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Distal Biceps Tendon Repair

A Cadaveric Analysis of Suture Anchor and Interference Screw Restoration of the Anatomic Footprint

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Background: Distal biceps tendon repair with interference screw or double suture-anchor fixation are 2 successful techniques performed with either 1- or 2-incision approaches. No study has examined the accuracy and quality of the repaired tendon footprint with these devices and approaches.

Hypothesis: A 2-incision approach will allow a more anatomic repair of the distal biceps footprint compared with a 1-incision anterior approach. Fixation technique will affect insertional footprint location and footprint contact area.

Study Design: Controlled laboratory study.

Methods: After randomization, 36 distal biceps repairs were performed on human cadaveric upper extremity specimens, with 1- or 2-incision approaches and with fixation devices of either two 5.5-mm suture anchors or an 8-mm interference screw. Native and repaired footprint areas and centroid location were calculated with a 3-dimensional digitizer.

Results: Interference screw repair had the smallest footprint area (135 mm^2) compared with suture anchor repair (197 mm^2) and the native tendon (259 mm^2) (P = .013). The 2-incision approach repaired the footprint to a more posterior and anatomic position (2.5 mm) than a 1-incision approach (P = .001). The fixation device did not affect footprint location significantly.

Conclusion: Suture anchor repair more closely re-creates the footprint area on the radial tuberosity of the native distal biceps tendon compared with the interference screw repair. A 2-incision approach more closely re-creates footprint position compared with the 1-incision approach.

Clinical Relevance: A 2-incision approach with double suture-anchor fixation may yield a more anatomic distal biceps repair based on reproduction of the footprint compared with a 1-incision approach.

Keywords: distal biceps; footprint; repair; interference screw; suture anchor

Distal biceps tendon rupture is a rare injury that usually occurs in middle-aged men after a forced eccentric contraction of the dominant arm.[2,7,30,31] This rupture causes weakness of forearm supination (40%) and elbow flexion (20%) strength compared with the unaffected arm.[25] Repair of acute distal biceps tendon ruptures is recommended in all active and compliant patients to restore supination strength and elbow function.[16,19,25]

Many methods of distal biceps tendon repair have been described,[†] with the first technique performed by tunneling the distal tendon into the radial tuberosity and securing it with transosseous sutures. A 2-incision approach was recommended by Boyd and Anderson[4] to lessen the risk of radial nerve injury, although rates of radioulnar synostosis were significant. A muscle-splitting modification[25] minimized periosteal injury and rates of heterotopic bone formation have been successfully reduced.[16,22] More recently, new fixation devices such as suture anchors, interference screws, and fixation buttons have been introduced and biomechanically tested,[14,17,21,23,29] demonstrating encouraging

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early results.[3,10,18] Current repair methods generally fall into categories of approaches and fixation techniques. Approaches include 1-incision techniques, in which the ruptured tendon is reattached through an anterior incision, or 2-incision techniques, in which the tendon is reattached from a dorsal approach. Fixation techniques include bone tunnels, interference screws, suture anchors, and cortical buttons.

A major goal of distal biceps repair is to reestablish flexion and supination strength.[33] The supination torque of the biceps is related to its insertion site on the radial tuberosity.[11] The distal biceps tendon wraps around the bicipital tuberosity and inserts on its posterior and ulnar aspect when the forearm is fully supinated,[13] such that the tuberosity functions as a cam to increase the moment arm that is required for supination.[11] Despite numerous biomechanical evaluations to determine fixation strength of different repairs, studies have not focused on the functional anatomy of the repair. Given the importance of biceps insertion anatomy in re-creating the biceps supination mechanics,[20] the objective of this study was to characterize the insertion characteristics of the native biceps tendon and the insertion after repair. We hypothesized that surgical approach and fixation technique may show differences in re-creating the native biceps insertional footprint area and location.

METHODS

Nine matched pairs of fresh-frozen human cadaveric arms were used in this study and 36 distal biceps repairs were performed after computer-generated randomization to a 1-incision or a 2-incision approach as well as to fixation method with either 2 suture anchors or an interference screw. For each matched pair, 1 arm received either a 1-incision suture anchor repair followed by a 2-incision interference screw repair or with this sequence reversed, while the other arm of the matched pair received either a 1-incision interference screw repair followed by a 2-incision suture anchor repair or with this sequence reversed. Therefore, each set of matched pair elbows received all 4 combinations of surgical approach and fixation technique in a randomized allotment. The average age of the cadavers used was 62 ± 12 years, and 89% of the specimens were male.

The anterior approach to the elbow was made through a transverse incision over the distal antecubital crease. The brachioradialis was retracted laterally and the pronator teres medially, and the biceps tendon was identified and dissected down to the attachment onto the tuberosity. To apply static loading to the biceps tendon, the tendon was transected 8 cm proximal to its distal insertion and the muscle removed from the tendon. A running whipstitch was placed in the proximal aspect of the tendon and connected to a pulley system loaded with 30 N in line with the pull of the native biceps. If randomized to the 2-incision approach, the approach was performed as described by Morrey et al.[25] With the forearm in full pronation, a blunt curved clamp was inserted through the interosseous space

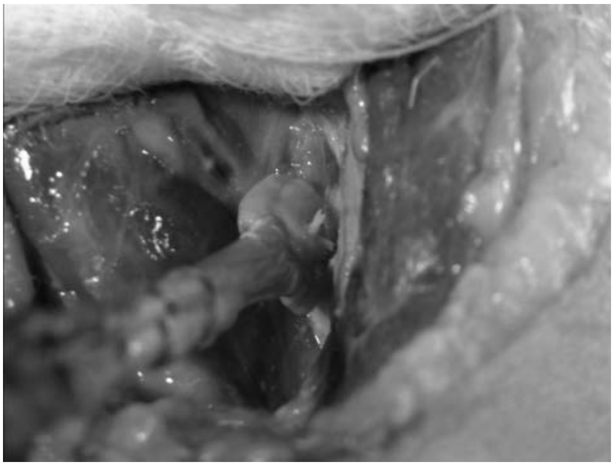

Figure 1. Suture anchor repair via a single anterior approach.

intermuscularly toward the radial tuberosity. A longitudinal incision was made over the palpated clamp and the underlying muscle was split to expose the radial tuberosity (Figure 1).

The specimens were mounted in a joint rig statically secured proximally via the humerus and dynamically controlled distally via a transmetacarpal fixation system so that reliable 3-dimensional digitization of the biceps footprint could be obtained. A lag bolt was placed in the medullary canal of the midshaft of the humerus, and mounted in a 2-inch–diameter steel pipe filled with Rockite expansion cement (Hartline Products, Cleveland, Ohio) and securely mounted in a custom rig. The elbow was maintained at 90° of flexion and full supination by securing the hand between 2 flat clamps attached to a U-shaped holder. The native footprint of the distal biceps was measured by digitizing the periphery of the biceps tendon attachment onto the proximal radius using a MicroScribe 3-dimensional digitizer with accuracy of 0.23 mm (Immersion Corporation, San Jose, California).

Distal tendon transection was performed sharply on the tuberosity and then the randomization card was opened for allotment of surgical approach and fixation method. If a 1-incision approach was allotted, then the anterior approach already used for exposing the native tendon was used for the repair (Figures 1 and 2); if randomized to a 2-incision approach, a posterior-lateral approach was made to expose the tuberosity in full pronation. Attention was then placed on repair of the distal biceps tendon. The arm was placed in pronation for the 2-incision approach and implants were placed through the posterior incision. For the 2-incision approach, implants were placed through the anterior approach. Figure 2 illustrates the 1- and 2-incision approaches.

Interference Screw Fixation

A No. 2 braided nonabsorbable suture was placed with a Krackow stitch in the distal end of the biceps tendon for 3 cm. A 2.8-mm pin with an eyelet was placed into the central

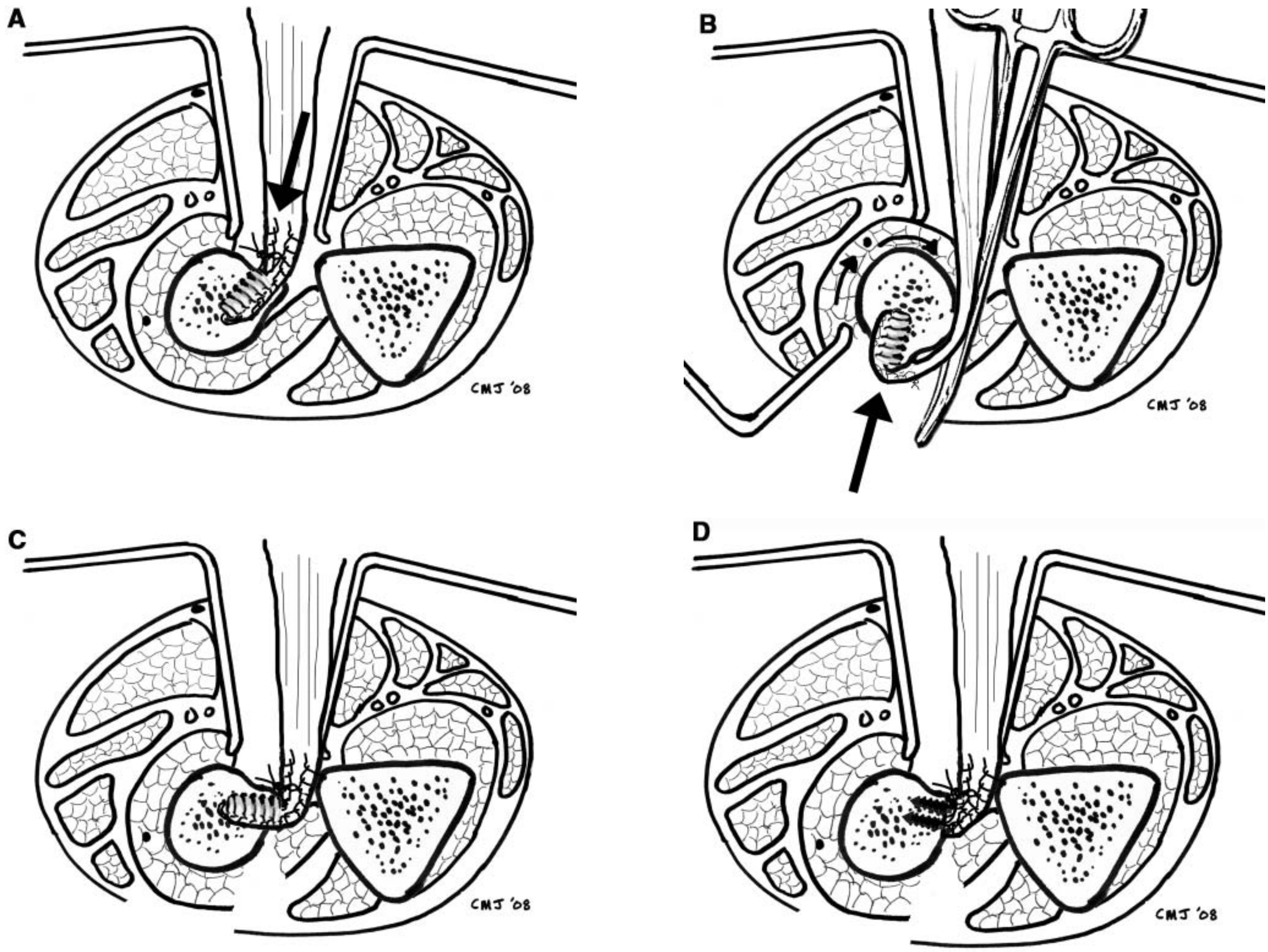

Figure 2. A, axial view of the 1-incision approach with forearm in full supination with implantation of interference screw. Notice how the insertion angle (arrow) is limited by the approach and that only the anterior aspect of the biceps tuberosity is available for device implantation. B, axial view of the 2-incision approach with the forearm pronated, demonstrating implantation of an interference screw from the posterior incision. Notice how the insertion angle (arrow) is unrestricted and that the posterior portion of the biceps tuberosity is available for device implantation. C, axial view of a 2-incision approach after interference screw repair with the forearm returned to full supination to demonstrate the relative posterior location of the repair on the tuberosity compared with the 1-incision approach shown in Figure 2A. D, axial view of a 2-incision approach after suture anchor repair, with the forearm returned to full supination. Regardless of fixation device, the location of the repaired biceps footprint depends on the approach used during device insertion.

aspect of the radial tuberosity and drilled through both cortices. An 8-mm cannulated reamer was used to drill through the proximal cortex to a depth of 14 mm. The 8 mm × 12 mm Bio-Tenodesis screw (Arthrex, Naples, Florida) and driver system were assembled and positioned in the hole with the tendon abutting the floor of the drilled hole. The tendon was stabilized with forceps on the posterior and ulnar side of the bone tunnel and the screw was advanced via the tenodesis driver. After the screw was inserted and the tenodesis driver removed, the suture passing through the cannulated screw was then tied around the outside of the distal biceps to enhance the fixation (Figure 3).

Suture Anchor Fixation

The 2 suture anchors were positioned approximately 8 mm apart in the proximal and distal aspects of the posterior-ulnar quadrant of the tuberosity. The appropriately sized punch and tap were used and 5.5 mm × 15 mm fully threaded poly-L-lactide (PLLA) suture anchors were placed in the holes loaded with 2 No. 2 FiberWire sutures (Arthrex). One limb of each anchor was sutured in a running whipstitch and then the 2 free ends tied together. The other limbs of these sutures were used to tension the repair and tied (Figure 4 and Figure 2D).

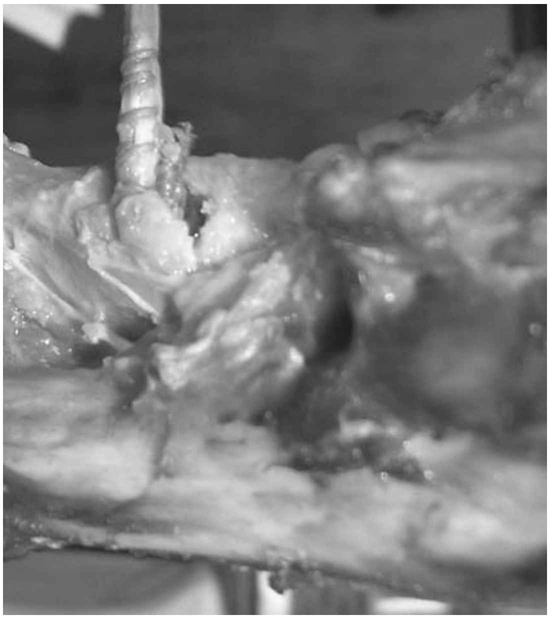

Figure 3. Interference screw fixation of the distal biceps in a right forearm after a 2-incision approach. The soft tissue was removed around the elbow capsule to allow full visualization of the repair.

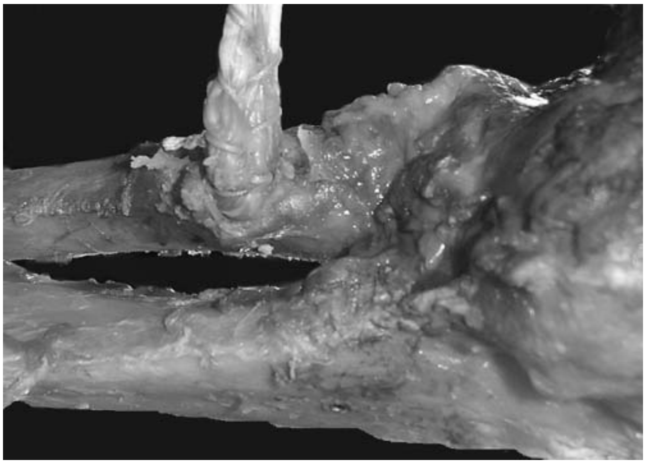

Figure 4. Double suture-anchor fixation of the distal biceps in a right forearm. The soft tissue was removed around the elbow capsule to allow full visualization of the repair.

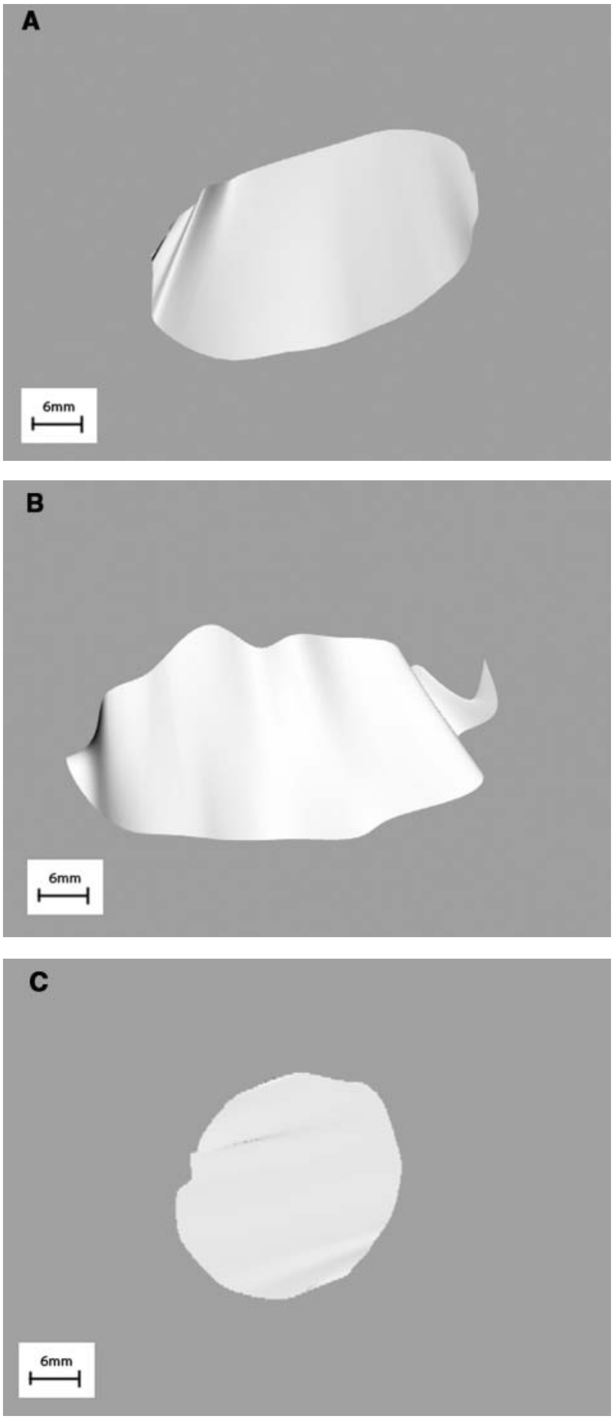

Figure 5. Computer-generated graphic representation of the distal biceps footprint as calculated via the 3-dimensional digitizer. A, native tendon footprint, 379 mm^2; B, suture anchor footprint, 393 mm^2; C, interference screw footprint, 150 mm^2.

Footprint Measurement

The footprint was again measured via the anterior incision with the elbow flexed to 90° and the forearm in full supination with 30 N of static load applied to the biceps tendon. The reconstructed footprint was measured via the 3-dimensional digitizer by following the periphery of the point of contact between the newly repaired tendon and the radius cortex. The NURBS modeling from Rhino version 4.0 software (McNeal and Associates, Seattle, Washington) was used to calculate the surface area of this footprint and the center, or centroid, of this irregular-shaped footprint area (Figure 5).

Measurement Technique and Validation

The location and rotational orientation of each bone were measured by triads of location points rigidly fixed on the humerus, radius, and ulna. A fixed coordinate system was set by the orientation of the mounted specimens with 90° of supination and the elbow flexed to 90°. The x-axis was defined as the anterior direction relative to the proximal radius; the y-axis, as the distal direction toward the wrist; and the z-axis, as the ulnar direction in right-handed specimens. Left-handed specimens had the z-axis data transformed so that comparisons could be made between left-and right-handed specimens. Data were collected 5 times for each of the points on each triad for each bone. The relative location and rotational orientation of these triads were defined in the fixed coordinate system. Multiple validation experiments were run to confirm the accuracy and reproducibility of the measurements obtained from the 3-dimensional digitizer. Five measurements of a fixed point on the humerus reproducibly found a location with a standard deviation of <0.1 mm in each axis. Five repeated measurements of a single native biceps footprint area had a standard deviation of 16 mm^2. Distance calibration was confirmed measuring the distance of 20 mm 5 times between the points of a Vernier caliper with 0.1-mm resolution. Comparison of footprint data between experimental interventions (for example, between native distal biceps and single-approach suture-anchor fixation) was made when the arm was placed in the same full supination position. Any slight rigid body motion of the radius relative to the fixed humerus after the arm was placed in the same supination position was corrected by using transformation algorithms defined between the body-centered coordinate system of the radius and the fixed coordinate system of the humerus.

Statistical Analysis

Multivariate analysis with factors of approach and fixation method was performed in a general linear model with SPSS software (SPSS Inc, Chicago, Illinois) to confirm that both approach and fixation method had a significant effect on both footprint area and centroid location. A *P* value of <.05 was considered significant. Then, repeated-measures analyses of variance were run on both footprint area and centroid location. A Student-Newman-Keuls multiple comparisons test was used to discern differences between fixation methods and the native biceps footprint area. Separate 1-way repeated-measures analyses of variance were run and another analysis of variance with side as the factor was run to confirm that there was no significant difference between left and right specimens. Data are presented as means ± standard deviation in the article text, and means with 95% confidence interval and standard error of the mean in the tables.

RESULTS

All repairs were successful without implant failure or fracture. Both the fixation technique (*P* = .020) and the approach (*P* = .027) were significant factors in determining footprint area and footprint position.

Footprint Area

There was no difference in the footprint area between native left (257 ± 106 mm^2) and right (260 ± 69 mm^2) distal biceps insertions. The native footprint area (259 ± 87 mm^2) was found to be statistically larger than the repaired footprint area with suture anchors for both 1-incision (187 ± 46 mm^2) and 2-incision (201 ± 58 mm^2) approaches, which in turn was statistically larger (*P* = .013) than the footprint area of the interference screw fixation for 1-incision (133 ± 64 mm^2) and 2-incision (138 ± 55 mm^2) approaches. Suture anchor fixation created an oval-shaped footprint similar in appearance to the native footprint and interference screw fixation created a more circular-appearing footprint. There was no significant difference in the footprint area between the 1-incision and the 2-incision approaches for either the suture anchor or interference screw techniques (*P* = .66).

Footprint Location

The repaired distal biceps footprint was significantly more anterior (2.51 mm) when a 1-incision approach was performed compared with a 2-incision approach (*P* = .001). There was no significant malposition of the footprint in either the proximal-distal direction or the ulnar-radial direction compared between approaches or fixation devices. The overall average distance of translation of the repaired footprint centroid compared with the native footprint centroid was 3.8 mm for different repair types. The interference screw fixation footprint was found to be slightly more posterior and ulnar (0.20 mm and 0.24 mm, respectively) than the suture-anchor repair footprint (–0.27 mm and 0.03 mm, respectively), but this difference was not significant. Only the anterior-posterior direction had significant differences between combinations of approach and fixation devices, which are summarized in Tables 1 and 2.

DISCUSSION

The radial tuberosity and distal biceps insertion footprint are important structures affecting forearm supination mechanics, and an anatomic repair of a ruptured tendon is important for restoration of power, endurance, and terminal forearm rotation.[11] Repairs that malposition the footprint to the anterior aspect of the tuberosity likely reduce the supination torque capacity compared with anatomic repairs.[11] A posteriorly located footprint repair is important for restoration of supination torque because in this position, the tuberosity functions as a cam to increase the moment arm for torque production. A recent biomechanical study demonstrated that both 1-incision and 2-incision distal biceps repairs provide near equal force of flexion, but a 2-incision repair increased supination torque by approximately 20% compared with an anterior repair.[11] Our study confirms that distal biceps repairs through a 1-incision approach have a more anterior footprint than the native

TABLE 1
Repaired Footprint Location Compared With Native Footprint[a]

	1-Incision: Anterior Approach			2-Incision: Anterior/Posterior Approach			Significant Difference[b]
	mm	SEM	95% CI	mm	SEM	95% CI	
Anterior	1.29	0.53	0.16 to 2.42	–1.22	0.42	–2.11 to –0.32	P = .001
Distal	0.09	0.56	–1.09 to 1.27	0.29	0.63	–1.03 to 1.62	
Ulnar	0.03	0.48	–0.98 to 1.04	0.25	0.32	–0.44 to 0.93	
Distance	3.78	0.36	3.01 to 4.54	3.08	0.42	2.20 to 3.96	
	Suture Anchor			Interference Screw			
	mm	SEM	95% CI	mm	SEM	95% CI	
Anterior	0.27	0.56	–0.94 to 1.47	–0.20	0.57	–1.39 to 0.99	
Distal	–0.26	0.65	–1.35 to 0.83	0.64	0.52	–0.72 to 2.01	
Ulnar	0.03	0.45	–0.72 to 0.79	0.24	0.36	–0.71 to 1.20	
Distance	3.66	0.38	2.86 to 4.45	3.20	0.41	2.32 to 4.08	

[a]The 1-incision anterior approach had an anteriorly located footprint compared with a 2-incision approach that had a posteriorly located footprint. The difference between these approaches was 2.51 mm in the anterior-posterior direction. SEM, standard error of the mean; CI, confidence interval.
[b]Fixation with either interference screw or suture anchor did not significantly affect footprint location.

TABLE 2
Anterior Location of Repaired Footprint Compared With Native Tendon[a]

	1-Incision Approach		2-Incision Approach	
	mm	95% CI	mm	95% CI
Suture anchor	1.84[b]	0.14 to 3.54	–1.31[b]	–2.41 to –0.21
Interference screw	0.73[b]	–1.04 to 2.51	–1.13[b]	–2.82 to 0.56

[a]The 1-incision approaches had more anteriorly located footprints. CI, confidence interval.
[b]Significant differences: 1-incision suture anchor versus 2-incision suture anchor (P = .002), 1-incision interference screw versus 2-incision suture anchor (P = .039), 1-incision suture anchor versus 2-incision interference screw (P = .011).

tendon compared with repairs performed via a 2-incision approach. The 2-incision approach uses the posterior incision for tuberosity exposure and tendon fixation and, not surprisingly, these repairs tended to be more posterior. The reason for this difference is likely that the anterior exposure only allows the anterior portion of the footprint to be accessed for repair and does not provide an ideal angle to insert the implant on the tuberosity (Figure 2). In contrast, the 2-incision approach facilitates exposure to the entire tuberosity, including the posterior aspect, and provides an optimal angle for insertion of the fixation implant (Figure 2).

Our findings are consistent with those of other anatomical studies. A CT study concluded that 35% of radial tuberosities were oriented in a position that prohibited anatomic reinsertion with a 1-incision approach, although no repairs were actually performed.[9] The reason for insertion malpositioning with anterior approaches is that the bony morphologic characteristics of the tuberosity are unpredictable,[9,13,24] with an angular orientation ranging from 75° to –30° relative to the coronal forearm plane in full supination.[9] This variability of the tuberosity angular orientation supports using a 2-incision approach to ensure adequate exposure of the tuberosity for more anatomic repairs, which is confirmed with our study.[9,13]

We found no difference in the location of the repaired footprint between interference screw and suture-anchor fixation. Suture anchors pull the tendon down to the tuberosity in line with the anchor, while interference screws compress the tendon to the side of a bone tunnel, resulting in an eccentric position within the tunnel. Theoretically, this eccentric tendon location within the bone tunnel allows for a more anatomic posterior and ulnar tendon position. We in fact expected that for a 1-incision approach, interference screw fixation would more anatomically position the tendon repair compared with the suture-anchor repair. The reason the repair locations were similar for interference screw and suture-anchor fixation methods is that the tunnel for interference screw fixation must be drilled more anterior and central within the radius to avoid cortical blowout. Therefore, while the interference screw places the tendon repair in a more posterior and ulnar position within the tunnel, the overall tendon position is offset by the tunnel being drilled relatively more anterior and radial. Suture anchors have more freedom to be placed in a posterior and ulnar position without compromising the fixation, and therefore these suture-anchor repairs resemble the location of the interference screw repair.

To our knowledge, this is the first study to evaluate the distal biceps insertion footprint with different repair techniques. Double suture-anchor repairs restore a larger footprint area than interference screw repairs regardless of

1- or 2-incision approach. These repaired footprints were also smaller than the native footprint, which has been previously measured and defined with a semilunar configuration on the posterior and ulnar aspect of the tuberosity.[1,9,13] The importance of a broad footprint area for tendon-to-bone healing has not been studied in the distal biceps, but authors have proposed that an anatomic repair and restoration of the native footprint will maximize clinical outcomes.[24] In rotator cuff repair studies, larger pressurized footprint areas are advantageous for tendon-to-bone healing and strength.[26-28] Animal studies are inconclusive as to the optimal method to attach tendon to bone so that direct healing may occur.[32] In our study, there were inherent differences in the tendon-to-bone fixation as interference screw fixation compresses tendon to bone within a tunnel, while suture anchors pull the tendon down to the tuberosity surface. Interference screw tunnels provide an intraosseous area for tendon-to-bone healing, which may or may not be beneficial. Compression within the bony tunnel may create an avascular tendinous state and inhibit tendon healing to the tunnel walls. Studies on interference screw fixation in sheep anterior cruciate models demonstrate loss of tendinous material within bone tunnels with evidence of tendon-to-bone healing, mostly at the tunnel aperture where fibers experience tension.[12,34] Nevertheless, the optimal fixation method for tendon-to-bone healing is still unknown, but larger areas with stable fixation are likely advantageous.

The clinical importance of restoring an anatomic footprint of the distal biceps is controversial and likely balances between the risks of a 2-incision approach versus the limited exposure but minimally invasive nature of a 1-incision anterior approach. Recent clinical studies have found minimal differences between 1- and 2-incision approaches in terms of serious complications, reruptures, and flexion and supination strength and endurance.[5,6,8,15] Even when an anatomic repair is performed with a 2-incision approach, the injured arm may have 10% deficit of supination strength compared with the uninjured arm.[6] Nevertheless, if the chosen fixation method is strong enough to withstand the early forces of rehabilitation so that tendon-to-bone healing may occur, then an anatomic repair will likely provide the most durable repair and restore the mechanical characteristics of forearm supination and flexion.

This study has a few shortcomings, as it is a cadaveric study without measurement of biologic healing. It assumes that an anatomic reconstruction is best for healing and function, although no study has been able to demonstrate an advantage. The age of our specimens was older (62 years) than the typical patient with a ruptured biceps. Also, the exact surface area of tendon-to-bone apposition is not directly measured by our technique, but rather the surface area created by the circumference of the repaired footprint was calculated. However, our finding that the footprint areas between the 1- and 2-incision approaches for either repair technique were very similar was consistent with our expectation that the approach should have minimal impact on the footprint area.

In conclusion, a double suture-anchor distal biceps repair more closely approximates the footprint area of the native tendon compared with an interference screw repair. We found that a 2-incision approach provided a footprint location in a more posterior and anatomic location. Clinically, it is unknown if an anatomic repair of the distal biceps will afford a measurable advantage, but in theory a posteriorly positioned anatomic footprint may better restore the supination mechanics of the forearm.

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