Biomechanical comparison of graft fixation at 30° and 90° of elbow flexion for ulnar collateral ligament reconstruction by the docking technique

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Background: Ulnar collateral ligament (UCL) injuries have been successfully treated by the docking reconstruction. Although fixation of the graft has been suggested at 30° of elbow flexion, no quantitative biomechanical data exist to provide guidelines for the optimal elbow flexion angle for graft fixation.

Methods: Testing was conducted on 10 matched pairs of cadaver elbows with use of a loading system and opto-electric tracking device. After biomechanical data on the native UCL were obtained, reconstruction by the docking technique was performed with use of palmaris longus autograft with one elbow fixated at 30° and the contralateral elbow at 90° of elbow flexion. Biomechanical testing was undertaken on these specimens.

Results: The load to failure of the native UCL (mean, 20.1 N-m) was significantly higher (P = .004) than that of the reconstructed UCL (mean, 4.6 N-m). There was no statistically significant difference in load to failure of the UCL reconstructions fixated at 30° of elbow flexion (average, 4.86 N-m) compared with those at 90° (average, 4.35 N-m). Elbows reconstructed at 30° and 90° of elbow flexion produced similar kinematic coupling and valgus laxity characteristics compared with each other and with the intact UCL. Although not statistically significant, the reconstructions fixated at 30° more closely resembled the biomechanical characteristics of the intact elbow than did reconstructions fixated at 90°.

Conclusion: No statistically significant difference was found in comparing the docking technique of UCL reconstruction with graft fixation at 30° vs. 90° of elbow flexion.

Level of evidence: Basic Science, Biomechanics.

Keywords: UCL reconstruction; ulnar collateral ligament; elbow; docking; biomechanics of ligament; cadaver study

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The anterior bundle of the ulnar collateral ligament (UCL) is the primary stabilizer to valgus stress in the functional range of motion at the elbow (20°-120°).2,3 Overhead activities such as throwing a baseball, striking a tennis shot, or
hurling a javelin can challenge the ultimate strength of the UCL. The highest stresses are observed in the late cocking, early acceleration phases of the throwing motion when the elbow is at approximately 80° to 90° of elbow flexion. It is at this point in the throwing motion that the forces generated may exceed the tensile strength of the ligament, resulting in UCL injury. These injuries range from stretching of the collagen fibers to partial tear and complete rupture. Overhead throwing athletes are particularly susceptible to injury of the UCL from the repetitive load that these activities entail. Improper throwing mechanics and chronic overuse can significantly increase the overhead athlete’s vulnerability to UCL injury as repetitive stress and muscle fatigue decrease the tolerability to the valgus forces generated at the elbow.

Treatment of UCL injury in a competitive throwing athlete often begins with a trial of nonoperative management. If nonoperative management fails to restore appropriate UCL stability to allow return to the preinjury level of competition, reconstruction of the UCL may be required. One of the commonly accepted reconstruction procedures, termed the docking technique, uses a graft that is woven into a single humeral tunnel and tied over a bone bridge at the 2 free ends are then secured with sutures that are pulled over a bone bridge at the medial epicondyle. The docking technique has been shown to have consistent results, with the majority of patients returning at or above preinjury level of competition.

Most current reconstruction techniques recommend fixation of the graft at 30° of elbow flexion, but maximum valgus stresses are noted in the late cocking, early acceleration of the throwing motion with the elbow at approximately 80° to 90° of flexion. No study has specifically identified the biomechanical properties of the reconstructed UCL tensioned and fixated at different degrees of elbow flexion. The purpose of this study was to evaluate the biomechanical features of UCL reconstruction, including valgus laxity as a function of flexion angle, valgus load to failure, and the kinematic coupling between forearm rotation and valgus motion, by use of the docking technique with the graft fixated at 30° vs. 90° of elbow flexion. We hypothesized that the biomechanical characteristics of the reconstructed elbow, including valgus laxity, load to failure, and kinematic coupling, are significantly affected by the elbow flexion angle at which the UCL graft is tensioned and fixated with the docking reconstruction.

Materials and methods

Instrumentation

Testing was undertaken with use of a 4° of freedom apparatus that permitted unconstrained elbow motion in response to applied valgus loads. The system provided the ability to test the elbow at different angles of fixed elbow flexion that could be set at 10° increments covering the range from full flexion to full extension. At each fixed elbow flexion position, the system provided measures of the applied varus/valgus moment and of the resulting varus/valgus angle and forearm rotation. Detailed description of this system is provided in a previous study. An optoelectronic kinematic data acquisition system (Optotrak 3020; Northern Digital, Inc., Waterloo, ON, Canada) was used to track changes in length of the anterior, central, and posterior portions of the anterior bundle of the UCL as described in detail in an earlier publication.

Specimen preparation

Testing was performed on 10 matched pairs of fresh frozen cadaveric upper extremities from the proximal humeral metaphysis through the hand. All specimens were stored at −20°C and thawed to room temperature before dissection was begun. The skin, subcutaneous tissue, and musculotendinous structures were removed with care to maintain the elbow capsule and ligamentous structures. The palmaris longus tendon was harvested during the dissection and kept in gauze soaked in 0.9% saline. The humerus was osteotomized within the proximal third of the shaft; the radius and ulna were osteotomized at the level of the pronator quadratus. The proximal and distal ends were then longitudinally aligned in 2 separate PVC cylinders and secured with plaster. The PVC cylinders were then fixed to the elbow loading system. The anterior, central, and posterior portions of the anterior bundle of the UCL were marked at the proximal and distal insertions to allow easy and consistent measurements of length and elongation.

Testing procedure

After specimen preparation, valgus loading tests were performed. During the first loading tests, the operator manually loaded the elbow slowly into valgus to a moment of 5 N-m and then slowly unloaded it. The value of 5 N-m maximal torque was selected because preliminary observations showed that under this torque, the extreme of range of motion of the elbow is reached but no failure occurs. Maintaining the same level of maximum valgus moment for all specimens was necessary to minimize the effect of morphologic variations, such as radius/ulna length and size, on the assessment of the valgus stabilization provided by the native UCL and subsequent reconstructions. This loading/unloading cycle, lasting approximately 6 to 8 seconds, was repeated a minimum of 5 times. Data from both the loading device (applied moment and the valgus and ulnar rotations) and the kinematic system were collected and recorded throughout the test. These nondestructive loading tests were performed at 30°, 60°, 90°, and 100° of elbow flexion. The elbow was then positioned at 90° of flexion to simulate the late cocking, early acceleration phase of throwing and loaded to failure with slowly increasing valgus torque. The mode of failure, consisting of either midsubstance tear or avulsion at the insertion sites, was then recorded.

After failure of the native UCL, surgical reconstruction of the UCL was undertaken with use of the harvested palmaris longus tendon autograft and the docking procedure described by Rohrbough et al and standardized docking surgical instrumentation (Arthrex, Naples, FL, USA) (Fig. 1). A whip stitch with No. 2 FiberWire FiberLoop (Arthrex) was sewn into each end of the tendon grafts and used for final tensioning and fixation of all reconstructions. One elbow in each pair was reconstructed with graft
tensioning and fixation at 30°/C14 of elbow flexion and full supination with a varus stress to reduce the joint; the contralateral elbow was reconstructed with graft tensioning and fixation at 90°/C14 of elbow flexion and full supination, likewise with varus stress (Fig. 2). The reconstructed elbows were then subjected to the same subfailure valgus loading and load to failure tests previously described for the native UCL.

Data analysis

Five parameters were used to characterize the mechanical behavior of the elbow of the native UCL compared with those of the UCL reconstructions fixated at 30° and 90° of elbow flexion.

Resting length

The resting length (in millimeters) of the anterior, posterior, and central portions of the anterior bundle was defined as insertion-to-insertion distance with the elbow in neutral varus/valgus angulation and neutral forearm rotation. This resting length was determined for each degree of elbow flexion including 30°, 60°, 90°, and 100°. The technique for determining the ligament length from the Optotrak data was previously described.6 Two groups of specimens, one with the reconstructed UCL fixated at 30° and the other with the UCL fixated at 90°, were observed and compared with the native ligament.

Maximum elongation under a valgus stress vs. flexion angle

The change in length of the different bands of the anterior bundle (anterior and posterior) expressed as a percentage of resting length was measured at each degree of elbow flexion (30°, 60°, 90°, and 100°). Data were recorded for the reconstructions fixated at 30°, the reconstructions fixated at 90°, and the native UCL.

Valgus laxity

Valgus laxity (in degrees per newton-meter) was defined as the maximal valgus rotation (degrees) divided by the corresponding applied valgus moment (newton-meters). This was measured in the reconstructions fixated at 30°, the reconstructions fixated at 90°, and the native UCL.

Kinematic coupling ratio

Kinematic coupling ratio was defined as the ratio of forearm rotation and valgus rotation. This variable was measured initially in the intact specimens and compared with the ligaments reconstructed with fixation at 30° and fixation at 90° of elbow flexion.

Maximum load to failure and mode of failure (native UCL and both reconstructions)

Maximum load to failure was used to measure the ultimate strength of the native UCL and both reconstructions. It was calculated as the valgus torque (newton-meters) required to completely disrupt the native or reconstructed UCL.

The mode of failure was also recorded and placed in 1 of 6 categories: ulnar avulsion, midsubstance tear, suture pullout at the humeral side, tunneling, bone fracture at the tunnel, and anterior branch tear. Tunneling was noted when both sides of the reconstruction became loose and provided no valgus support of the elbow.

Statistical analysis

Simple descriptive studies and a mixed design repeated analysis of variance were used to compare the properties of the native UCL with those of the reconstructed UCL tensioned and fixated at 30° and 90°. All statistical analyses were performed with the SPSS statistical package (SPSS Inc., Chicago, IL, USA).

Results

Resting length

Change in the resting length with increasing angles of elbow flexion was noted in the intact specimens (Fig. 3).
For the anterior band of the anterior bundle of the UCL, a statistically significant decrease in the resting length was noted as the elbow flexed from 30° to 100°. In addition, the posterior band demonstrated a statistically significant increase in resting length as the elbow was flexed from 30° to 100°. The central band remained isometric throughout this range of motion. Statistically significant differences for the anterior and posterior bands were observed between 30° and 60° ($P = .033$), 30° and 90° ($P = .004$), 30° and 100° ($P = .018$), and 60° and 90°.

A statistically significant difference in resting length was noted in the intact elbow and the reconstructions fixed at 30° and 90° with respect to the anterior band ($P = .001$), but no differences were observed in the posterior or central bands. No statistically significant difference was observed in the resting lengths between the reconstructions tensioned and fixed at 30° vs. those tensioned and fixed at 90°.

**Maximum elongation under a valgus stress vs. flexion angle**

Maximum elongation in the anterior and posterior bands was not found to be affected by the flexion angle. No significant difference was noted in comparing the reconstructed ligaments with the native ligament and between the two reconstructions (tensioned and fixed at 30° and 90°).

**Valgus laxity**

Valgus laxity was affected by the flexion angle of the elbow (Fig. 4). In the intact ligament, the valgus laxity decreased as the flexion angle increased from 30° to 100°. Statistically significant findings were documented between 30° and 60° ($P = .029$), between 30° and 90° ($P = .013$), and between
30° and 100° ($P = .013$) for the native ligament. The valgus laxity of the elbow with surgical reconstruction fixated at 30° of elbow flexion more closely matched the valgus laxity of the intact elbow than that of the reconstruction fixated at 90° of elbow flexion, but the differences were not statistically significant.

**Kinematic coupling ratio**

The kinematic coupling ratio was significantly affected by flexion angle for the intact elbow and for the elbow reconstructions fixated at either 30° or 90° (Fig. 5). As the elbow moved from 30° of flexion to 100° of flexion, the coupling for all 3 conditions changed from pronation coupled with valgus rotation to supination coupled with valgus rotation. No statistically significant difference in kinematic coupling ratio was observed between the 3 conditions; however, the kinematic coupling ratio of UCL reconstruction fixated at 30° of elbow flexion more closely matched that of the intact elbow than of the UCL reconstruction fixated at 90° of elbow flexion.

**Maximum load to failure and mode of failure**

The load to failure in valgus of the elbow after the docking surgical reconstruction fixated at either 30° or 90° of elbow flexion was significantly ($P = .004$) lower than the load to failure in valgus in elbows with the native UCL ligament (Table I). No significant difference was observed in the load to failure in valgus between the UCL reconstructions fixated at 30° of flexion and the reconstructions fixated at 90° of elbow flexion.

The native UCL failed in valgus at an average of 20 N-m with approximately equal incidences of ulnar avulsions and midsubstance tears (Table I). The UCL reconstructions fixated at 30° of elbow flexion failed primarily through tear of the anterior branch of the reconstruction at an average ultimate valgus moment of 4.85 N-m. The UCL reconstructions fixated at 90° of elbow flexion failed primarily through bone fracture at the ulnar tunnel at an average valgus moment of 4.35 N-m.

**Discussion**

The overhead-throwing athlete constantly challenges the integrity of the UCL by placing extreme repetitive stress on the medial side of the elbow. When the ligament ruptures, reconstruction of the UCL is often required for the athlete to return to competitive throwing activity. Most current reconstruction techniques recommend fixation of the graft at 30° of elbow flexion,5,6,10,14,20,24 but maximum valgus stresses are noted in the late cocking, early acceleration phases of the throwing motion with the elbow at approximately 80° to 90° of elbow flexion.2,4,6,12 No study has specifically identified the biomechanical properties of the reconstructed UCL tensioned and fixated at different degrees of elbow flexion. Certain biomechanical properties are paramount to the success of the reconstruction, including resting length, valgus stability, normal kinematics, and a comparable load to failure profile. The purpose of this cadaveric study was to compare the biomechanical profile of the native UCL with the reconstructed UCL tensioned and fixated at 30° and 90° of elbow flexion.
The resting length with respect to the lengths of the anterior, central, and posterior bands of the anterior bundle of the native UCL demonstrates that the anterior and posterior bands change significantly with differing angles of elbow flexion. As noted in previous biomechanical studies, this study supported the finding that the central band of the anterior bundle remains the most relatively isometric portion of the UCL. As such, to avoid the variability in tension seen in the other bands with changes in elbow flexion, our findings agree that these isometric fibers should be reconstructed and that finding the point of maximum isometry is paramount to the success of the reconstruction. This study supported the finding that the central band of the UCL will elongate while the anterior bundle remains relatively isometric. This challenges the standard technique of tensioning the UCL reconstruction at 30° of elbow flexion as the ligament tension increases with elbow flexion and may experience excessive strain at increasing flexion angles. This study demonstrated no significant difference with regard to valgus laxity in the reconstruction with the graft tensioned and fixed at 30° of elbow flexion vs. reconstruction with the graft tensioned and fixed at 90°.

The kinematic coupling ratio was initially defined by Morrey and An and refers to the linked motion of forearm rotation with valgus angulation. Their study concluded that forearm rotation with valgus laxity increased significantly when the UCL was absent. Callaway et al concluded that coupling does occur but does not significantly change with sectioning of the UCL. This study compared the kinematic coupling of the native UCL with reconstructions tensioned and fixed at 30° and 90° of elbow flexion. Although findings were not statistically significant, the surgical reconstruction fixed at 30° displayed coupling characteristics more similar to the intact elbow compared with the reconstruction fixed at 90°. In addition, the angles of elbow flexion that display the closest similarities to the native coupling occur at 80° to 90° in the surgical reconstructions tensioned and fixed at 30°. The UCL sees the most significant stresses at these angles as the elbow goes from late cocking to the early acceleration phase of the throwing motion. Maintaining the kinematic coupling characteristics of the native UCL likely contributes to the overall success of the reconstruction.

The load to failure of the surgically reconstructed elbows was significantly lower than that of the native UCL at time zero. The majority of the failures in the reconstructed elbows occurred with either tunnel failure or suture pullout. Because the reconstructions were tested immediately after fixation, biologic healing was not taken into account. This may account for the lower load to failure noted in the reconstructed specimens. Theoretically, as biologic healing occurs during the rehabilitation period, osseointegration of the graft in the humeral tunnel would proceed to replace the sutures as the load bearer. No significant difference or trend in load to failure characteristics was noted between the surgical reconstructions fixed at 30° vs. 90°.

Jobe et al described the UCL reconstruction angle of elbow flexion for graft tensioning and fixation to be 30° in a landmark article. Since that time, most UCL reconstruction biomechanical studies and reconstruction descriptions have been described with the graft tensioned and fixed at 30°. However, other elbow flexion angles have been described for tensioning in UCL reconstruction. Paletta and Wright describe tensioning and fixation of the graft at 45° of elbow flexion, and Ruland et al report tensioning and fixation of the graft with the elbow in 90° of flexion. This investigation and its follow-ups will attempt to provide biomechanical evidence for the optimum elbow flexion angle for UCL graft tensioning and fixation.

Multiple biomechanical studies have been undertaken testing the characteristics of both the intact UCL and the various reconstruction techniques. The most common

### Table I

<table>
<thead>
<tr>
<th>Mode of failure</th>
<th>Native</th>
<th>Reconstructed</th>
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</thead>
<tbody>
<tr>
<td>a</td>
<td>44.5%</td>
<td>55.5%</td>
</tr>
<tr>
<td>b</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>c</td>
<td>0%</td>
<td>50%</td>
</tr>
<tr>
<td>d</td>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>e</td>
<td>50%</td>
<td>20%</td>
</tr>
<tr>
<td>f</td>
<td>4.35 (3.33)</td>
<td>4.85 (1.52)</td>
</tr>
</tbody>
</table>

*Load to failure in N-m (standard deviation)*

a: Avulsion at the ulnar side. b: Mids substance ligament tear. c: Suture pullout at the humeral side. d: Tunneling. e: Bone fracture at the tunnel. f: Tear of the anterior branch of the reconstruction.
characteristic evaluated is the load to failure; however, differing techniques have emerged that make it difficult to compare results. Simple axial loading to force valgus stress on the elbow used by McAdams et al.15 and Paletta et al.17 does not appear to re-create the in vitro loading of the UCL as closely as use of both valgus and rotational forces seen in the normal throwing motion evaluated by Ruland et al.21 and Lynch et al.13 Similar to the study by Ciccotti et al.,6 this testing apparatus allowed full unconstrained elbow motion including both valgus stress and torsional rotation to provide the load to failure characteristics of the intact and reconstructed UCL. In addition, the kinematic characteristics of the UCL have also been evaluated in previous studies using angular displacement as a function of valgus stress and flexion angle13 as well as the change in length of the various bands of the UCL in the face of valgus and torsional stress.5 This study used a validated testing apparatus8,26 to measure the kinematic characteristics of the UCL with respect to coupling, valgus laxity as a function of flexion angle, and maximum elongation vs. flexion angle similar to the parameters used by Ciccotti et al.6.

There are several strengths of this study. The unique testing apparatus allowed unconstrained motion and testing of the elbow. This 4° of freedom testing apparatus, which has been previously used to compare the docking vs. the modified Jobe reconstruction technique, provides a more physiologic system as opposed to other testing procedures.6 In addition, the insertion-to-insertion length kinematic changes were precisely measured with an optoelectronic kinematic data acquisition system. Furthermore, the study used a consistent docking technique with standardized docking surgical instrumentation in all specimens. To our knowledge, the elbow flexion angle for UCL graft tensioning and fixation at 30° vs. 90° has never been tested in this manner.

There are several limitations of this study. The advanced age of some of the cadavers may have allowed some of the lower load to failure profiles. Furthermore, the cadaveric design does not allow biologic healing, which also may have had an impact on the lower load to failure profiles of the UCL reconstructions.

**Conclusion**

UCL reconstructions by the docking technique with the graft tensioned and fixated at 30° and 90° are statistically similar. The load to failure, resting length, and maximum elongation under a valgus stress did not differ significantly between the reconstructions at 30° and 90°. The optimal angle of elbow flexion for tensioning and fixation of the UCL reconstruction that most closely retains the biomechanical characteristics of the native UCL has yet to be determined. Future directions will compare tensioning of the graft at different elbow flexion angles (50° and 70°) in an effort to determine the optimal angle for fixation that most closely adheres to the biomechanical characteristics of the intact UCL.

**Disclaimer**

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