P, Reilmann H. Rupture of the distal biceps brachii tendon: isokinetic power analysis and complications after anatomic reinsertion compared with fixation to the brachialis muscle. J Shoulder Elbow Surg 2003;12:607-11. doi:10.1016/S1058-2746(03)00212-X
31. Kuxhaus L, Schimoler PJ, Vipperman JS, Miller MC. Validation of a feedback-controlled elbow simulator design: Elbow muscle moment arm measurement. J Med Devices 2009;3:031002.
32. Leighton MM, Bush-Joseph CA, Bach BR Jr. Distal biceps brachii repair. Results in dominant and nondominant extremities. Clin Orthop Relat Res 1995:114-21.
33. Lemos SE, Ebramzedeh E, Kvitne RS. A new technique: in vitro suture anchor fixation has superior yield strength to bone tunnel fixation for distal biceps tendon repair. Am J Sports Med 2004;32:406-10. doi:10.1177/0363546503261720
34. Lynch SA, Beard DM, Renstrom PA. Repair of distal biceps tendon rupture with suture anchors. Knee Surg Sports Traumatol Arthrosc 1999;7:125-31.
35. Matsuoka J, Berger RA, Berglund LJ, An KN. An analysis of symmetry of torque strength of the forearm under resisted forearm rotation in normal subjects. J Hand Surg [Am] 2006;31:801-5.
36. McKee MD, Hirji R, Schemitsch EH, Wild LM, Waddell JP. Patient-oriented functional outcome after repair of distal biceps tendon ruptures using a single-incision technique. J Shoulder Elbow Surg 2005;14:302-6. doi:10.1016/j.jse.2004.09.007
37. Moosmayer S, Odinsson A, Holm I. Distal biceps tendon rupture operated on with the Boyd-Anderson technique: follow-up of 9 patients with isokinetic examination after 1 year. Acta Orthop Scand 2000;71: 399-402. doi:10.1080/000164700317393411
38. Morrey BF, Askew LJ, An KN, Dobyns JH. Rupture of the distal tendon of the biceps brachii. A biomechanical study. J Bone Joint Surg Am 1985;67:418-21.
39. Murray WM, Delp SL, Buchanan TS. Variation of muscle moment arms with elbow and forearm position. J Biomech 1995;28:513-25.
40. Nesterenko S, Domire ZJ, Morrey BF, Sanchez-Sotelo J. Elbow strength and endurance in patients with a ruptured distal biceps tendon. J Shoulder Elbow Surg 2009;19:184-9. doi:10.1016/j.jse.2009.06.001
41. Peeters T, Ching-Soon NG, Jansen N, Sneyers C, Declercq G, Verstreken F. Functional outcome after repair of distal biceps tendon ruptures using the endobutton technique. J Shoulder Elbow Surg 2009; 18:283-7. doi:10.1016/j.jse.2008.10.004
42. Safran MR, Graham SM. Distal biceps tendon ruptures: incidence, demographics, and the effect of smoking. Clin Orthop Relat Res 2002: 275-83. doi:10.1097/01.blo.0000026560.55792.02
43. Weinstein DM, Ciccone WJ II, Buckler MC, Balthrop PM, Busey TD, Elias JJ. Elbow function after repair of the distal biceps brachii tendon with a two-incision approach. J Shoulder Elbow Surg 2008;17:82S-6. doi:10.1016/j.jse.2007.07.006
44. Wiley WB, Noble JS, Dulaney TD, Bell RH, Noble DD. Late reconstruction of chronic distal biceps tendon ruptures with a semitendinosus autograft technique. J Shoulder Elbow Surg 2006;15:440-4. doi:10.1016/j.jse.2005.08.018