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Original Research

Power-Optimizing Repair for Distal Biceps Tendon Rupture: Stronger and Safer

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Purpose: Many approaches have been described to accomplish tendon reattachment to the radial tuberosity in a distal biceps tendon rupture, with significant success, but each is associated with potential postoperative complications, including posterior interosseous nerve (PIN) injury. To date, there has been no consensus on the best approach to the repair. The purpose of this study was to evaluate the supination strength and the distance of drill exit points from the PIN in a power-optimizing distal biceps repair method and compare the findings with those of a traditional anterior approach endobutton repair method.

Methods: Cadaveric arms were dissected to allow for distal biceps tendon excision from its anatomic footprint. Each arm was repaired twice, first with the power-optimizing repair using an anterior single-incision approach with an ulnar drilling angle and biceps tendon radial tuberosity wraparound anatomic footprint attachment, then with the traditional anterior endobutton repair. Following each repair, the arm was mounted on a custom-built testing apparatus, and the supination torque was measured from 3 orientations. The PIN was then located posteriorly, and its distance from each repair exit hole was measured.

Results: Five cadaveric arms, each with both the repairs, were included in the study. On average, the power-optimizing repair generated an 82%, 22%, and 13% greater supination torque than the traditional anterior endobutton repair in 45° supination, neutral, and 45° pronation orientations, respectively. On average, the power-optimizing repair produced drill hole exit points farther from the PIN (23 mm) than the traditional anterior endobutton repair (14 mm).

Conclusions: The power-optimizing repair provides a significantly greater supination torque and produces a drill hole exit point significantly farther from the PIN than the traditional anterior endobutton approach.

Type of study/level of evidence: Therapeutic III.

A distal biceps tendon rupture is a rare but devastating injury most often occurring in active middle-aged men.[1–9] The rupture can result in the weakness of arm flexion and supination.[1–3,5–21] The restoration of functional strength following a biceps tendon rupture is possible with surgical intervention and has largely been shown to be a direct function of reattachment position relative to anatomic footprints.[2,6–13,15,17–19,21] Achieving full supination from a partially supinated orientation, an action potentially clinically relevant for the performance of activities such as using a screwdriver, has been shown to be particularly strongly related to tendon reattachment position.[18,19]

Many approaches, including single-incision anterior and double-incision posterior techniques, with various fixation methods have been described to accomplish tendon reattachment to the radial tuberosity.[1–3,6–14,18–22] Although both single-incision

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anterior and double-incision posterior techniques have shown significant repair success, each is associated with operative difficulties and postoperative complications that negatively impact the quality of the repair.[1,2,7–10,12–14,17–22] Thus, to date, there has been no consensus on the best approach to the repair.[1–3,7–14,20] The double-incision posterior technique consistently allows exposure for true anatomic footprint reattachment, but the extensor carpi ulnaris and, importantly, the supinator must be split to do so, potentially resulting in functionally significant decreases in the supination torque.[7,10,13,14,18–20] This approach has also been shown to be associated with heterotopic bone formation and muscle fatty infiltration.[7,10,14,18–20] Additionally, this procedure can be cumbersome and is associated with the risk of suture cut through.[10] The single-incision anterior approach is elegant in using the plane between the brachioradialis and pronator teres to access the radial tuberosity anteriorly, but it does not allow for true anatomic footprint reattachment to the posterior aspect of the radial tuberosity.[1,2,5–7,9,10,13,14,16,17,19,20,22] This may mitigate functional recovery by impacting the flexion and supination strength as well as resistance to fatigue while also running the risk of an iatrogenic posterior interosseous nerve (PIN) injury following tendon repair.[1,2,5–7,9,10,13,14,16,17,19,20,22] Steeper drilling angles are associated with less risk of a PIN injury.[5,14,17,22] However, steeper drilling angles in a traditional single-incision anterior repair lead to the sacrifice of any chance at an anatomic repair because this angle moves the attachment point away from the anatomic footprint and, thus, negatively impacts the supination torque.[5,14,17,22]

Additionally, research has shown that there is minimal tendon-bone bonding present in the medullary canal.[23] Rather, the majority of tendon-to-bone fixation occurs at the level of the cortical surface.[23] This suggests that tendon fixation within a bone tunnel, as is done in traditional approaches, is unnecessary and merely increases the risk of radial stress fracture and leads to the wastage of vital biceps tendon length.[23] This decrease in the tendon length prevents anatomic tendon insertion into the posterior aspect of the radial tuberosity and, therefore, decreases its ability to use radial protuberance as a cam during supination, thus decreasing the cam's effect and supination torque generation.[6,17]

The purpose of this study was to evaluate the supination strength and proximity between a drill exit point and PIN that can be afforded by the power-optimizing repair method for a distal biceps tendon rupture, described by Tanner et al,[21] compared with those afforded by the traditional anterior endobutton approach, as described by Bain et al.[24] The power-optimizing repair method uses an anterior single-incision approach with a hypersupinated ulnar drilling angle and an exit point near the posterior radial tuberosity anatomic footprint that also maximizes the distance between the drill exit point and PIN.[21] The approach allows the biceps tendon to wrap around the radial tuberosity and attach to its posterior anatomic footprint.[21] Fixation is accomplished by tying the suture anteriorly over a cortical button. This allows for surface cortex adhesion in lieu of bone tunnel fixation, allowing for optimized healing and increased available tendon length without significantly impacting the osseous structure of the radius.[23] The primary outcome was supination torque in the partially supinated orientation. The secondary outcomes included supination torque in the neutral and partially pronated orientations and proximity between the drill exit point and PIN. We hypothesized that the power-optimizing repair generates greater supination torque than the traditional anterior endobutton repair throughout all forearm rotation orientations, most significantly evident when starting from a partially supinated position. This is achieved because the power-optimizing repair method provides better anatomic footprint reinsertion and, thus, minimizes the limitations of the rotational axis seen in the traditional anterior endobutton repair method.[21] Additionally, we hypothesized that the hypersupinated ulnar drilling angle used by the power-optimizing repair technique generates a drill exit point located at a significantly greater distance from the PIN compared with that generated by the traditional anterior endobutton repair technique.

Materials and Methods

Five fresh, frozen arms from cadavers aged 64 years (range 57–71 years) on average that were anatomically normal upon inspection were used in this study. A power analysis and test statistics guided the size of this study, with a sample size of 3 for each repair type necessary to achieve 80% power with respect to supination torque from a partially supinated orientation, and a sample size of 5 for each repair type necessary to demonstrate significant differences between the repairs in both supination torque from all orientations and PIN proximity.

The specimens were thawed to room temperature and were then dissected to expose the biceps tendon and its distal insertion as well as to disarticulate the wrist. Following the dissection, the arm was repeatedly pronated, supinated, flexed, and extended to loosen natural cadaveric stiffness prior to proceeding with the load protocol. A #5 braided suture was used to secure the proximal biceps tendon to a rig-pulley system via Krackow stitching, thus allowing a load to simulate biceps brachii contraction.

The arms were mounted on a custom-built testing apparatus (Fig. 1) that represented an elbow simulator similar to that used by Prud'homme-Foster et al[17] and were fixed transversely at the olecranon and mid humerus, longitudinally at the ulnar head, and transversely through the radial shaft. This setup prevented ulnar motion and allowed isolated and unrestricted radial rotation. The radial shaft was connected to a force or torque sensor. The sensor was attached to an amplifier, which generated input charge signal readings, and an oscilloscope, which generated voltage readings in response to the applied force. The charge and voltage readings were then manipulated to calculate the isolated supination torque generated by the arms after repair.

The supination force was measured at the wrist at 45° supination, neutral, and 45° pronation orientations using a 9.07 kg pulling force on the biceps tendon. The 9.07 kg pulling force was used because it approximated the 80-N pulling force used for a similar simulation by Prud'homme-Foster et al[17] and was deemed suitable for the representation of various occupational and recreational activities. This 9.07 kg pulling force was also heavy enough to demonstrate the accurate representation of the distinctions between the arm orientations and repairs while not being heavy enough so as to damage the specimen or repair.

All the specimens were tested after the excision of the distal biceps tendon at the site of its insertion and subsequent repair, first with the power-optimizing repair technique, as described by Tanner et al,[21] using a #5 braided suture and Krackow stitching (Fig. 2). Using a spinal needle, the suture was then passed through the drill holes in a posterior-to-anterior fashion and secured anteriorly to tow the biceps tendon to its anatomic footprint on the posterior aspect of the radial tuberosity.[21] Following the testing of the power-optimizing repair method, the specimen was prepared for the traditional endobutton repair, as described by Bain et al,[24] using a #5 braided suture and Krackow stitching (Fig. 3). The traditional anterior endobutton approach uses an anterior single-incision approach with a hypersupinated ulnar drilling angle and exit point near the posterior radial tuberosity anatomic footprint but uses anterior bone tunnel fixation rather than posterior cortical fixation.[24] The guide pin for the standard endobutton repair was drilled bicortically to establish a pathway for a later assessment of PIN proximity.[24] Because a traditional anterior repair approach

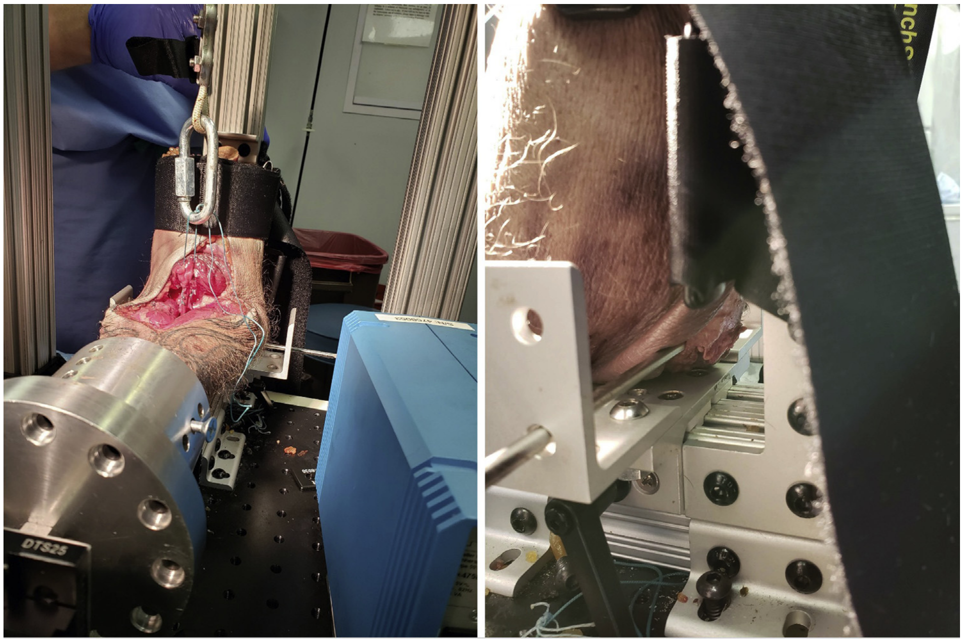

Figure 1. Demonstration of a cadaveric arm mounted on a custom-built testing apparatus with distal plate fixation connected to a torque sensor and proximal fixation via an olecranon pin and a mid-humeral strap. A pulley attaches the biceps tendon to a 9.07 kg weight.

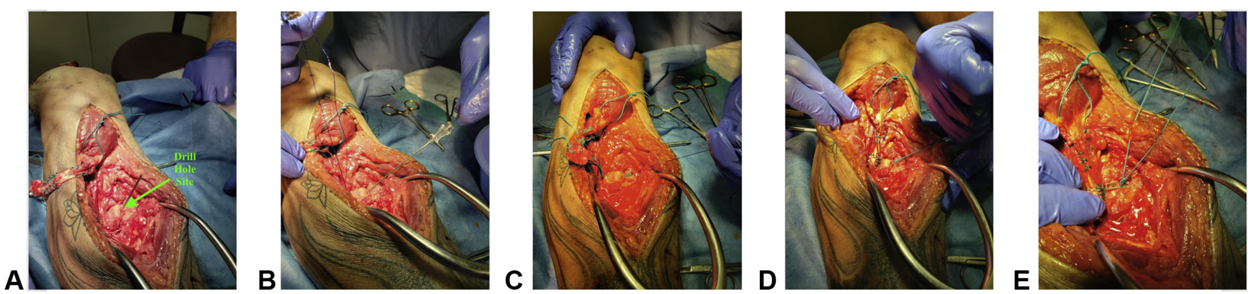

Figure 2. Power-optimizing wraparound repair of the left arm. **A** Site of drill hole for repair with the arm hypersupinated. **B**–**D** A spinal needle is used to thread the suture through the bone and wrap repair around the radius to the native footprint. **E** Secured power-optimizing wraparound repair.

with either anchors or an endobutton allows for the biceps tendon to heal toward the anterior cortical bone, the entry point into the anterior aspect of the radius is the point at which force is applied to the bone rather than the point at which the endobutton happens to sit on the posterior aspect of the radius. Therefore, for the purpose of this study, to most closely replicate that point of force application, the endobutton was placed just under the anterior cortex such that when force was applied to the biceps, it would be pulling on the tendon cortex interface similar to when the tendon is healed there.[24]

Both the repairs were performed on the same cadaver arm to control for cadaveric variation in anatomy and, subsequently, force readings. The torque was measured in the same positions with the same force after each repair. The repairs in all the specimens were performed sequentially, first the power-optimizing repair and then the traditional anterior endobutton repair, because the placement and removal of the intramedullary endobutton required damaging the arm, rendering it untestable for the power-optimizing repair.

Lastly, the PIN was located posteriorly (Fig. 4), and its distance from the repair exit holes was measured using calibrated electronic calipers.

Statistical analysis was performed using paired 1-tailed *t* tests on Microsoft Excel or Mac (version 16.39, build 20071300).

Results

With the arm oriented at 45° supination, the power-optimizing repair generated an 82% greater supination torque than the traditional anterior endobutton repair ($P < .01$). With the arm in a neutral orientation, the power-optimizing repair generated a 22% greater supination torque than the traditional anterior endobutton repair ($P < .01$). With the arm oriented at 45° pronation, the power-optimizing repair generated a 13% greater supination torque than the traditional anterior endobutton repair ($P = .01$). Across all the specimens and orientations, there were no instances of a greater supination torque with the traditional anterior endobutton repair compared with that with the power-optimizing repair.

Additionally, the distance from the drill hole exit point to the PIN was significantly greater ($P = .03$) with the power-optimizing repair (x = 23 mm) than with the traditional anterior endobutton repair (x = 14 mm). Across all the specimens, there were no instances of a greater distance from the exit point of the drill hole to the PIN with the traditional anterior endobutton repair compared with that with the power-optimizing repair.

Tables 1 and 2 summarize the individual measurements for each cadaveric specimen as well as the relevant means and *P* values.

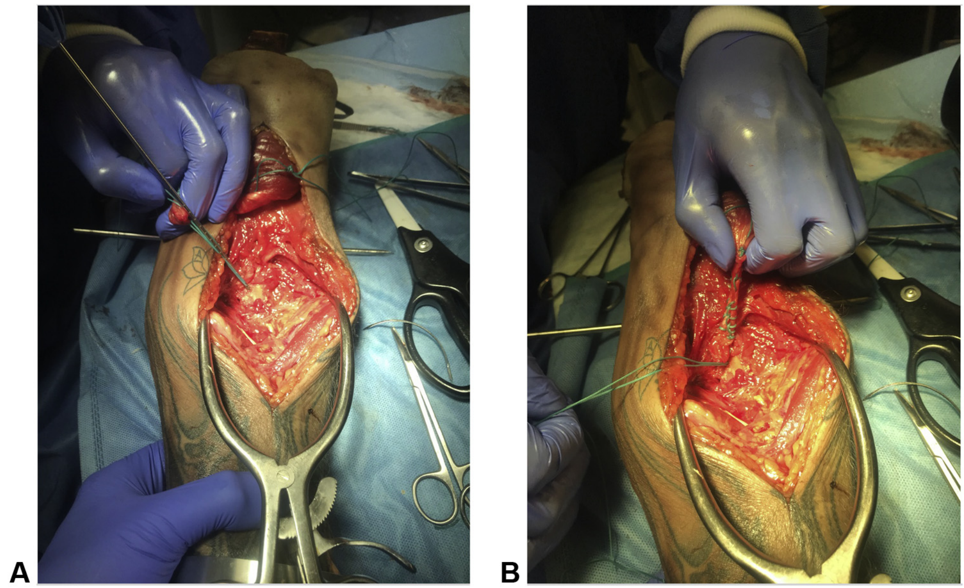

Figure 3. Traditional anterior endobutton repair of the left arm. **A** Drill and endobutton release site. **B** Secured traditional anterior endobutton repair.

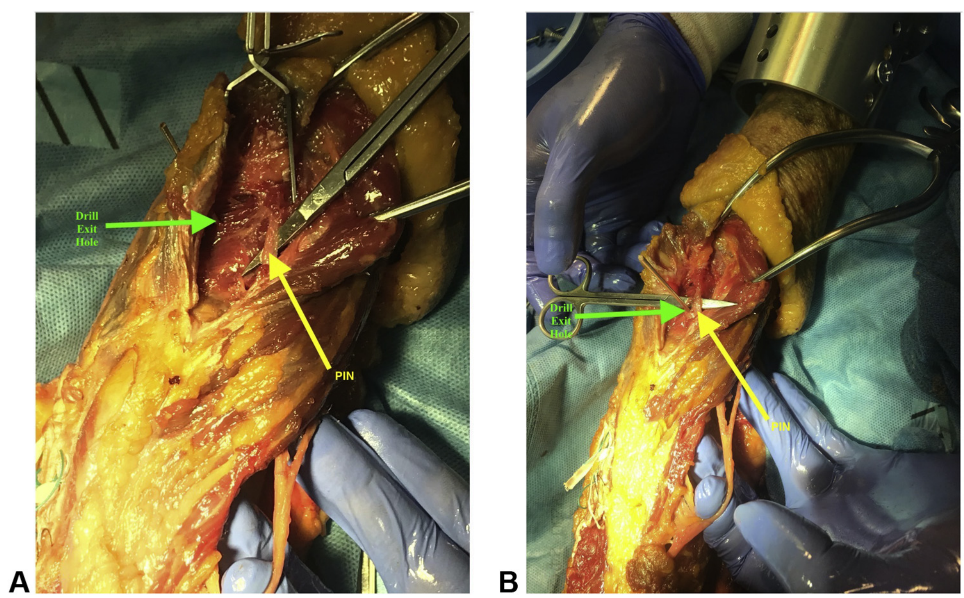

Figure 4. Isolated PIN and drill exit holes. A guide wire pin was passed through the drill holes (green arrow) created by each repair to demonstrate proximity to the PIN (yellow arrow). **A** Representation of a power-optimizing repair. **B** Representation of a traditional anterior endobutton repair.

Discussion

To date, multiple repair techniques have been shown to have high levels of success, but each is met with multiple complications.[1,2,7–10,12–14,17–22] The ideal surgical repair method elegantly uses natural tissue planes rather than damaging the muscle tissue, attaches the tendon to its native footprint, and minimizes the risk of a PIN injury.

We performed both the power-optimizing and traditional anterior endobutton repairs on each of the 5 arms and found that the power-optimizing repair generated a significantly greater supination torque than the traditional anterior endobutton repair from all 3 orientations. This difference could perhaps make a clinically meaningful difference in the patients' lives. The standard for a minimally important difference in the clinical forearm supination torque has not been determined.[25] Thus, clinically significant findings on supination torque generation may be more commonly found in patients that place a high demand on supination ability with actions such as turning a screwdriver or swinging a golf club or baseball bat.[19,25] These findings corroborate the findings of prior biomechanical studies detailing the increased cam effect and, thus, supination strength associated with an anatomic repair compared with those associated with the repair offered by the traditional anterior endobutton approach that limits true anatomic footprint reattachment.[2,6–13,15,17–19,21]

Additionally, we found that the power-optimizing repair generated a posterior drill exit hole in a location at a significantly greater distance from the PIN than the traditional anterior endobutton repair. This could perhaps make a clinically meaningful difference in the safety of the operation by minimizing the

Table 1
Supination Torque Results

Orientation	Specimen Data	Power-Optimizing Repair (Nm)		Traditional Anterior Endobutton Repair (Nm)
45° supination	Specimen number			
	1	3.6		1.5
	2	6.0		4.5
	3	4.5		3.0
	4	4.2		2.4
	5	5.7		1.8
	Mean	4.80		2.64
	P value		<.01	
Neutral	Specimen number			
	1	6.6		6.0
	2	8.1		6.0
	3	6.6		5.4
	4	5.4		4.2
	5	7.2		6.3
	Mean	6.78		5.58
	P value		<.01	
45° pronation	Specimen number			
	1	7.5		6.9
	2	8.7		7.5
	3	6.0		6.0
	4	6.0		4.8
	5	7.2		6.0
	Mean	7.08		6.24
	P value		.01	

Table 2
Drill Exit Point-PIN Distance Results

Specimen Data	Power-Optimizing Repair (mm)		Traditional Anterior Endobutton Repair (mm)
Specimen number			
1	20		11
2	38		16
3	24		19
4	16		12
5	16		12
Mean	23		14
P value		.03	

potential for unintended complications in the form of a PIN injury. The findings of this study corroborate the findings of prior work detailing the preservation of the PIN, as shown by the drill angle in the power-optimizing repair technique, which was increased in these studies.[5,14,17,22]

The limitations of this study include the limited sample size of 5 arms. This was done because of ethical and economic considerations about achieving statistical significance and potentially clinically meaningful results. Additionally, the power analysis of a continuous endpoint, a 2-sample study with respect to the supination torque from partial supination indicated that a sample size of only 3 for each repair type was necessary to maintain a power of 80%. The study is also limited by an order-assignment bias because all the repairs were performed sequentially, first the power-optimizing repair and then the traditional anterior endobutton repair. Testing both the repairs on the same cadaveric arm was necessary to eliminate intercadaveric anatomic differences and to provide a standard for comparison. Additionally, a consistent order of the repairs was necessary because the process of performing and removing in the traditional anterior endobutton repair method causes substantial damage to the arm, which would have rendered the subsequent power-optimizing repair and torque evaluation impossible. Although the power-optimizing repair required only a small drill hole, which did not impact the subsequent traditional anterior endobutton repair, the traditional anterior endobutton repair required the drilling of a larger hole for button deployment and fixation as well as the postprocedure removal of the intramedullary endobutton, which resulted in significant bony destruction. Additionally, our study is limited, in that our cadaveric model did not include an assessment of a patient's ability to recover or an assessment of a repair's response to the nonisolated movements associated with the rigors of daily life over time.

This study supports the idea that the power-optimizing repair of the biceps tendon provides a significantly greater supination torque from 45° supination, neutral, and 45° pronation orientations and generates a drill hole at a significantly greater distance from the PIN than the traditional anterior endobutton repair approach.

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