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The effect of tendon rotation on distal biceps repair

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Background: The distal biceps tendon externally rotates from proximal to distal before inserting onto the radius. Our hypothesis is that an externally rotated (anatomic) repair would re-create native supination moment arm and flexion force, whereas an internally rotated (nonanatomic) repair would result in reduced force transmission.

Methods: The mechanical tests performed in this study measured isometric moment arms and elbow flexion force using a validated elbow simulator as previously published. Mechanical testing was performed on 8 native cadaveric elbows (61 ± 15 years). The distal biceps tendons in all specimens were then incised from their footprint and repaired with anatomic and nonanatomic tendon rotations. After each repair, the specimens were retested. The repair sequence was randomly assigned.

Results: Gross observation showed repair site bunching with the nonanatomic repairs. There was no statistical difference in the moment arms between the native, anatomic, and nonanatomic rotations for the 3 forearm angles ($P \geq .352$). Analysis showed no statistical difference in flexion force ratio for the elbow at 90° ($P \geq .283$).

Discussion: The study showed that biceps tendon rotation does not play a role in supination moment arm or flexion force. Twisting the distal biceps tendon around the tendon axis does not change the direction of its applied force on the tuberosity. Tendon bunching in nonanatomic reattachments increases repair site width, which may lead to tendon-ulnar impingement during forearm rotation.

The distal biceps tendon consists of short and long heads that externally rotate as it travels from the myotendinous junction to the radial tuberosity (Fig. 1).[1,11,20] Proximally, the short head is medial to the long head, and as the tendon twists from the coronal to the sagittal plane, the rotation places the short head distal to the long head on its radial insertion.[1,5,11] The 2 heads of the tendon both insert onto its radial footprint just posterior to the radial protuberance (Fig. 2).[19] The protuberance acts as a cylindrical cam, increasing biceps supination torque.[19] Ruptures of the distal biceps tendon can decrease supination strength by 22%-50% and flexion strength by 12%-40%.[2,9,13,14,18]

Cadaveric mechanical studies have demonstrated that reattaching the distal biceps tendon to its anatomic footprint and preserving the radial protuberance lead to a return of native supination moment arms and flexion strength.[16,19,21] However, in clinical practice, restoration of full supination strength comparable to that of the uninjured arm rarely occurs during a full range of motion.[4,7,17] A study using postoperative magnetic resonance imaging scans verified an anatomic reattachment site and radial protuberance preservation, but the injured arm recovered 81.3% ± 16.4% of isometric supination strength normalized to the contralateral side in 60° of forearm supination ($P = .027$).[17]

During surgery, the tendon could easily become internally rotated and reattached with the long head distal to the short head (nonanatomic; Fig. 3). This surgeon-controlled repair step might

Institutional Review Board approval was not required for this Basic Science Study.

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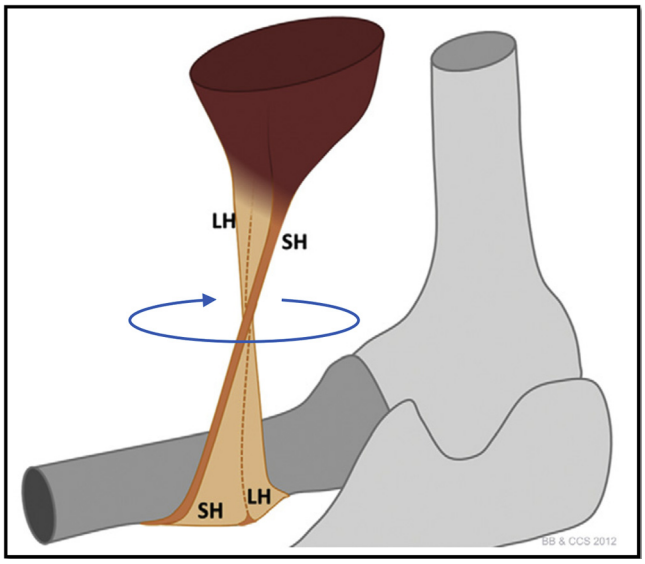

Figure 1 The schematic illustrates the external rotation of the biceps tendon from its myotendinous junction to its insertion on the radius. The short head (*SH*) of the biceps is medial to the long head (*LH*) proximal, and with tendon external rotation, the short head inserts distal to the long head on the radial tuberosity. (Reproduced with permission from[20]).

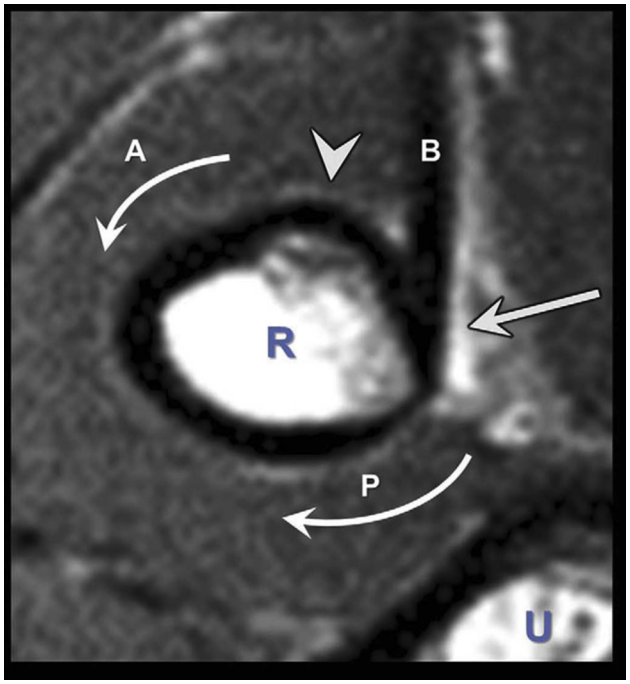

Figure 2 Magnetic resonance imaging axial view through the center of the distal biceps insertion. The biceps tendon (*B*) inserts onto the radius (*R*) just posterior to the radial protuberance (≫); ⇀, biceps insertion; *U*, ulna; *A*, arc of the radial protuberance anterior to biceps insertion; *P*, arc of the radial protuberance posterior to biceps insertion. (Reproduced with permission from[19]).

influence postoperative forearm supination and elbow flexion strength. To our knowledge, no study has attempted to quantify the effect of the tendon rotation on the ability of the biceps to act as a forearm supinator or elbow flexor.

Our hypotheses are that an externally rotated distal biceps reattachment (anatomic) would restore native forearm supination moment arm and elbow flexion force, whereas an internally rotated reattachment (nonanatomic) would result in reduced force transmission.

Materials and methods

Before initiation of this study, approval was obtained to use cadaveric specimens from the institution of the principal investigator. Eight human male upper extremity cadaveric specimens (average age, 61±15 years; range, 45-75 years) were used in this study. No specimens were obtained from donors with preexisting degenerative or inflammatory arthritis. Specimens were verified to have preservation of proximal and distal biceps tendons. All specimens demonstrated full elbow and forearm range of motion.

Isometric forearm supination moment arms and elbow flexion force ratios were measured in this study as previously described.[19,21] Testing was first performed on cadavers with intact

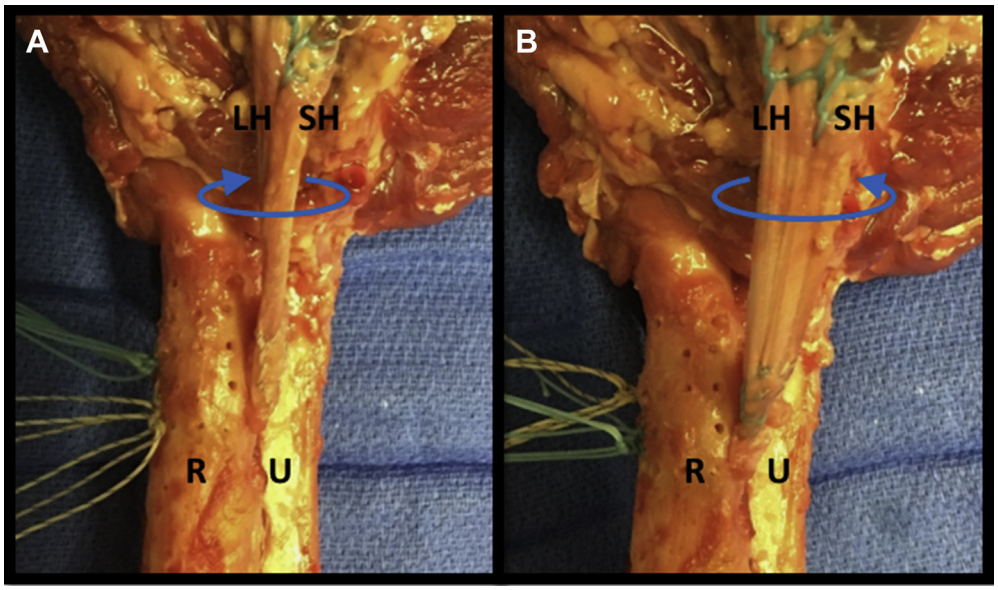

Figure 3 (**A**) Image showing the distal biceps tendon externally rotating as it travels from the myotendinous junction to the radial tuberosity. (**B**) Image showing an incorrect rotation of the distal biceps tendon internally rotating as it travels from the myotendinous junction to the radial tuberosity. The short head (*SH*) is connected to bone with *striped suture*, the long head (*LH*) with *solid suture*. *R*, radius; *U*, ulna.

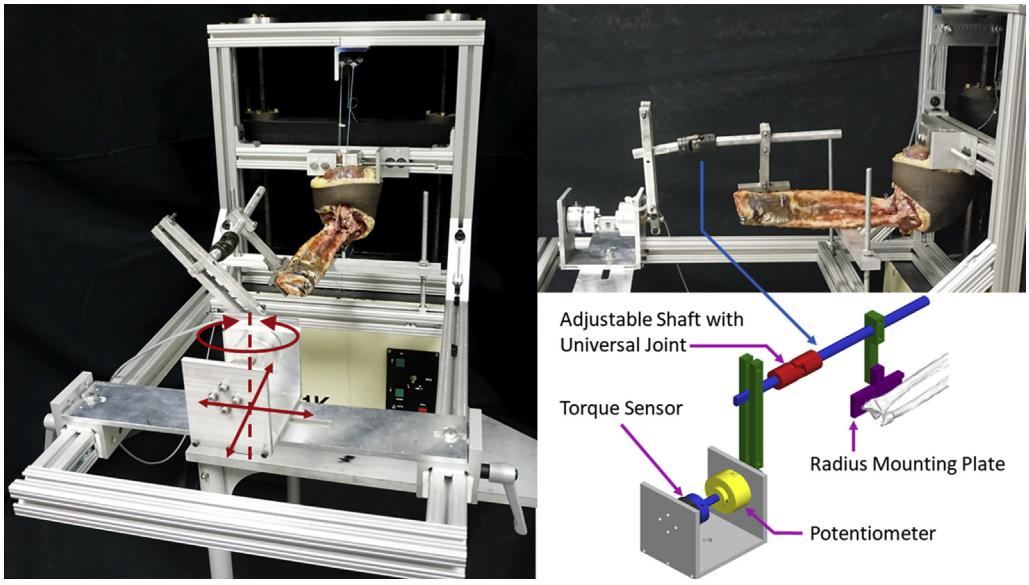

Figure 4 An image and schematic of the device used for the forearm supination torque test. The humerus and ulna were fixed to the frame at 90° of flexion. The radius was attached to an adjustable shaft and torque sensor.

distal biceps tendons. After baseline testing, the distal biceps tendons were detached at their insertion sites and reattached to their footprint in tendon external rotation (anatomic; Fig. 3, *A*) or internal rotation (nonanatomic; Fig. 3, *B*). The sequence of reattachment and subsequent mechanical testing was determined randomly using a random number generator (MATLAB; MathWorks, Inc., Natick, MA, USA). A resting period was allowed between tests of the 3 different states (native, external rotation, internal rotation).

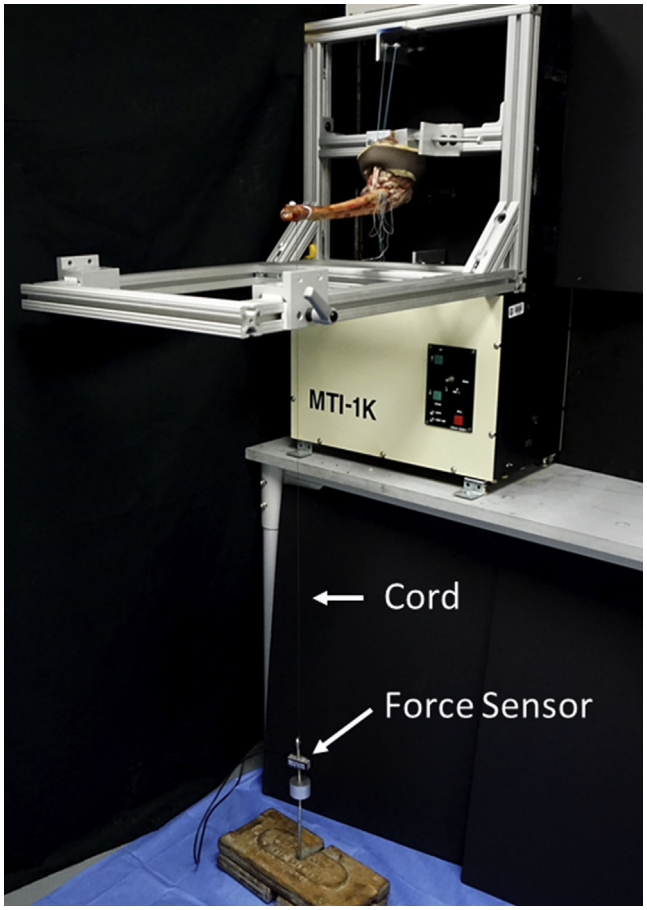

Figure 5 The elbow flexion test setup. The elbow was held at 90° of flexion using a cord containing a force sensor attached to the distal forearm.

Specimen preparation

Care was taken to measure and to record the native proximal short and long head biceps force vectors (lines of pull) for each specimen before mechanical testing. The cadaver-specific biceps vectors were reproduced using an adjustable pulley system mounted to the elbow simulator designed to simulate the coracoid and bicipital humeral groove. The vectors were replicated by suturing the proximal short and long heads with individual Krackow sutures (No. 2 heavy sutures). The short head suture limbs were tunneled under the skin toward the coracoid; the long head suture limbs were directed toward the bicipital groove. The respective sutures were pulled tight and tensioned at 90° of elbow flexion. Using the length of the short and long head sutures, the distance from radial tuberosity to each landmark, and the angle between the long axis of the radius and the distal biceps tendon, the short and long head vectors were calculated using a custom MATLAB program. After vector calculations, the humeri were osteotomized, and the proximal portion of the skin and the biceps and triceps muscles were circumferentially removed for clamp fixation to the elbow simulator. The wrist was then disarticulated, and the dorsal and volar forearm muscles were removed. The proximal radioulnar joint, biceps tendon, interosseous membrane, and distal radioulnar membrane were preserved. The specimens were mounted to the simulator, and the pulleys were adjusted according to MATLAB calculations to duplicate the short and long head force vectors (Fig. 4).

Testing of the native (uninjured) tendon was performed first. The tendon of the distal biceps was then detached from the insertion site at the bicipital tuberosity. The insertional footprint was cleared of residual tissue, and 3 bicortical holes were drilled using a 2.0-mm drill bit.[11] The drill holes were oriented with the

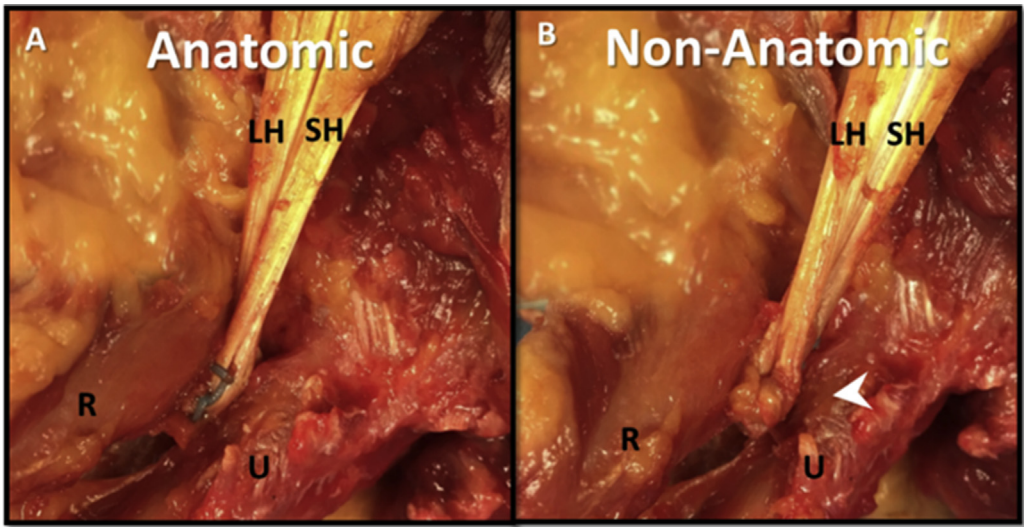

Figure 6 A distal biceps tendon repaired in different orientations. (**A**) The anatomic repair seemed to insert in a ribbon-like form, like the native tendon. (**B**) The nonanatomic repair seemed to bunch at the tendon-bone interface (≫). *LH*, long head; *SH*, short head; *R*, radius; *U*, ulna.

central hole sitting between the insertion sites of the long and short heads. The distal tendons of the long and short heads were sutured using the Krackow method with heavy No. 2 suture. Striped suture was used for the short head and solid suture was used for the long head. With the tendon in external rotation, as in native anatomy, the medial striped suture limb from the short head was passed through the distal drill hole, and the lateral solid suture limb from the long head was passed through the proximal hole. The center sutures from both the short and long heads were passed through the center drill hole. The respective like suture limbs were tied over the bone bridges to secure the reattachment. Removable knots were used to allow facile removal after each test state. For testing of the tendon in internal rotation (nonanatomic repair), the reverse was performed as the short head (striped) was attached proximally and the long head (solid) was attached distally (Fig. 3, *B*).

Elbow simulator

The testing device consisted of an L-shaped aluminum frame oriented vertically with a clamp at the superior end for fixation of the humerus. The inferior portion of the frame was attached to an adjustable carriage. At the far end of the carriage, there was a torque sensor (Transducer Techniques, Temecula, CA, USA) with connections to a data acquisition system (National Instruments, Austin, TX, USA). The torque sensor was attached to the distal radius by a plate mounted on the radius and an adjustable connecting shaft. The ulna was secured distally. The carriage was adjusted and locked in place for each specimen to allow anatomic forearm rotation and alignment during testing. The frame was mounted to a material testing system (MTS; Measurements Technology Inc., Roswell, GA, USA). To re-create the biceps vector, the sutures attached to the proximal heads of the biceps were attached to a system of pulleys that connected to the MTS and allowed the computer to apply a prescribed force (Figs. 4 and 5).

Before testing of specimens, the custom elbow simulator used in this study was tested for internal validity by comparisons with published data on native moment arm values. By independent *t*-tests, all values measured with the simulator were not statistically different from previously published values ($P \geq .168$).[19,21]

Mechanical testing

Forearm supination moment arm and elbow flexion tests were completed using protocols that have been previously validated and

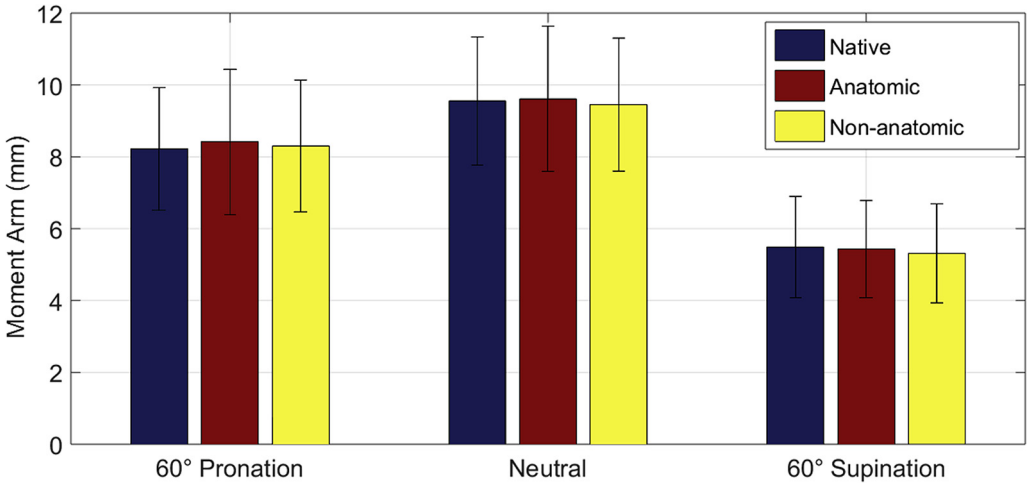

Figure 7 Average moment arm for native tendon and 2 repaired tendon orientations at 3 forearm positions. Tendon orientation did not significantly affect the supination moment arm.

Table I
Average moment arm and flexion force ratio for native tendon and 2 repaired tendon orientations at 3 forearm positions

ID	Orientation	Moment arm (mm)			Efficiency, flexion (%)
		60° pronation	Neutral	60° supination	
1	Native	10.3 ± 0.005	10.4 ± 0.005	7.6 ± 0.014	0.17 ± 0.002
	Anatomic repair	10.4 ± 0.071	10.5 ± 0.014	7.5 ± 0.026	0.17 ± 0.002
	Nonanatomic repair	10.4 ± 0.032	10.5 ± 0.017	7.5 ± 0.084	0.18 ± 0.003
2	Native	7.9 ± 0.059	9.2 ± 0.058	6.1 ± 0.020	0.18 ± 0.002
	Anatomic repair	8.6 ± 0.026	8.7 ± 0.045	6.4 ± 0.066	0.18 ± 0.002
	Nonanatomic repair	8.5 ± 0.058	8.8 ± 0.058	6.3 ± 0.042	0.18 ± 0.002
3	Native	6.3 ± 0.173	6.9 ± 0.176	3.6 ± 0.018	0.18 ± 0.002
	Anatomic repair	5.8 ± 0.149	6.6 ± 0.175	3.7 ± 0.149	0.18 ± 0.003
	Nonanatomic repair	5.8 ± 0.043	6.6 ± 0.177	3.5 ± 0.195	0.18 ± 0.005
4	Native	6.2 ± 0.390	7.0 ± 0.002	3.9 ± 0.190	0.17 ± 0.003
	Anatomic repair	5.9 ± 0.033	6.9 ± 0.001	4.1 ± 0.085	0.18 ± 0.001
	Nonanatomic repair	5.8 ± 0.008	6.8 ± 0.003	4.1 ± 0.069	0.17 ± 0.003
5	Native	8.6 ± 0.072	10.5 ± 0.002	4.5 ± 0.108	0.17 ± 0.001
	Anatomic repair	8.9 ± 0.119	11.0 ± 0.003	4.6 ± 0.1	0.17 ± 0.002
	Nonanatomic repair	8.9 ± 0.187	11.0 ± 0.001	4.5 ± 0.052	0.17 ± 0.001
6	Native	8.7 ± 0.173	10.1 ± 0.002	5.3 ± 0.212	0.17 ± 0.002
	Anatomic repair	9.0 ± 0.149	10.6 ± 0.003	4.8 ± 0.098	0.17 ± 0.002
	Nonanatomic repair	9.1 ± 0.092	10.5 ± 0.001	4.7 ± 0.093	0.17 ± 0.002
7	Native	10.7 ± 0.131	11.9 ± 0.004	6.7 ± 0.111	0.18 ± 0.004
	Anatomic repair	11.5 ± 0.103	12.3 ± 0.002	6.9 ± 0.038	0.18 ± 0.002
	Nonanatomic repair	10.6 ± 0.102	11.2 ± 0.002	6.6 ± 0.039	0.18 ± 0.004
8	Native	7.0 ± 0.205	10.4 ± 0.003	6.3 ± 0.548	0.18 ± 0.002
	Anatomic repair	7.3 ± 0.128	10.3 ± 0.001	5.4 ± 0.073	0.18 ± 0.002
	Nonanatomic repair	7.4 ± 0.027	10.2 ± 0.002	5.2 ± 0.431	0.18 ± 0.001
	ANOVA *P* value		>.352*		>.283†

ANOVA, analysis of variance.
Tendon orientation did not significantly affect the supination moment arm or flexion force ratio. Values are mean ± standard deviation.
* Lowest *P* value comparing orientations and arm position.
† Lowest *P* value comparing orientation.

published.[11,19,21] The forearm supination moment arm was performed with elbows in 90° of flexion (Fig. 4). The forearm was tested in 60° of pronation, neutral, and 60° of supination. For each state, the forearm was rotated and then locked in place. A digital protractor was used to align both the humerus (perpendicular) and forearm (parallel) with the floor. The forearm was oriented with a radial joint surface line connecting the styloid to a point bisecting the sigmoid notch. The supination torque was recorded while a 67 N force at 1 cm/s was applied to the distal biceps tendon. Recorded supination torque vs. biceps load was used to calculate a least-squares regression line; the slope of this regression line was the supination moment arm.[21] Forearm supination torque tests were performed 3 times, and measured values were averaged for each position tested.[21]

The elbow flexion test measured the biceps flexion moment efficiency (Fig. 5).[11,19] For this test, the proximal biceps tendons were loaded with the MTS machine. The forearms were pinned in full supination (60°). The biceps tendons were incrementally loaded until the elbow was flexed to 90°. A cord attached to the distal 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 loading the biceps tendon to 67 N at 1 cm/s.

Recorded flexion load vs. applied load was used to calculate a least-squares regression line; the slope of this regression line was the elbow flexion force ratio.[11,19] The elbow flexion test was repeated 3 times, and the recorded values were averaged.[19]

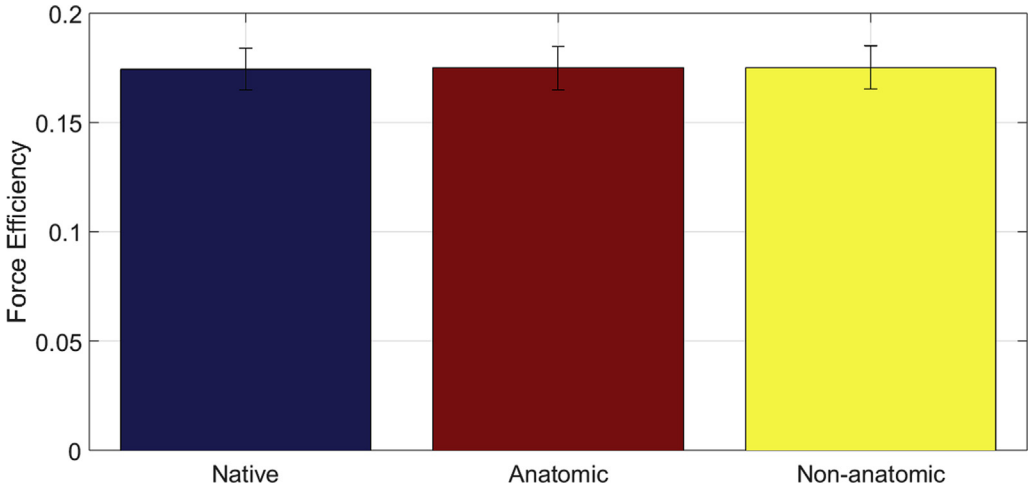

Figure 8 Average flexion force ratio for native tendon and 2 repaired tendon orientations. Tendon orientation did not significantly affect the flexion force ratio.

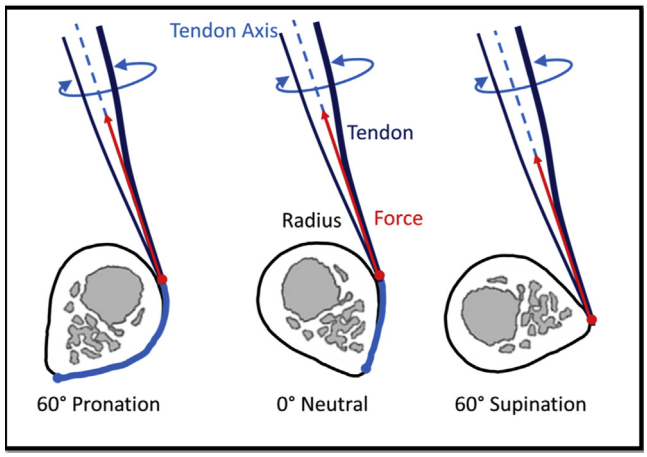

Figure 9 Axial view through the center of the biceps insertion at 3 forearm positions. Rotating the biceps tendon about the tendon axis does not change the biceps force vector (→). The supination moment arm and flexion force ratio are unaffected.

Statistical analysis

A 2-way repeated-measures analysis of variance test was used to evaluate the effects of tendon orientation and forearm positioning on biceps tendon moment arm ($P < .05$). A 1-way analysis of variance was used to evaluate whether tendon orientation affects the elbow flexion force ratio of the biceps tendon. For all statistical analyses, significance was set at $P < .05$.

Results

Gross observations

No abnormalities or deficiencies of the distal biceps tendon were noted in any specimen tested. The native tendon was observed to insert just posterior to the radial protuberance. The distal tendon wrapped smoothly around the radial tuberosity with forearm pronation. It produced a ribbon-like quality. At 60° of pronation, the biceps tendon was completely wrapped around the radial tuberosity without bulk. It was in comparing tendon wrapping that the anatomic and nonanatomic groups differed from the native group. The anatomic repair mimicked the native condition and smoothly wrapped around the radial tuberosity with pronation (Fig. 6, *A*). The nonanatomic tendon exhibited bunching after suturing of the distal biceps tendon to the insertion site (Fig. 6, *B*). This repair site bunching produced an abnormal increase in repair site tendon width with pronation. The bunching of the tendon occurred only when low force was being applied to the tendon; at 10 N, the tendon began to appear ribbon like.

Isometric forearm supination moment arm test

Orientation of the tendon in anatomic vs. nonanatomic positioning did not significantly alter the moment arm ($P = .352$; Fig. 7; Table I). Positioning of the forearm did result in significant differences in moment arm ($P < .01$). The native tendon orientation recorded a mean moment arm of 8.2 ± 1.7 (60° supination), 9.6 ± 1.8 (neutral), and 5.5 ± 1.4 (60° pronation). Similar to previous reports, the largest moment arm values were observed with neutral forearm angle and the smallest values in full supination.[8,15,21]

Isometric flexion force ratio test

Orientation of the tendon in anatomic vs. nonanatomic positioning did not significantly alter the flexion force ratio ($P = .284$; Fig. 8; Table I). The mean flexion force ratios were 0.17 ± 0.01 (native), 0.18 ± 0.01 (anatomic repair), and 0.18 ± 0.01 (nonanatomic repair).

Discussion

It has been shown that the short head contributes 15% greater flexion force than the long head ($P = .001$), whereas the long head, compared with the short head, generates 9% greater supination moment at 60° of supination ($P < .05$).[11] It stands to reason that internally rotating the distal biceps tendon by reattaching the long head proximal to the short head would alter the native force transmission on the radius. However, the results of this study show that biceps tendon rotation does not play a role in forearm supination moment arm ($P \geq .352$) or elbow flexion force ($P \geq .284$). This result is because twisting the distal biceps tendon around the tendon axis does not change the direction of its applied force (Fig. 9). Therefore, tendon rotation after a distal biceps repair is not a mechanical determinant of forearm supination or elbow flexion strength.

Distal biceps tendon bunching at the repair site was constantly observed only in the internally rotated (nonanatomic) specimens. This tendon bunching increases the repair site width. The concern is that an increase in repair site width could lead to tendon-ulnar impingement and subsequent rerupture. The rerupture rate has been reported to be 5.1% for acute and 7.0% for chronic repairs.[23] To our knowledge, clinical repair site impingement has not been reported as a cause of biceps rerupture.[3,6,10] Nonetheless, Seiler et al[22] measured the distance between the ulna and radial tuberosity using computed tomography scans and reported an average distance of 7.82 mm in supination and 3.97 mm in pronation; furthermore, on cross-sectional anatomy, the tendon occupied an average of 85% of the radioulnar space. Krueger et al[12] noted that repairs without a cortical hole or trough had the smallest clearance between the repaired tendon and the adjacent ulna. This study did not quantify the increase in repair site width with an internal rotation (nonanatomic) reattachment, but it is rational that this observed bunching could result in tendon-ulnar impingement. Impingement after distal biceps reattachment can be assessed by simply rotating the radius through a full forearm arc and feeling for a click. During the impingement test, the repair should be placed under load by extending the elbow 10°-20° greater than the repair angle. It is important to place a small load on the reattachment tendon during the test because the repair site bunching decreased with loads greater than 10 N.

This research is a time-zero study looking at the effect of distal biceps tendon rotation on the ability of the muscle to generate supination and flexion torques. It does not consider tendon remodeling over time. Furthermore, this study was an in vitro design and could not re-create the in vivo condition; hence, we recommend reattaching the distal biceps tendon in anatomic tendon rotation. Nevertheless, the findings offer evidence that distal biceps tendon rotation does not affect elbow supination moment arm or flexion force transmission.

Conclusion

Surgeons should be aware that during a distal biceps tendon repair, rotation does not play a role in muscle supination moment arm and flexion force transmission to the radial tuberosity. However, if the distal biceps tendon is reattached in internal rotation (long head distal to short head), there is a possibility of creating repair site impingement, and this should

be checked by rotating the forearm and managing the situation appropriately.

Disclaimer

Christopher C. Schmidt is a consultant for Arthrex, Inc. All the other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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