Muscle Moment Arms in the First Dorsal Extensor Compartment After Radial Malunion. A Cadaver Study

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Muscle Moment Arms in the First Dorsal Extensor Compartment After Radial Malunion

A Cadaver Study

By Elly S. LaRoque, MD, Wendy M. Murray, PhD, Sarah Langley, MD, Sanaz Hariri, MD, Benjamin Parker Levine, MD, and Amy L. Ladd, MD

Investigation performed at Stanford University School of Medicine, Stanford, California, and the Palo Alto Veterans Affairs Health Care System, Palo Alto, California

Background: Functional loss is a common complication of the fractured distal part of the radius. The purpose of the present study was to determine if the moment arms of the first dorsal extensor compartment are altered by distal radial fracture malunion. We hypothesized that the moment arms of the abductor pollicis longus and extensor pollicis brevis are significantly affected by dorsal angulation, radial inclination, and radial shortening, the most common deformities accompanying distal radial malunion.

Methods: Moment arms of the extensor pollicis brevis and abductor pollicis longus were estimated in twelve cadaver wrists with use of the tendon-displacement method, which involves calculating the moment arm as the derivative of tendon displacement with respect to joint angle. Tendon displacement was quantified in different wrist postures before and after a closing-wedge osteotomy simulating a complex malunion of an extra-articular radial fracture.

Results: The simulated distal radial malunion resulted in a decrease in the wrist flexion moment arm for both the extensor pollicis brevis (p = 0.0003) and the abductor pollicis longus (p < 0.0001). The wrist flexion moment arms for the extensor pollicis brevis and abductor pollicis longus decreased by a mean (and standard deviation) of 114% ± 75% and 77% ± 50%, respectively, after the osteotomy. The wrist radial deviation moment arms for the extensor pollicis brevis and abductor pollicis longus increased by 16% ± 26% (p = 0.071) and 28% ± 44% (p = 0.043), respectively, after the osteotomy. Radiographs of the wrist that were made before and after the osteotomy indicated that radial tilt changed from 11.1° of volar angulation to 14.8° of dorsal angulation, radial inclination decreased from 21.8° to 7.7°, and radial height decreased from 11.6 to 4.4 mm.

Conclusions: Distal radial malunion alters the mechanical advantage of the muscles in the first dorsal extensor compartment.

Clinical Relevance: The present study reinforces current treatment methods that restore architecture to improve function following a distal radial fracture. In particular, for levels of deformity similar to those tested here, the results of the present study support corrective osteotomy to improve the biomechanics of the thumb tendons of the first dorsal compartment.

Distal radial fractures account for approximately 10% of all injuries and are considered to be the most common fracture requiring evaluation in the emergency department. Malunion is one of the most common complications following a distal radial fracture. Many complications of distal radial fractures and fracture malunions have been described, such as abnormal wrist positions, neuropathies, radiocarpal and radioulnar arthrosis, malunion, tendon ruptures, Volkmann ischemia, finger stiffness, reflex dystrophy syndromes, and de Quervain (first dorsal compartment) tenosynovitis.

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In a review of distal radial fracture complications, Zemel commented that the fracture often occurs at the area of the pulley of the first dorsal extensor compartment, and de Quervain tenosynovitis has been described in the literature as a complication following distal radial fractures. In a review of de Quervain tenosynovitis, Moore related stenosing tenosynovitis to distal radial fractures, hypothesizing that increased friction of the abductor pollicis longus and extensor pollicis brevis tendons over the callus that forms on the distal radial styloid could produce thickening of the retinaculum. The tendons of the first dorsal compartment contribute to wrist and thumb movement and stabilization, and, therefore, radial-sided wrist pain over the abductor pollicis longus and extensor pollicis brevis tendons, pain with active extension and abduction of the thumb, and weakness of grasp are common manifestations found in patients with de Quervain tenosynovitis.

Despite the high prevalence of distal radial fractures and the association of de Quervain tenosynovitis with distal radial

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**Fig. 1**
The extensor pollicis brevis and abductor pollicis longus tendons were dissected and tagged with number-2 FiberWire suture. The de Quervain sheath was left intact.

**Fig. 2**
A tendon was tagged and attached with an O-ring to the position transducer along the direction of pull of its muscle fibers. The voltage source box (right) and digital voltmeter (left) are shown in the background.
Anteroposterior and lateral radiographs of the wrist were made before (Figs. 3-A and 3-B) and after (Figs. 3-C and 3-D) osteotomy. Radial tilt, radial inclination, and radial height were calculated from the radiographs by hand with use of a goniometer.
fractures, the alterations in the biomechanical properties of the abductor pollicis longus and the extensor pollicis brevis after distal radial fracture have not been studied, to our knowledge. A previous study demonstrated significant differences in the moment arms of the five principal wrist motor tendons after dorsal and radial angulation, common deformities associated with distal radial fracture malunion. However, the influence of malunion on the first dorsal extensor compartment was not examined.

The purpose of the present study was to analyze alterations in the biomechanical properties of the first dorsal extensor compartment tendons as they act on the wrist following distal radial fracture malunion with use of a cadaver model to simulate an extra-articular fracture. We hypothesized that the moment arms of the abductor pollicis longus and extensor pollicis brevis are significantly affected by dorsal angulation, radial inclination, and radial shortening, the most common radiographic deformities associated with acute distal radial fractures as well as distal radial malunions.

**Materials and Methods**

Twelve fresh-frozen cadaver upper extremities from seven donor cadavers were studied, with six limbs from male donors (two unmatched) and six limbs from female donors being amputated at the midhumeral level. The average age of the donors at the time of death had been seventy-nine years (range, fifty-eight to ninety-one years). Radiographs of the wrist were made to eliminate specimens with evidence of a previous distal radial fracture or obvious arthritis. Radial tilt, radial inclination, and radial height were measured on anteroposterior and lateral radiographs of the intact specimens by hand with a goniometer.

The distal part of the radius was exposed through the volar approach with use of the interval between the flexor carpi radialis and the radial artery. The pronator quadratus was divided longitudinally. By extending the incision distally and proximally, the tendons of the abductor pollicis longus and extensor pollicis brevis were visualized from the musculotendinous junction to their insertions. The tendons were transected at the musculotendinous junction. The de Quervain sheath, joint capsule, and slips and compartments of the abductor pollicis longus and extensor pollicis brevis were preserved. Number-2 FiberWire sutures (Arthrex, Naples, Florida) were placed through the proximal portion of the distal tendon ends with use of a Bunnell technique (Fig. 1).

Two Steinmann pins were used to fix the radius and ulna to a stable wooden platform, as described by Loren et al. and Zissimos et al., with the forearm in neutral rotation (Fig. 2). The radial side of the wrist was positioned in the jig superiorly. Wrist flexion, extension, radial deviation, and ulnar deviation were referenced off the second metacarpal shaft and the radial shaft. A Kirschner wire was drilled through the thumb interphalangeal and metacarpophalangeal joints to focus movement, and thus to isolate moment arms, about the wrist only. Similarly, the thumb was taped to the proximal phalanx of the index finger during wrist moment arm testing to assist in isolation of measurements about the wrist joint.

The suture ends for each tendon were then sequentially tied to an O-ring attached to a position transducer (Celesco

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**TABLE I** Moment Arms of the First Dorsal Extensor Compartment in the Native State*

<table>
<thead>
<tr>
<th>Cadaver, Wrist</th>
<th>Extensor Pollicis Brevis</th>
<th>Abductor Pollicis Longus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Radial Deviation</td>
<td>Flexion</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>1, R</td>
<td>35</td>
<td>2</td>
</tr>
<tr>
<td>1, L</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>2, R</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>2, L</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>3, R</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td>3, L</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>4, R</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>4, L</td>
<td>31</td>
<td>3</td>
</tr>
<tr>
<td>5, R</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>5, L</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>6, R</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>7, L</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Average</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>9</td>
<td>5</td>
</tr>
</tbody>
</table>

*All values are given in millimeters. Each result is the average (and standard deviation) of ten trials.
Transducer Products, Chatsworth, California) for testing, oriented along the natural direction of the muscle fibers. The position transducer loaded the attached muscles with a constant tension of 7.5 N and was capable of an accuracy of ±0.3 mm and a resolution of ±0.02 mm.

Moment arms of the abductor pollicis longus and extensor pollicis brevis were estimated with use of the tendon-displacement method. This method involves calculating moment arm as the derivative of tendon displacement with respect to joint angle. For each specimen, the moment arm for a muscle in a particular degree of freedom (e.g., the extensor pollicis brevis wrist flexion moment arm) was calculated as the average of ten individual trials. For each trial, the voltage output of the position transducer was recorded in two joint positions. A handheld goniometer was used to measure wrist angles. Voltage was converted to length with use of the specifications of the position transducer given by the manufacturer. The moment arm was calculated from the length data by calculating the derivative numerically;

![Fig. 4-A](image1.png)
![Fig. 4-B](image2.png)

Flexion (Fig. 4-A) and radial deviation (Fig. 4-B) moment arms of the extensor pollicis brevis (EPB) and abductor pollicis longus (APL) in the native state (solid bars) and following a simulated distal radial malunion (open bars). Error bars indicate standard deviations.

**TABLE II Measurements of Radial Tilt, Inclination, and Height Before and After Osteotomy**

<table>
<thead>
<tr>
<th>Cadaver, Wrist</th>
<th>Age of Donor (yr)</th>
<th>Pre-osteotomy</th>
<th>Post-osteotomy</th>
<th>Difference†</th>
<th>Pre-osteotomy</th>
<th>Post-osteotomy</th>
<th>Difference†</th>
<th>Pre-osteotomy</th>
<th>Post-osteotomy</th>
<th>Difference†</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, R</td>
<td>91</td>
<td>−11</td>
<td>15</td>
<td>26</td>
<td>22.5</td>
<td>8.5</td>
<td>−14</td>
<td>13</td>
<td>5.5</td>
<td>−7.5</td>
</tr>
<tr>
<td>1, L</td>
<td>91</td>
<td>−11</td>
<td>15</td>
<td>26</td>
<td>21.5</td>
<td>7</td>
<td>−14.5</td>
<td>12.5</td>
<td>7</td>
<td>−5.5</td>
</tr>
<tr>
<td>2, R</td>
<td>58</td>
<td>−10.5</td>
<td>12</td>
<td>22.5</td>
<td>22</td>
<td>6</td>
<td>−16</td>
<td>12</td>
<td>4.5</td>
<td>−7.5</td>
</tr>
<tr>
<td>2, L</td>
<td>58</td>
<td>−11.5</td>
<td>14.5</td>
<td>26</td>
<td>23.5</td>
<td>8.5</td>
<td>−15</td>
<td>11</td>
<td>4.5</td>
<td>−6.5</td>
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<tr>
<td>3, R</td>
<td>86</td>
<td>−11.5</td>
<td>13</td>
<td>24.5</td>
<td>21</td>
<td>8</td>
<td>−13</td>
<td>11.5</td>
<td>5</td>
<td>−6.5</td>
</tr>
<tr>
<td>3, L</td>
<td>86</td>
<td>−10.5</td>
<td>15.5</td>
<td>26</td>
<td>22</td>
<td>7</td>
<td>−15</td>
<td>12</td>
<td>4</td>
<td>−8</td>
</tr>
<tr>
<td>4, R</td>
<td>82</td>
<td>−11.5</td>
<td>16.5</td>
<td>28</td>
<td>21</td>
<td>7</td>
<td>−14</td>
<td>11.5</td>
<td>3.5</td>
<td>−8</td>
</tr>
<tr>
<td>4, L</td>
<td>82</td>
<td>−11</td>
<td>14</td>
<td>25</td>
<td>21</td>
<td>8.5</td>
<td>−12.5</td>
<td>11</td>
<td>3</td>
<td>−8</td>
</tr>
<tr>
<td>5, R</td>
<td>72</td>
<td>−12</td>
<td>15</td>
<td>27</td>
<td>23</td>
<td>9</td>
<td>−14</td>
<td>11</td>
<td>5</td>
<td>−6</td>
</tr>
<tr>
<td>5, L</td>
<td>72</td>
<td>−11</td>
<td>15</td>
<td>26</td>
<td>22</td>
<td>7.5</td>
<td>−14.5</td>
<td>11.5</td>
<td>4</td>
<td>−7.5</td>
</tr>
<tr>
<td>6, R</td>
<td>83</td>
<td>−12</td>
<td>14.5</td>
<td>26.5</td>
<td>21.5</td>
<td>7.5</td>
<td>−14</td>
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<td>−10</td>
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<td>27.5</td>
<td>20.5</td>
<td>7.5</td>
<td>−13</td>
<td>12</td>
<td>3.5</td>
<td>−8.5</td>
</tr>
<tr>
<td>Average</td>
<td>79</td>
<td>−11.1</td>
<td>14.8</td>
<td>25.9</td>
<td>21.8</td>
<td>7.7</td>
<td>−14.1</td>
<td>11.6</td>
<td>4.4</td>
<td>−7.3</td>
</tr>
</tbody>
</table>

*Negative values indicate volar tilt, and positive values indicate dorsal tilt. †Difference = post-osteotomy value minus pre-osteotomy value.
specifically, the difference in tendon displacement recorded between the two joint postures was divided by the difference in joint position, in radians. The moment arm estimated in this way is associated with the midpoint between the two joint positions.

For estimation of the wrist flexion moment arms, the wrist was moved through a 40° arc, centered at 12° of wrist extension, which was the reading on the goniometer that corresponded to our clinical assessment of “neutral” flexion-extension. For estimation of the radial deviation moment arms, the wrist was moved through a 20° arc, centered at 10° of radial deviation, which was the reading on the handheld goniometer that corresponded to our clinical assessment of “neutral” deviation.

Following estimation of moment arm in the native state, the cadaver upper extremity was removed from the testing frame with the radial and ulnar Steinmann pins still in place. Thus, with remounting, the radius and ulna remained in the same orientation. A generous osteotomy was performed to create approximately 15° of dorsal tilt with corresponding radial shortening and loss of radial inclination. Starting with a transverse cut through the distal part of the radius with use of an oscillating saw placed 3 cm proximal to the radial styloid tip, a second angled cut was made distally to take 3 mm off the ulnar side of the distal part of the radius and 8 mm off the radial side. The bone block was removed, and the remaining bone ends were compressed and secured with a volar locking distal radial plate (TriMed, Valencia, California) with three locking screws distally and three standard screws proximally. Anteroposterior and lateral radiographs were made after fixation of the osteotomy site to measure radial tilt, radial inclination, and radial height in order to quantify the malunion simulated by the osteotomy (Figs. 3-A through 3-D). The testing protocol was repeated for the abductor pollicis longus and extensor pollicis brevis after osteotomy and remounting.

Paired two-sample t tests were used to determine if radial tilt, radial inclination, and radial height differed before and after the osteotomy, with results being considered significant at p < 0.05. Similarly, paired two-sample t tests were used to determine if the flexion and radial deviation moment arms of the extensor pollicis brevis and abductor pollicis longus differed before and after the osteotomy, with results being considered significant at p < 0.05. The abductor pollicis longus data from one cadaver (7, L; see Table I) were not included in the calculations because of a likely data-transcription error in which the moment arm estimated in the native state was inconsistent with the muscle acting as a radial deviator of the wrist. The extensor pollicis...
brevis data from this specimen were included because the moment arm in the native state was consistent with the data from the eleven other specimens as well as with data from the literature.

Results

In the native state, the extensor pollicis brevis and the abductor pollicis longus both flex and radially deviate the wrist. For the extensor pollicis brevis, the radial deviation moment arm was more than three times larger than the wrist flexion moment arm (p < 0.001) (Table I). For the abductor pollicis longus, the radial deviation moment arm was 1.6 times larger than the wrist flexion moment arm (p = 0.054) (Table I). The extensor pollicis brevis had a larger radial deviation moment arm than the abductor pollicis longus did (p = 0.007), whereas the abductor pollicis longus had a larger wrist flexion moment arm than the extensor pollicis brevis did (p = 0.0016).

Radiographs of the wrist indicated that the osteotomy in the present study simulated a complex malunion of the distal part of the radius (Table II). On the average, 26° of dorsal angulation was introduced by the osteotomy as radial tilt shifted from −11.1° ± 0.6° to 14.8° ± 1.4° (p < 0.001), with negative values indicating volar tilt and positive values indicating dorsal tilt. Radial inclination significantly decreased from 21.8° ± 0.9° to 7.7° ± 0.9° (p < 0.001), and radial height significantly decreased from 11.6 ± 0.7 to 4.4 ± 1.2 mm (p < 0.001).

The simulated malunion resulted in a significant decrease in the wrist flexion moment arm for both the extensor pollicis brevis (p = 0.0003) and the abductor pollicis longus (p < 0.0001) (Fig. 4-A). On the average, wrist flexion moment arms decreased 114% ± 75% for the extensor pollicis brevis (from 7 ± 5 mm before the osteotomy to 0 ± 4 mm after the osteotomy) and decreased 77% ± 50% for the abductor pollicis longus (from 13 ± 6 mm before the osteotomy to 4 ± 6 mm after the osteotomy). In contrast, the radial deviation moment arm of the abductor pollicis longus significantly increased by 28% ± 44% following the simulated malunion (from 21 ± 9 mm before the osteotomy to 25 ± 10 mm after the osteotomy; p = 0.043) (Fig. 4-B). The radial deviation moment arm of the extensor pollicis brevis trended toward a significant increase as well; specifically, it increased by 16% ± 26% (from 25 ± 9 mm before the osteotomy to 28 ± 10 mm after the osteotomy; p = 0.071).

Discussion

The present study demonstrated that the wrist flexion moment arms of the extensor pollicis brevis and abductor pollicis longus significantly decreased after a distal radial osteotomy simulating the most common radiographic deformities.
associated with distal radial malunion: radial shortening, dorsal angulation, and loss of radial inclination. Our data also demonstrated that the radial deviation moment arms of these two muscles tended to increase after the osteotomy; the increase observed for the abductor pollicis longus was significant. These data support our hypothesis that the osseous deformities associated with distal radial malunion influence the biomechanics of the first dorsal extensor compartment.

The moment arms that were estimated for the extensor pollicis brevis and abductor pollicis longus in the present study in the native state were consistent with previous findings (Fig. 5). The muscles of the first dorsal extensor compartment are flexors and radial deviators of the wrist, with the extensor pollicis brevis having a larger radial deviation moment arm and the abductor pollicis longus having a larger wrist flexion moment arm. As has been observed previously, the mechanical actions of the first dorsal extensor compartment at the wrist are substantial; the radial deviation moment arms that were measured in the present study were comparable in magnitude with those of the extensor carpi radialis longus.

Tang et al. documented the separate effects of varying degrees of dorsal and radial angulation on the moment arms of five principal wrist muscles (the extensor carpi radialis longus, extensor carpi radialis brevis, extensor carpi ulnaris, flexor carpi radialis, and flexor carpi ulnaris). We modeled the effects of a single, complex distal radial malunion (involving approximately 25° of dorsal angulation, 15° of radial angulation, and 7 mm of radial shortening) on the wrist moment arms of the first dorsal extensor compartment. Ours is a clinically relevant model with a substantial deformity, one that would also suggest that complex fractures substantially increase the biomechanical consequences for muscles that cross the wrist. Additional research is required to better understand how different levels and combinations of deformities, including rotation (the fourth deformity component of distal radial fractures, which was not modeled here), interact.

A limitation of the present study is that the twelve wrists were harvested from seven cadaver specimens. Thus, it is possible that the results for any two wrists harvested from a single donor are correlated. We performed sensitivity analyses in which the results from just one arm from each pair were studied (i.e., we used seven unique specimens in the sensitivity analyses). The results regarding the flexion moment arms of the first dorsal extensor compartment were not affected when the data from seven unique specimens were used; flexion moment arms significantly decreased following osteotomy for both muscles in every analysis. However, while the average difference in radial deviation moment arms before and after osteotomy always increased in the sensitivity analyses, including just one arm from each pair weakened the trends for the radial deviation moment arms for both the extensor pollicis brevis and the abductor pollicis longus.

Our data demonstrated significant changes in the mechanics of the first dorsal extensor compartment for both wrist flexion and radial deviation after an osteotomy that simulated a complex distal radial malunion. The present study reinforces current treatment methods that restore architecture to improve function. In particular, for levels of deformity similar to those in the present study, the results described here support corrective osteotomy to improve biomechanics and to prevent secondary clinical problems associated with the muscles of the first dorsal compartment that provide important contributions to both the
thumb and the wrist. Whereas a cadaver study cannot reproduce clinical symptoms, many studies have shown the deleterious effect of malunion on wrist and hand function, as well as the benefits of corrective osteotomy, for both intra-articular and extra-articular distal radial fractures. The changes in moment arms may provide a biomechanical basis for understanding aspects of this functional loss. The role of the first dorsal extensor compartment may be especially important because of the critical role these muscles play in key pinch and other functional tasks of grasp and release requiring substantial mechanical actions at the wrist.

References