The Importance of Preserving the Radial Tuberosity During Distal Biceps Repair

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Background: The radial tuberosity contributes to the biceps supination moment arm and the elbow flexion moment. The purpose of our study was to compare the impact of a cortical bone trough versus an anatomic repair on measurements of the forearm supination moment arm and elbow flexion force efficiency. Our hypothesis was that a trough repair would decrease the tuberosity height, the native biceps supination moment arm, and elbow flexion force efficiency compared with an anatomic repair.

Methods: The isometric supination moment arm and elbow flexion force efficiency were measured in ten matched pairs of cadaveric upper limbs. After testing, the geometry of the proximal aspect of the radius was reconstructed with use of stereophotogrammetry. All of the repair sites were three-dimensionally reconstructed to quantify the disturbance of the trough on native anatomy. The tuberosity distance was defined as the distance between the central axis of the radius and the centroid of the respective repair site.

Results: Specimens with a trough repair had a 27% lower supination moment arm at 60° of supination (p = 0.036). There were no differences found for pronation or neutral forearm positioning (p > 0.235). Flexion force efficiency was not significantly different between the trough and anatomic repair groups. The average tuberosity distance was 11.0 ± 2.1 mm for the anatomic repairs and 8.3 ± 1.4 mm for the trough repairs (p = 0.003). The percentage of distance lost due to the trough was 25%. Furthermore, the supination moment arm in the supinated position was significantly correlated with the tuberosity distance.

Conclusions: The trough technique resulted in a significant decrease (p = 0.036) in the moment arm of a 60° supinated forearm and a significant reduction (p = 0.003) in radial tuberosity height. The loss of the supination moment arm was correlated with the decrease in tuberosity height, providing evidence that the radial protuberance acts as a mechanical cam.

Clinical Relevance: The anterior protuberance of the radial tuberosity functions as a supination cam; therefore, consideration should be given to preserve its topographical anatomy during a distal biceps repair.

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The biceps tendon can be repaired with or without making a cortical trough (a socket or window) in the radial tuberosity. Repairs that utilize a trough do so to increase the bone-tendon interface or strength1-3. The fixation devices commonly used in trough repairs include extramedullary cortical buttons, direct sutures, interference screws, or a

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strength has been devoted to the study of time-zero failure of the forearm supination moment arm and elbow bone trough versus an anatomic repair on the measurements of distal biceps repair is currently undetermined.

The importance of maintaining native skeletal anatomy during a protuberance as a mechanical cam (Fig. 1) increases the biceps ability of the biceps to generate a supination torque theoretical that the creation of a trough during repair may decrease the height of the protuberance and thereby reduce the efficiency. A secondary goal was to mathematically describe the repair-site anatomy and correlate it with the mechanical data. We hypothesized that anatomic repair, in contrast with trough repair, conserves the radial tuberosity anatomy and that this preservation results in a greater forearm supination moment arm and better elbow flexion force efficiency.

Materials and Methods

Ten matched pairs of fresh-frozen, disease-free human cadaveric upper limbs (from eight male and two female donors with an average age of sixty-six years [range, fifty-two to seventy-five years]) were mechanically tested and served as intact controls. After intact testing, the right and left limb of each pair were randomly assigned to either anatomic or trough repair and were retested. They were then dissected, stereophotographed, and geometrically modeled.

Distal Biceps Repair

A 3 to 4-cm incision was made posteriorly over the pronated radial tuberosity. The extensor carpi ulnaris and supinator muscles were split, and the forearm was pronated to visualize the biceps tendon and the radial tuberosity. The biceps tendon was detached at its footprint. A volar incision was made to expose the biceps musculotendinous junction, and two Krackow stitches (one stitch each in the short and long heads) were placed in the distal aspect of the detached tendon. Anatomic repair involved fastening the tendon to the centroid of the footprints of the long and short heads using intramedullary cortical buttons (Arthrex) (Fig. 2-A, panels 1 through 4). The steps of the trough repair were as follows: burring a socket that was 7 mm wide by 10 mm long at the anatomic footprint, drilling three holes 4 mm posterior to the socket, passing the sutures through the three holes, and tying the tendon to bone (Fig. 2-B, panels 1 through 4).

Mechanical Testing

Details of the forearm supination torque test and elbow flexion test have been previously published. The forearm supination torque test was designed to measure the biceps supination moment arm (Fig. 3-A). The humerus and ulna in each specimen were secured in a validated physiologic elbow simulator capable of measuring isometric radial torque. The testing angle for all specimens was 90° of flexion. The forearm was rotated and locked into one of three testing positions: 60° of pronation, neutral, or 60° of supination. A digital protractor aligned both the humerus and forearm perpendicular to the floor; the forearm was oriented with a radial joint surface line connecting the styloid to a point bisecting the sigmoid notch. The distal biceps tendon was then loaded to 67 N at 8.9 N/s, while the supination torque was recorded with a torque sensor (Transducer Techniques). A least-squares regression line was fitted to the curve of supination torque versus biceps load. The slope of this regression line was the supination moment arm.

The elbow flexion test measured the efficiency of the biceps tendon in producing a flexion moment (Fig. 3-B). The radius and ulna were pinned in 60° of supination, and the biceps was loaded until the elbow was at 90° of flexion. The elbow was held at 90° of flexion using a cord containing a load cell (Transducer Techniques), attached to the distal part of the forearm proportionally to the forearm’s overall length. The biceps tendon was then loaded to 67 N at 8.9 N/s, and the flexion force was recorded. A least-squares regression line was fitted to the flexion load generated versus applied biceps load data. The slope of the regression line was the ratio of the flexion load to biceps load, termed the elbow flexion force efficiency.

Repair-Site Anatomy

The specimens were then surgically dissected under loupe magnification and geometrically compared. The trough repairs were measured with a caliper (L.S. Starrett) that had a reported accuracy of 0.01 mm. The width of the trough was measured at one-third and two-thirds of its length; the length was the greatest dimension of the trough (Fig. 4-A). The distance from the

![Image](image_url)

Fig. 1

A magnetic resonance imaging (MRI) axial view through the center of the distal biceps insertion. The biceps tendon (B) insertion footprint (arrow) was used as a reference point throughout this study. The curved arrows indicate the arc of the radial tuberosity anterior (A) and posterior (P) to the native biceps footprint. Notice that the protuberance (arrowhead) of the radial tuberosity is located anterior to the tendon insertion. The protuberance is believed to function as a mechanical cam increasing the biceps supination moment arm. R = radius, and U = ulna.

Combination of buttons and interference screws. Repairs that do not use a trough secure the tendon with suture anchors or cortical buttons that can be positioned either intramedullary or extramedullary. Clinically, time-zero repair strength with all combined button and interference screws served as intact controls. After intact testing, the right and left limb of each pair were randomly assigned to either anatomic or trough repair and were retested. They were then dissected, stereophotographed, and geometrically modeled.

The biceps tendon attaches to the posterior aspect of the radial tuberosity at its apex and is believed to utilize its anterior protuberance as a mechanical cam (Fig. 1). It has been theorized that the creation of a trough during repair may decrease the height of the protuberance and thereby reduce the ability of the biceps to generate a supination torque. The importance of maintaining native skeletal anatomy during a distal biceps repair is currently undetermined.

The purpose of our study was to compare the effect of a bone trough versus an anatomic repair on the measurements of the forearm supination moment arm and elbow flexion force.

The specimens were then surgically dissected under loupe magnification and geometrically compared. The trough repairs were measured with a caliper (L.S. Starrett) that had a reported accuracy of 0.01 mm. The width of the trough was measured at one-third and two-thirds of its length; the length was the greatest dimension of the trough (Fig. 4-A). The distance from the...
proximal radial head to the most distal drill hole was measured and defined as the distal drill-hole distance. All caliper measurements were performed twice, two weeks apart.

Three-dimensional (3-D) images of the repair site (Fig. 4-B) for each specimen were created with use of stereophotogrammetry, with a two-camera optical tracking system (Spica Technology Corporation) that had a reported
accuracy of 0.025 mm. The optical tracking system imaged the radius at an initial position and at three incremental rotations of 90°. We then used fiducial markers to align the scans and compute a reconstructed 3-D model, using custom MATLAB code (MathWorks). The trough length, the two width measurements, and the distal drill-hole distance were then determined. Further, the tuberosity distance was computed. This was defined as the distance between the central axis of the radius and the centroid of the repair site. The central axis of the radius was determined by computing the centroid of the radial head and of the most distal cross-section of the radius. The centroid of the anatomic repair was defined as the midpoint of the two drill holes, and the centroid of the trough repair was defined as the centroid of the trough itself. For each matched pair, the tuberosity distance was normalized by dividing the anatomic tuberosity distance into the trough tuberosity distance. These computational assessments were repeated twice and compared with the corresponding caliper measurements.

**Statistics**
The degree of intraobserver agreement for each distance measured was analyzed using the kappa statistic. A paired t test was used to compare the caliper measurements with the measurements from the stereophotogrammetric...
reconstructions. Two-way mixed ANOVA (analysis of variance) with Tukey post-hoc testing was used for the supination moment arm data. A one-way independent ANOVA was used for the flexion force efficiency data. An independent t test was used to compare the tuberosity distance of the anatomic repairs with that of the trough repairs. A bivariate correlation test was performed to study the relationship between supination moment arm and tuberosity distance. Significance for all tests was set at p < 0.05.

**Source of Funding**
There was no external funding utilized for this study.

**Results**

**Repair-Site Anatomy**

The anatomic dissections revealed a clear decrease in tuberosity height in all trough specimens, except one, when compared with the contralateral anatomic repair (Figs. 5-A, 5-B, and 5-C). In the one exception, the trough was made posterior to the tuberosity (Fig. 5-C), which was unintentional and related to a lapse in our surgical technique. Table I shows the measurements of the trough length and widths made using the caliper and the computer. We found no differences between the caliper and computer measurements. As demonstrated by the low standard deviation in the width and length measurements, the trough size was constant among all of the specimens. Further, the κ values for all repeated measurements were >0.8, indicating almost perfect agreement.

There was no significant difference between the anatomic repair and trough repair specimens (p > 0.232) in terms of the distal drill-hole distance. The average tuberosity distance for anatomic repairs was 11.0 ± 2.1 mm, and for the trough repairs, it was 8.3 ± 1.4 mm (p = 0.003). Simply stated, the tuberosity distance of the trough repairs was significantly less than that of the anatomic repairs, by about 25%.

**Mechanical Supination and Flexion Testing**

The forearm supination torque testing results are seen in Figure 6. Our statistical analysis showed that the forearm angle (p = 0.004) and type of repair (p = 0.031) affected the supination moment arm. Furthermore, the interaction of forearm angle and repair type was significant (p = 0.003). Post-hoc testing revealed that the specimens with a trough repair had a significantly lower (27%) supination moment arm at 60° of supination compared with the intact controls (p = 0.036) as well as compared with the specimens with an anatomic repair (p = 0.022). The specimens with an anatomic

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**TABLE I** Comparison of Repair-Site Measurements

<table>
<thead>
<tr>
<th></th>
<th>Caliper* (mm)</th>
<th>Computer* (mm)</th>
<th>P Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trough dimensions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>13.2 ± 1.3</td>
<td>13.4 ± 1.7</td>
<td>0.680</td>
</tr>
<tr>
<td>Width</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At one-third of length</td>
<td>6.2 ± 0.8</td>
<td>6.3 ± 0.9</td>
<td>0.785</td>
</tr>
<tr>
<td>At two-thirds of length</td>
<td>6.1 ± 0.8</td>
<td>6.3 ± 0.9</td>
<td>0.474</td>
</tr>
<tr>
<td>Distal drill-hole distance</td>
<td>3.8 ± 0.5</td>
<td>3.7 ± 0.3</td>
<td>&gt;0.388‡</td>
</tr>
<tr>
<td>Anatomic repair</td>
<td>3.9 ± 0.4</td>
<td>3.8 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>Trough repair</td>
<td>3.9 ± 0.4</td>
<td>3.8 ± 0.3</td>
<td></td>
</tr>
</tbody>
</table>

*The values are presented as the mean and the standard deviation. †No significant differences between the two measurement techniques were detected. ‡P value for all caliper versus computer distal drill-hole measurements.
repair did not differ significantly from the intact controls \((p = 0.443)\). There were no differences in 60° of pronation or neutral forearm positioning between the intact controls and either the specimens with an anatomic repair or those with a trough repair \((p > 0.235)\). Analysis showed a significant \((p = 0.011)\) and strong \((r = 0.558)\) positive correlation between the tuberosity distance and the supination moment arm. The results from the elbow flexion testing (Fig. 7) showed no significant differences between the two types of repairs and their intact controls \((p = 0.335)\).
preserving anterior approach or a tuberosity trough performed.

In a previous laboratory model, eleven pairs of cadaveric arms had had a biceps repair with either a tuberosity-flap/C176 or a biceps repair with a posterior approach that was utilized may have allowed for better footprint exposure, in turn, resulting in a more anatomic repair, had no significant effect on elbow flexion strength.

In a previous laboratory model, eleven pairs of cadaveric arms had had a biceps repair with either a tuberosity-preserving anterior approach or a tuberosity trough performed with a posterior approach27. The generated resultant force, measured only in a neutral position, showed no significant difference between the repair groups27. The present study similarly showed no significant difference between the anatomic and trough repairs in a neutral forearm position, but it also showed that trough repairs cause a significant drop in the supination moment arm at 60° of supination. The likely explanation is that the tendon in 60° of pronation and in neutral rotation is wrapped on native bone anterior to the trough, meaning that the trough would not affect the moment arm (Fig. 8). Between neutral and 60° of supination, the tendon in an anatomic repair wraps around the radial protuberance, which is located just anterior to the biceps insertion. However, in a trough repair, the radial protuberance has been partially or totally burred away, so the tendon wraps over the hole and abuts the anterior edge of the trough, which substantially decreases its moment arm. That is to say, the trough shifts the line of action of the tendon force into a mechanically less advantageous, nonanatomic position25,35.

The clinical importance of an anatomic versus a trough repair has not been fully studied. A randomized clinical trial comparing an anterior suture-anchor repair with a posterior trough repair found no difference in supination torque tested in neutral rotation, although other forearm positions were not tested35. Further, that study did not quantify the repaired biceps position35. Interestingly, that clinical study did show a 10% advantage in isometric flexion strength for the trough repair35, whereas the present laboratory study showed no difference in flexion force efficiency between either of the repair types and the intact controls. The gross dissections and the distal drill-hole distance measurements showed no difference in the repaired position in the lateral plane (Table I; Figs. 5-A, 5-B, and 5-C). An explanation for the increase in flexion strength in the clinical study was not given; one could conjecture that the posterior approach that was utilized may have allowed for better footprint exposure, in turn, resulting in a more anatomic repair25,36,37.

During our anatomic dissections, as noted above, one specimen was found to have its trough posterior to the tuberosity, leaving its tuberosity protuberance grossly intact (Fig. 5-C). That specimen’s moment arm was greater than that of the other nine specimens, and only 8% less than its intact control. This suggests that a trough repair can restore normal supination strength through a full arc of rotation if the trough is positioned posterior to the tuberosity. This observation, of
course, needs to be viewed in the context of involving only one specimen, but it is consistent with the findings of a clinical study in which the biceps tendon was sutured posterior to the tuberosity, resulting in a supination torque that was maintained through the full arc of rotation.

The present study used a posterior muscle-splitting extensor carpi ulnaris approach with the forearm in maximum pronation, to expose the tuberosity during both the anatomic and trough repairs. The muscle-splitting approach was initially designed to limit functional synostosis, by avoiding ulnar dissection. The posterior muscle-splitting approach was extremely useful in exposing the entire tuberosity as needed for our anatomic repair. An alternative to the posterior muscle-splitting approach is the anterior approach, whereby the forearm is hyper-supinated; however, an anterior approach does not consistently expose enough of the radial tuberosity for an anatomic repair. Concern has been expressed that a muscle-splitting approach could lead to forearm synostosis; however, a clinical series comparing anterior with posterior approaches found no significant differences in rotation.

We selected an anatomic repair technique in which the biceps tendon was secured with two intramedullary cortical buttons because of the ability to improve time-zero repair strength and to decrease the occurrence of posterior interosseous nerve palsy. Two intramedullary buttons have been shown to have a failure load significantly greater than that of a single extramedullary button, and comparable with that of the native tendon. Traditionally, extramedullary cortical-button fixation has been combined with an anterior approach, whereby the button is placed on the far radial cortex by passing a guidewire through the radius and forearm. Permanent posterior interosseous nerve injuries have been reported with this extramedullary button technique, and cadaveric studies have shown that, in order to protect the posterior interosseous nerve, the guidewire should not be directed in a distal, radial, or distal-radial direction. Usage of two intramedullary buttons, as in the present anatomic repairs, eliminates the need to drill a guide pin across the far cortex, thus seemingly reducing the risk of a posterior interosseous nerve injury.

Given that preservation of the protuberance of the radial tuberosity appears to be a prerequisite to full recovery of the supination moment, and that a trough can create a stress riser, what is the justification for burring/drilling a trough? Trough repairs were originally developed to enhance healing, although animal and human studies have shown that tendons heal to cortical bone without a cancellous window. Trough repairs with drill holes also served as an ingenious method to secure the tendon to bone, prior to the invention of suture anchors and cortical buttons. Now that reliable tendon-to-cortical bone fixation devices exist, it is our opinion that trough creation during a distal biceps repair needs to be reconsidered.

The present study’s time-zero mechanical findings may or may not transfer to the clinical arena, given the human body’s ability to adapt to the alteration of the tuberosity. However, two other cadaveric studies have also shown that nonanatomic anterior biceps tendon repair leads to loss of moment arm/supination torque in neutral and supinated forearm positions, a finding that has been validated by two clinical studies. Moreover, the supinator muscle cannot compensate for weak biceps at the end ranges of supination.

Is the loss of 27% of the supination moment arm in 60° of supination clinically relevant? To definitively answer that question would require a prospective randomized clinical trial comparing anatomic and trough repairs, measuring postoperative tendon repair position, including supination-dependent outcome measures, and quantifying rotational strength in supinated positions. To date, clinical studies involving trough repairs have reported good to excellent outcomes in terms of the Mayo Elbow Performance Score, the Disabilities of the Arm, Shoulder and Hand score, the American Shoulder and Elbow Surgeons elbow score, and strength measurements in neutral rotation. However, those outcome tools may not be sensitive enough to detect functional differences in high-supination tasks. Examples of such tasks are opening a door, locking or unlocking a stiff deadbolt, turning a car key, tightening or loosening a difficult screw, and swinging a baseball bat or a golf club. Furthermore, previous studies have failed to measure strength in supinated forearm positions. Two studies involving trough repair reported that postoperative isometric strength tested in neutral forearm rotation was 89% and 91% of the uninjured side. The present results suggest that if the testing had been done in a supinated position, the strength loss would have been greater.

In conclusion, the protuberance of the tuberosity is a functional structure that acts as a mechanical cam. Its topographical anatomy deserves preservation.

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