Impact of Ulnar Collateral Ligament Tear on Posteromedial Elbow Biomechanics

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abstract

Ulnar collateral ligament insufficiency has been shown to result in changes in contact pressure and contact area in the posteromedial elbow. This study used new digital technology to assess the effect of a complete ulnar collateral ligament tear on ulnohumeral contact area, contact pressure, and valgus laxity throughout the throwing motion. Nine elbow cadaveric specimens were tested at 90° and 30° of elbow flexion to simulate the late cocking/early acceleration and deceleration phases of throwing, respectively. A digital sensor was placed in the posteromedial elbow. Each specimen was tested with valgus torque of 2.5 Nm with the anterior band of the ulnar collateral ligament intact and transected. A camera-based motion analysis system was used to measure valgus inclination of the forearm with the applied torque. At 90° of elbow flexion, mean contact area decreased significantly (107.9 mm$^2$ intact vs 84.9 mm$^2$ transected, $P=.05$) and average maximum contact pressure increased significantly (457.6 kPa intact vs 548.6 kPa transected, $P<.001$). At 30° of elbow flexion, mean contact area decreased significantly (83.9 mm$^2$ intact vs 65.8 mm$^2$ transected, $P=.01$) and average maximum contact pressure increased nonsignificantly (365.9 kPa intact vs 450.7 kPa transected, $P=.08$). Valgus laxity increased significantly at elbow flexion of 90° (1.1° intact vs 3.3° transected, $P=.01$) and 30° (1.0° intact vs 1.7° transected, $P=.05$). Ulnar collateral ligament insufficiency was associated with significant changes in contact area, contact pressure, and valgus laxity during both relative flexion (late cocking/early acceleration phase) and relative extension (deceleration phase) moments during the throwing motion arc. [Orthopedics. 2015; 38(7):e547-e551.]

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he anterior bundle of the ulnar collateral ligament has been shown to be the most important restraint in maintaining valgus elbow stability, especially during the throwing motion. Attenuation or rupture of the ulnar collateral ligament in overhead throwing athletes may cause valgus instability of the elbow, which results in disabling elbow pain.

Previous studies reported various findings on the occurrence and extent of posteromedial elbow joint changes throughout the throwing motion secondary to ulnar collateral ligament insufficiency. Ahmad et al used an ulnar collateral ligament insufficiency model with Fuji film and found significantly higher posteromedial elbow contact pressure and significantly lower contact area compared with the intact elbow at 30° of elbow flexion but not at 90° of elbow flexion. This finding suggested that the effects of ulnar collateral ligament insufficiency may be important primarily at the deceleration phase of the throwing motion. Osbahr et al used Fuji film to compare intact specimens with specimens with the ulnar collateral ligament transected. They found significantly higher contact pressure and significantly decreased contact area in the posteromedial elbow at 90° of elbow flexion with ulnar collateral ligament transection. Since the advent of these studies, newer digital pressure sensors have been manufactured to allow for improved data analysis during testing. Further biomechanical study of posteromedial elbow forces with this new technology is needed to clarify whether these changes occur throughout the throwing motion. If significant changes in contact area and contact pressure occur throughout the throwing arc, this finding could help to confirm the clinical manifestations of ulnohumeral chondral and ligamentous overload.

The goal of this study was to use a digital sensor system to characterize the alteration in contact area and contact pressure in the posteromedial compartment of the elbow during the late cocking/early acceleration phase (90° of elbow flexion) and the deceleration phase (30° of elbow flexion) of the throwing motion after simulated ulnar collateral ligament insufficiency in a cadaveric model. The authors hypothesized that a complete ulnar collateral ligament tear would be associated with decreased contact area, increased contact pressure, and increased valgus laxity in the ulnohumeral joint at both 30° and 90° of elbow flexion.

**MATERIALS AND METHODS**

Nine individual male frozen upper extremities transected at the mid-humerus were obtained for this study. To avoid the issue of degenerative changes and poor soft tissue and bone quality in older cadavers, younger specimens (average age, 49.2 years; range, 41-59 years) were used for this study. Skin and muscle tissue distal to the mid-humerus was preserved throughout testing to maintain the secondary restraints to valgus torque. A medial skin incision was made, and the thin, membranous posteromedial capsule was dissected, with care taken to avoid damaging the anterior bundle of the ulnar collateral ligament, to gain access to the posteromedial compartment of the ulnohumeral articulation. The anterior bundle of the ulnar collateral ligament was identified by splitting the flexor carpi ulnaris and gently elevating the muscle off the ulnar collateral ligament.

A Tekscan 6900 quad sensor (I-scan; Tekscan, Inc, South Boston, Massachusetts) was used to measure contact area and average maximum contact pressure. These sensors are 14×14 mm and have a capacity of 7585 kPa, with sensel density of 62 sensels/cm². The electronics are gain adjustable, which means that the sensitivity of the sensor can be adjusted for the project requirements. The I-scan sensors were calibrated with a known load between 2 high-density polyurethane plates. Calibration was optimized by confirming that the load recorded by the pressure sensors was within 8% of the applied load.

A similar method was reported previously with Tekscan software in a study of patellofemoral contact pressure across the trochlear surface. Pressure measurements were accurate to within 5% of full scale. The sensor was inserted into the joint between the posteromedial trochlea and the olecranon (Figure 1). As previously reported, the measurement device was inserted in standardized fashion into the posteromedial trochlear curvature. The sensor was inserted so that it extended laterally to the trochlear ridge on the olecranon and covered the proximal tip of the olecranon. The sensor was secured to the olecranon along its medial border with cyanoacrylate (Loctite SuperGlue; Henkel Corp, Rocky Hill, Connecticut). In all specimens, the authors ensured that the sensor covered the posteromedial compartment between the olecranon and the medial trochlea.

The proximal humerus was potted into a polyvinyl chloride pipe with polyester resin (Bondo; 3M Corp, St Paul, Minnesota) that was rigidly fixed to the base of the MTS Q-Test electromechanical test frame (MTS Systems, Eden Prairie, Minnesota). The long axis of the humerus was in the horizontal plane, and the medial side was facing upward (Figure 2). The forearm was held in neutral supination-pronation position by a K-wire at the distal radioulnar joint to prevent rotation during testing. Next a 3-mm Steinmann pin was inserted through the ulna 12 cm from the center of rotation of the elbow. The flexion angle of the elbow was adjusted by moving the base plate. Each elbow was tested in 90° and then in 30° of flexion, as measured with a goniometer, to simulate the late-cocking/early acceleration (relative flexion) and deceleration (relative extension) phases of throwing, respectively. The load frame applied a valgus torque of 2.5 Nm to the elbow. Although the valgus torque in throwers approaches 64 Nm, the 2.5 Nm torque was selected based on the authors’ pilot testing.
and a previous study by Callaway et al that showed that valgus torque of more than 2.5 Nm in cadavers in the setting of ulnar collateral ligament sectioning results in cadaveric failure and dislocation. The specimen was preconditioned before each testing condition with 25 cycles at 2.5 Nm of valgus torque at the rate of 1.3°/s. After the specimen was tested with an intact ulnar collateral ligament, the authors completely transected the anterior band of the ulnar collateral ligament at midsubstance and repeated the testing at 30° and 90° of elbow flexion.

The valgus inclination of the forearm with respect to the humerus was measured with a 2-camera motion analysis system (MicronTracker Hx60; Clarion Technology, Toronto, Ontario, Canada). This device uses visible light illumination to locate objects marked with a printed target pattern (Figure 2). The device is precalibrated against distortion and misalignment. The calibration accuracy of the camera system was 0.35 mm, with a marker tracking error (root-mean square) of 0.18 mm or less in validation testing. Processing time was 15 to 20 ms/frame, and acquisition frequency was 20 Hz. A similar system was used previously to measure strain in a biomechanical study of ulnar collateral ligament reconstruction of the elbow.

Power analysis showed that 6 specimens would provide 99% power to detect a significant difference in valgus laxity at 90° for the intact vs sectioned state. A paired Student’s t test was used to determine whether observed differences between groups were significant (P≤.05).

RESULTS

A statistically significant decrease in contact area was observed after a simulated complete ulnar collateral ligament tear at both 90° and 30° of elbow flexion (Table). This finding was associated with a corresponding statistically significant increase in contact pressure with an ulnar collateral ligament tear at 90° of elbow flexion and a trend toward statistical significance in contact pressure at 30° of elbow flexion. Valgus laxity increased significantly with complete ulnar collateral ligament tear compared with the intact specimen at 90° and 30° of elbow flexion (Table).

DISCUSSION

The current study evaluated the effect of ulnar collateral ligament transection with digital technology. The findings showed that the posteromedial ulnohumeral contact area changed signifi-

![Figure 1: Photograph showing positioning of the sensor in the ulnohumeral joint and the potted humerus fixed to the base of the MTS Q-Test electromechanical test frame (MTS Systems, Eden Prairie, Minnesota).](image1)

![Figure 2: Photograph showing the test setup with the MTS Q-Test electromechanical test frame (MTS Systems, Eden Prairie, Minnesota) applying valgus torque to the forearm. Camera motion analysis sensors are shown.](image2)
significant increase in contact pressure at 30° of flexion. These findings supported the hypothesis that posteromedial impingement in association with ulnar collateral ligament insufficiency occurs throughout the throwing motion.

The valgus laxity values in the current study were lower than those reported by Ahmad et al., who used a valgus torque of 2.0 Nm with a simulated full ulnar collateral ligament tear and found valgus laxity of 7.37°±3.45° at 30° and 4.26°±3.10° at 90° of elbow flexion. The lower values in the current study may have resulted from the authors’ decision to retain most of the secondary valgus stabilizers, including the musculature surrounding the elbow. This study also found greater valgus laxity at 90° than at 30° of elbow flexion, which also contrasted with the findings of Ahmad et al. The current findings were in accord with those of Morrey and An, who showed that the contribution of the ulnar collateral ligament to elbow valgus stability increased from extension to flexion. The ulnar collateral ligament contributed approximately 55% of stabilization to valgus stress at 90° of elbow flexion. The authors believe that the excessive valgus laxity at the elbow after ulnar collateral ligament transection results in a wedging effect of the olecranon into the trochlear fossa, altering the contact forces. Increased valgus laxity at 90° of flexion may also lead to suboptimal kinematics, which could explain the current finding of greater changes in contact forces at 90° than at 30° with ulnar collateral ligament insufficiency.

The new measurement technology used in this study offers a new platform for future research on ulnar collateral ligament tear patterns and reconstruction techniques. The digital pressure sensor device has a number of important advantages over the pressure-sensitive film (Fuji film) used in previous studies. These include increased accuracy, dynamic testing capabilities, ease of calibration, reusability of the sensor, and direct computer

cantly and the change in average maximum contact pressure reached significance or near significance during both the late cocking/early acceleration phase and the deceleration phase of the throwing motion. There was a concomitant significant increase in valgus laxity. These biomechanical findings suggested that posteromedial impingement is a complex pathologic process that may occur in association with ulnar collateral ligament tears throughout the entire throwing motion arc. This process, which is known as ulnohumeral chondral and ligamentous overload, may result in joint degeneration, including chondromalacia and osteophyte formation. Concomitant posteromedial chondromalacia in the setting of ulnar collateral ligament reconstruction has been associated with lower rates of return to play in throwing athletes compared with throwing athletes with isolated ulnar collateral ligament injuries. The current and previous biomechanical data as well as previous clinical data suggested the need for early recognition and treatment of ulnar collateral ligament injuries before the occurrence of pathologic processes, including chondromalacia and osteophyte formation.

Posteromedial impingement was initially believed to occur as a result of abutment of the olecranon process into the trochlear fossa at ball release, when the elbow nears terminal extension. Ahmad et al. found statistically significant changes in contact pressure and area with ulnar collateral ligament insufficiency at 30° (position of the elbow at the deceleration phase of throwing) and not at 90° (position of the elbow at the acceleration phase of throwing) of elbow extension with Fuji film. Their results supported the idea that valgus extension overload typically results from significant changes in contact pressure and contact area that occur only during the deceleration phase of the throwing motion. Although these authors found no statistically significant changes in contact pressure or contact area at 90° of elbow flexion, their results showed a nonsignificant increase in contact pressure and a decrease in contact area at this elbow position. Based on these results, Osbahr et al. designed a similar study with Fuji film but with higher valgus torque of 2.5 Nm with elbow flexion of 90° and found a statistically significant change in contact pressure and contact area. These authors concluded that posteromedial impingement may also occur during the late cocking/early acceleration phase of the throwing motion. The current study used digital technology and confirmed the previous findings at 90° of flexion and further showed a significant decrease in contact area and a nearly significant increase in contact pressure at 30° of flexion. These findings supported the hypothesis that posteromedial impingement in association with ulnar collateral ligament insufficiency occurs throughout the throwing motion.

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<table>
<thead>
<tr>
<th>Comparison</th>
<th>Intact (n=9)</th>
<th>Cut (n=9)</th>
<th>P</th>
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<tr>
<td>30°, mean±SD</td>
<td></td>
<td></td>
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<tr>
<td>Contact pressure, kPa</td>
<td>365.9±114.6</td>
<td>450.7±176.5</td>
<td>.08</td>
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<tr>
<td>Contact area, mm²</td>
<td>83.9±29.3</td>
<td>65.8±29.1</td>
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<td>Valgus laxity</td>
<td>1.0°±0.4°</td>
<td>1.7°±1.0°</td>
<td>.05</td>
</tr>
<tr>
<td>90°, mean±SD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact pressure, kPa</td>
<td>457.6±155.0</td>
<td>548.6±147.9</td>
<td>&lt;.001</td>
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<tr>
<td>Contact area, mm²</td>
<td>107.9±23.6</td>
<td>84.9±23.9</td>
<td>.05</td>
</tr>
<tr>
<td>Valgus laxity</td>
<td>1.1°±0.3°</td>
<td>3.3°±1.2°</td>
<td>.01</td>
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interface. Use of this digital pressure sensor in the posteromedial elbow compartment provides an improved view of biomechanical changes associated with ulnar collateral ligament insufficiency. Although the previous 2 studies used gravity valgus positioning and hanging weights to apply the required valgus torque, the current study used the MTS Q-Test electromechanical test frame to apply the exact amount of torque required. Finally, in the earlier studies, the age of the specimens was not known, and the current findings, with a younger cadaveric specimen population, may reflect conditions more consistent with the clinical scenario.

Limitations

The current study had several limitations that are inherent to most biomechanical studies. The testing method did not test the entire arc of elbow motion. However, previous studies supported the use of 90° and 30° of elbow flexion to study contact forces. These positions simulate the 2 most important biomechanical points in the throwing motion, the late cocking/early acceleration phase and the deceleration phase, respectively. The study also used static and not dynamic loading. In a living subject, dynamic muscle forces around the elbow play a major role as secondary stabilizers. Although the authors could not fully counteract this limitation in the cadaveric model, they retained much of the soft tissue envelope about the forearm, wrist, and hand to maintain secondary valgus stabilizers of the elbow.

Conclusion

This biomechanical study that used digital technology supported the findings that an ulnar collateral ligament tear was associated with a significant change in contact area, a significant or nearly significant change in contact pressure, and a significant increase in valgus laxity during both relative flexion (late cocking/early acceleration phase) and relative extension (deceleration phase) moments during the throwing motion arc. These findings suggest the need for early recognition and treatment of ulnar collateral ligament injuries before the occurrence of pathologic processes, including chondromalacia and osteophyte formation.

References