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A Comparison of Cyclic Valgus Loading on Reconstructed Ulnar Collateral Ligament of the Elbow

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Abstract

A COMPARISON OF CYCLIC VALGUS LOADING ON RECONSTRUCTED ULNAR COLLATERAL LIGAMENT OF THE ELBOW. Roshan P. Shah, Derek P. Lindsey, Gannon W. Sungar, Timothy R. McAdams. Section of Sports Medicine, Department of Orthopaedic Surgery, Stanford University, Stanford CA. (Sponsored by Michael J. Medvecky, Department of Orthopaedic Surgery, Yale University School of Medicine.)

This study compares the biomechanics of early cyclic valgus loading of the ulnar collateral ligament (UCL) of the elbow repaired by either the Jobe technique or the docking technique. Better understanding of the biomechanical properties of each reconstruction may help surgeons choose the optimal surgical technique, particularly in planning earlier rehabilitation programs. Sixteen fresh frozen cadaver limbs (eight pairs) were randomized to either the Jobe cohort or the docking cohort. First intact UCLs were tested, followed by the repaired constructions. A Bionix MTS apparatus applied a constant valgus load to the elbows at 70^{o} flexion, and valgus displacement was measured and then used to calculate valgus angle displacement. The docking group had significantly less valgus angle displacement than the Jobe group at cycles 100 and 1,000 ($p = 0.0189$ and 0.0076, respectively). Four of the eight specimens in the Jobe group failed at the tendon-suture interface before reaching 1,000 cycles, at cycles 7, 24, 250, and 362. None of the docking specimens failed before reaching 1,000 cycles. In this cadaveric study, the docking technique resulted in less angulation of the elbow in response to cyclic valgus loading as compared to the Jobe technique. The better response to valgus loading of the docking reconstruction may translate into a better response to early rehabilitation. Further study is needed to determine if this difference translates into improved clinical outcomes.

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Introduction

The ulnar collateral ligament (UCL) of the elbow is commonly injured in overhead throwing sports (i.e., baseball or javelin, but also racket sports and ice hockey) or post-traumatically after a fall on an outstretched arm. A combination of valgus and external rotation forces are involved in the UCL injuries caused by trauma. In throwing athletes, attenuation and laxity of the UCL is due primarily to repetitive valgus stress to the elbow. Laxity in the UCL results in instability, pain, and impaired performance. Operative repair of the UCL is generally reserved for competitive throwing athletes and for those involved in heavy manual labor. (1, 2, 3, 4, 5)

Anatomy

The elbow joint is stabilized by its congruous bony articulations, its lateral and medial (ulnar) collateral ligaments, its capsule, and its secondary soft tissue stabilizers. The elbow comprises articulations between the humerus, ulna, and radius. The radial head contributes to stability of the ulnohumeral joint to valgus loads. (1) The lateral collateral ligament resists varus force and stabilizes the humerus to the annular ligament and proximal ulna. (1) The flexor and pronator muscles originate at the medial epicondyle and contribute additional support, mostly notably from the flexor carpi ulnaris and the flexor digitorum superficialis. (1).

The UCL resists valgus force and supports the ulnohumeral joint. (1) The UCL originates on the central 65% of the anteroinferior surface of the medial epicondyle, just posterior to the axis of the elbow. It inserts on average 18.4 mm dorsal to the coronoid tip. (6) The UCL is comprised of three bundles: the anterior, the posterior, and the transverse bundles. The anterior bundle is the strongest and stiffest ligament of the elbow, with an average load to failure of 260 N. (1, 7)

The anterior bundle consists of the anterior and posterior *bands*. The anterior band is taut from full extension to 60 degrees flexion; the posterior band is taut from 60 to 120 degrees flexion. (1)

Based on anatomic considerations and previous observations, an elbow in 70 degrees of flexion has been chosen for evaluating the effect of valgus loading on the UCL. Sojbjerg et al. found the maximum valgus angle after transection of the UCL occurred at 60 to 70 degrees of flexion. (8) Hechtman et al. found that at 70 degrees of elbow flexion, both the anterior and posterior bands of the anterior bundle are tight in the native and reconstructed UCL. (9) Importantly, the elbow extends rapidly from approximately 125 to 25 degrees during late cocking to ball release. (10) A 70 degree angle falls in the mid-range of this phase of throwing, when angular velocities are highest.

Injury to the Ulnar Collateral Ligament

During the acceleration phase of overhead throwing, intense valgus forces act on the elbow. During this phase, the forearm and hand lag behind the arm, generating the valgus stress. The static torque on the UCL has been estimated at 32 N-m during late cocking and acceleration phases of baseball pitching. (10)

Significantly, the average load-to-failure of the UCL is about 33 N-m. (11) Thus, every pitch approaches the maximum torque of the UCL. When the valgus force surpasses the threshold that the UCL can withstand, injury occurs, either as chronic microscopic tears or acute gross rupture.

Therapeutic Course

Rehabilitation following surgical reconstruction of the UCL can take more than six months and has been described as a four phase process. (12) The first phase begins with one week of post-operative immobilization in a posterior splint of the elbow in 90 degrees flexion. This immobilization is thought to be necessary for initial would healing. A range of motion brace is used from week two to week eight and gradually allows for increased range of flexion. During this time, wrist and hand range-of-motion exercises, grasping exercises, and isometric shoulder and arm exercises are performed. Phase two generally occurs concurrently during phase one, between weeks four and eight. This phase involves elbow range-of-motion exercises and isotonic resistance strengthening of the shoulder and arm.

Phase three, usually occurring between weeks nine and twelve, involves advanced strengthening through sport-specific exercises. Phase four begins around week fourteen and extends through week twenty-six or later. This phase reintroduces throwing in an interval throwing program.

It is believed that earlier rehabilitation following UCL reconstruction will lead to improved clinical outcomes for the overhead throwing athlete, just as earlier rehabilitation following anterior cruciate ligament surgery leads to better outcomes in the knee (13, 14). The first step in developing earlier rehabilitation protocols is to investigate how the various surgical reconstruction techniques perform with early cyclic valgus loading. Later clinical studies can then investigate whether better biomechanical performance of a surgical technique correlates with improved clinical outcomes.

It is believed that methods using ligament fixture through bone tunnels requires longer duration of post-operative immobilization than methods utilizing interference screw fixation (13). Thus, it will be important to extend this study to include an investigation of the biomechanical performance of surgical reconstructions involving interference screws.

Surgical Repair Techniques

Surgical reconstruction of the UCL in high performance athletes was originally described by Jobe in 1974. (4) The procedure, popularly known as the Tommy John procedure, has evolved over the last thirty-two years. Today, thousands of ulnar collateral ligament reconstructions are performed each year. (15) Jobe's technique used a tendon graft pulled through bone tunnels in the sublime tubercle of the proximal ulna and medial epicondyle of the distal humerus.

Additional techniques have modified Jobe's original technique in an effort to minimize dissection, improve tendon graft fixation, and decrease ulnar nerve complications. (9, 16, 17, 18) Efforts to minimize dissection and decrease ulnar nerve complications motivated the use of a muscle splitting approach rather than detaching the flexor-pronator origin. (3, 12, 19) Maintaining the flexor-pronator origin intact turns out to preserve an important dynamic stabilizer of the elbow in response to valgus torque; the flexor carpi ulnaris and flexor digitorum superficialis are notable for this contribution. (20) Consequently, it can be reasonably postulated that preservation of the flexor-pronator origin will facilitate rehabilitation after elbow UCL reconstruction.

Altchek et al. reported the docking procedure in 2002, a significant modification of Jobe's technique. (21) This technique used Jobe's muscle splitting approach, but with more widely spaced ulnar tunnels. Locking sutures were placed on each end of the tendon graft, and the free ends were docked into the medial epicondyle of the humerus. The sutures were tied over a proximal medial epicondyle bone bridge. This aspect allowed for easier and greater initial tensioning of the graft, and this was proffered as an operative improvement over the Jobe technique.

Ahmad et al. described a significant alteration of this technique using proximal and distal interference screw fixation. (16) Interference screws for soft tissue fixation had been used with great success in fixation of anterior cruciate ligament grafts, and new instrumentation made this a reasonable alternative for elbow ligament reconstruction. (13) The method used two 5.0 x 15.0 mm cannulated metal screws that locked to a soft tissue graft with four strands of strong nonabsorbable suture. This suture reinforced fixation was thought to be essential for the strength of the reconstruction. Ahmad et al. found that the ultimate moment of the interference screw technique compared favorably to studies of the classic Jobe technique and suture anchor fixation technique (30.5 N-m versus 15.4 N-m and 13.6 N-m, respectively). (4, 9, 16)

A newer technique, the DANE procedure, is a hybrid of the docking method and the interference screw method. A medial epicondyle docking technique is combined with a distal ulna interference screw. The distal fixation of the graft into a single tunnel may more closely recreate the isometry of the native ligament. (16, 20)

These recent advances in UCL reconstruction have come in a relatively short time frame. Careful analysis and comparison of each technique is necessary before settling on the preferred method of treatment. Selection of the optimal procedure will be of primary importance in returning competitive athletes to their prior level of performance.

Prior Investigations

Previously in this lab, McAdams et al. performed a biomechanical evaluation with cyclic loading to compare the docking technique with bioabsorbable interference screw fixation. (13) The interference screw fixation technique was found to be significantly stiffer than the docking technique in resistance to valgus torque at 10 and 100 cycles. These results suggest that, between these two techniques, the interference screw fixation technique may lead to less laxity at early phases of rehabilitation as compared to the docking technique.

Using the same apparatus employed in this study, all intact specimens this prior study reached 1,000 cycles of loading. One interference screw treated elbow failed at cycle 873 by tendon rupture distal to the humerus interference screw site. No gross slippage at the interference screw site was evident. Two docking technique treated elbows failed prior to 100 cycles with failure at the suture-bone interface. In one, the suture pulled through the humerus bone bridge at cycle 79, and in the other, the suture failed at the knot tied over the humerus bone bridge at cycle 20.

For all cycles there were no differences between the intact specimens that were randomly assigned to the docking and the interference screw groups. At cycle 1, the valgus angle was not different between the treated and intact cases. By cycle 10, the valgus angle for the docking technique was greater than both the intact (11.0^{o} vs. 4.4^{o}; $p = 0.0005$) and the interference screw technique (11.0^{o} vs. 7.4^{o}; $p = 0.0419$). Likewise at cycle 100, the valgus angle for the docking technique was greater than both the intact (17.5^{o} vs. 4.9^{o}; $p = 0.0005$) and the interference screw technique (17.5^{o} vs. 9.8^{o}; $p = 0.0229$). By the 1,000th cycle, both the docking and the interference screw techniques were larger than their respective intact specimens (19.3^{o} vs. 5.7^{o}; $p = 0.0010$) and (16.8^{o} vs. 5.6^{o}; $p = 0.0051$), and no difference was measured between the two techniques.

Based on that study, it appeared that the bioabsorbable interference screw technique may resist “slippage” better than the docking technique, as evidenced by a decreased valgus angle in response to valgus torque at cycles 10 and 100. This advantage seems to equilibrate at cycle 1,000. Significant healing occurs over the first 12 weeks after implantation of a tendon into the metaphyseal tunnel of bone, after which time the fixation sites are no longer the weakest points in the construct. (22) Further study is needed to compare these techniques with the Jobe technique and the DANE technique. This study addresses the comparison between the docking technique and the Jobe technique.

Statement of Purpose

This study compares the biomechanical properties of two surgical techniques to repair the ulnar collateral ligament (UCL) of the elbow: the Jobe procedure and the docking procedure. Better understanding of the biomechanical properties of each reconstruction may help the surgeon choose the optimal surgical technique in terms of early rehabilitation. This study will help us understand which reconstruction performs better (i.e., results in less valgus angle displacement) in early cyclic valgus loading of the elbow. This information is relevant to predicting the effect of earlier rehabilitation after UCL reconstruction.

Our hypothesis is that the docking technique will results in less valgus displacement than the Jobe technique in elbow reconstruction. This technique has two obvious advantages: (a) the strength of the Krackow stitches and (b) it avoids a contemplated weakness in the strength of Jobe’s three-ligand fixation, which results from suturing each limb together, i.e., the suture-tendon interface.

The null hypothesis for the biomechanical study is that both methods result in a statistically insignificant difference in valgus angle displacement at each cycle.

Future work will include a similar evaluative technique of two additional surgical procedures: the DANE technique and the all-interference screw technique. A thorough comparison of all four techniques will allow for a full analysis of early cyclic valgus loading on UCL reconstruction surgery. With further clinical correlation, this information may lead to optimizing UCL reconstruction surgery for early rehabilitation of the elbow.

Methods

Preparation of Specimens

Eight matched pairs of fresh-frozen cadaveric elbows were dissected to the capsule and the medial and lateral ligament complexes. Either the palmaris longus tendon (fifteen limbs) or the flexor carpi radialis tendon (one limb) was harvested from each tissue sample. The bone was sectioned 14 cm proximal and distal to the elbow joint and potted in neutral forearm rotation. The humerus and ulna/radius was potted in PMA cement inside 1.5 inch PVC piping. The elbows and grafts were kept moist throughout the preparation and testing by using sterile gauze soaked in normal saline.

Biomechanical Testing of Intact UCLs

The MTS apparatus is comprised of an MTS machine from Bionix and a digital video camera for motion analysis and capture of failure mechanisms. The elbows were placed into the apparatus at 70 degrees flexion. The radius/ulna was fixed on the MTS machine and the humerus was maintained in a position parallel to the floor. (**Figures 1a and 1b**.) The MTS actuator applied a constant force and the displacement will be measured. A 0.5 N-m pre-load was applied, followed by a 5 N-m valgus moment (50 N force applied 10 cm from the elbow joint). This moment was applied in a cyclical fashion at a rate of 1 cycle/second for 1,000 cycles.

The actuator displacement was recorded throughout the testing. An actuator limit of 70 mm was used to prevent instability of the MTS. Any specimen reaching this limit prior to 1,000 cycles was stopped automatically and the cycle was recorded.

Cycles 1, 10, 100, and 1,000 were analyzed to determine the maximal actuator displacement, which was converted to the valgus angle. Specimens stopped before reaching 1,000 cycles were recorded to have a valgus angle of 35 degrees for all remaining cycles.

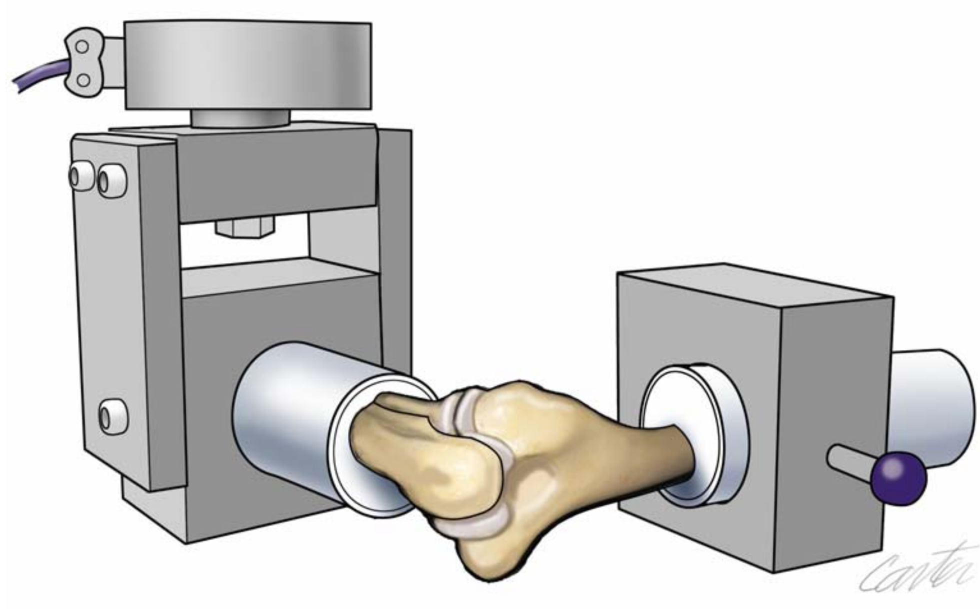

Figure 1a. A schematic of the MTS apparatus used for data collection. (Note that this figure shows the elbow in the opposite orientation to that used in this experiment, i.e., the medial side should face upwards such that the MTS applies a downward force to create the valgus load.)

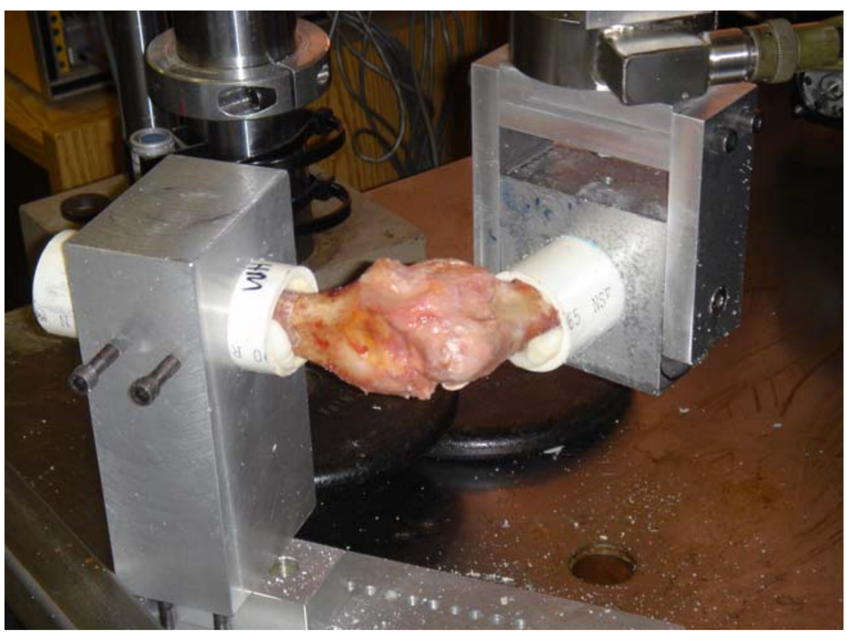

Figure 1b. The MTS apparatus used for data collection.

<u>Surgical Reconstructions</u>

After testing the native ligament, the UCL was excised and the elbows from each matched pair were randomly divided into two groups. The first group underwent the Jobe procedure and the second underwent the docking procedure. The procedures was performed on each elbow by a single surgeon who specializes in upper extremity sports medicine (Timothy R. McAdams, M.D.). The posterior capsule and lateral ligament complex were preserved throughout the investigation.

For the Jobe reconstruction, tunnels were made anterior and posterior to the sublime tubercle by using a 3 mm burr that created a 2 cm bone bridge between the tunnels. The tunnels were connected using a small, curved curette, and care was taken not to violate the bone bridge. A longitudinal humeral tunnel was created up the axis of the medial epicondyle to a depth of 15 mm using a 4 mm burr. Two adjacent tunnels were made on the upper border of the epicondyle just anterior to the remnants of the intramuscular septum. A small, curved curette was used to connect this y-shaped tunnel. A No. 2 Fiberwire was used to pass a looped suture through each tunnel in order to retrieve the graft.

A palmaris longus graft was pulled through the tunnels in a figure-of-eight fashion. The elbow was reduced with maximum forearm supination and gentle varus stress while tension was held on each free limb of the graft. The two free limbs were sutured to the bridging section of graft to form a three-ligand band. (**Figure 2**.)

Figure 2. The Jobe technique of surgical reconstruction of the UCL. The tendon graft is pulled through bone tunnels in the ulna and the humerus. The three ligands are sutured together at the joint.

The docking technique followed a previously reported technique (18) and is described here as modified by laboratory conventions. Tunnels were made anterior and posterior to the sublime tubercle by using a 3 mm burr to create a 2 cm bone bridge between the tunnels. The tunnels were connected using a small, curved curette, and care was taken not to violate the bone bridge. A No. 2 Fiberwire was used to pass a looped suture.

The humeral tunnel was made in the anterior half of the medial epicondyle in the anterior position of the existing MCL. A longitudinal tunnel was created up the axis of the medial epicondyle to a depth of 15 mm by using a 4 mm burr. Exit punctures were placed on the upper border of the epicondyle just anterior to the remnants of the intramuscular septum. A small drill bit was used to make 2 small exit punctures separated by 5 mm to 1 cm. A suture passer was used from each of the two exit punctures to pass a looped suture which was then used for passage of the graft sutures.

The limb of the graft that had sutures already in place was passed into the humeral tunnel, and the sutures were pulled through one of the small superior humeral punctures. With one limb of the graft securely docked in the humerus, the elbow was reduced with maximum forearm supination and gentle varus stress. While tension was maintained on the graft, the specimen was moved so that the elbow ranged from flexion to extension to eliminate potential creep within the graft. The final length of the graft was estimated by placing the free limb of the graft adjacent to the humeral tunnel and visually estimating the length of the graft that would allow the graft to be tensioned within the humeral tunnel. The excess graft was excised immediately. A No. 1 braided nonabsorbable suture was placed in a Krackow fashion on this limb. This end of the graft was docked securely in the humeral tunnel with the sutures exiting the small puncture holes.

Final graft tensioning was performed by again placing the elbow through a full range of motion with varus stress placed on the elbow. Once the surgeon was satisfied with the graft tension, the two sets of graft sutures were tied over the bone bridge on the humeral epicondyle. (**Figures 3a and 3b**.)

Reconstructed elbow specimens were then tested in the MTS apparatus previously described. Load-displacement characteristics were measured at 1, 10, 100, and 1,000 cycles using the same protocol as for the intact elbows. In addition, India Ink markers at the aperture-tendon junction, and real-time video analysis was performed.

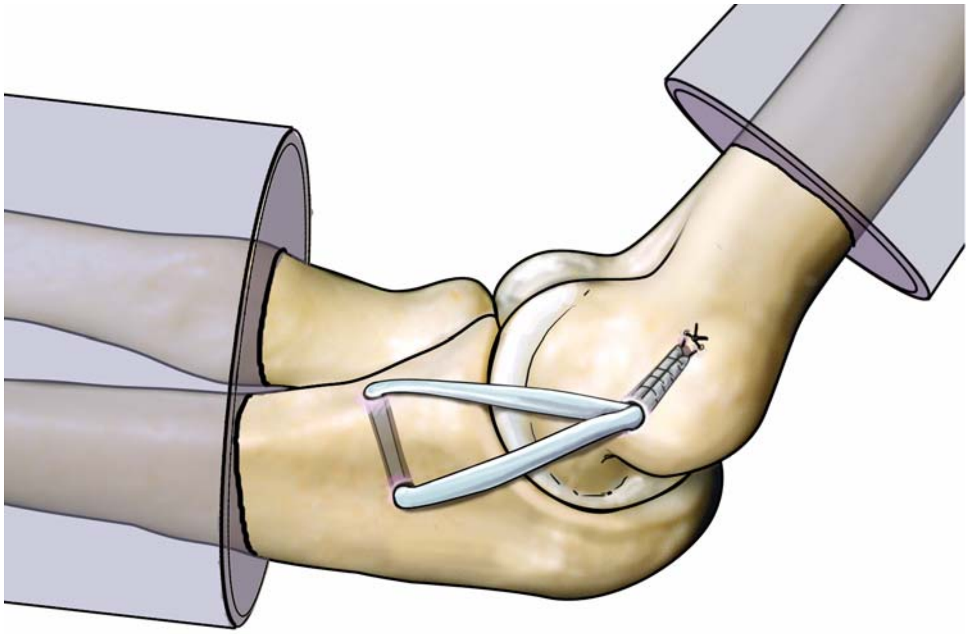

Figure 3a. A schematic of the docking technique of surgical reconstruction of the UCL. The tendon graft is pulled through ulnar bone tunnels and is docked in a humeral bone tunnel with small exit punctures for the graft sutures.

Figure 3b. The docking technique of surgical reconstruction of the UCL.

Calculating Valgus Angle Displacement

The raw data collected from experiments gave the magnitude of displacement in millimeters. To find the maximal displacement per cycle of concern, the entire data set of the cycle was examined, i.e., the ramp up and the ramp down, which gave around fifty data points. The point with maximal load was isolated, and the displacement at that point was used.

The moment arm of the valgus load was constantly applied at 100 mm from the joint line. Thus, the displacement angle in radians was calculated by finding the arctangent of the ratio of the displacement over the moment arm. This value was converted from radians to degrees.

Statistical Analysis

For each cycle 1, 10, 100, and 1,000, the valgus angles for the intact and reconstructed specimens were compared using an analysis of variance with a significance criterion of 0.05. Differences between groups were analyzed using a Fisher's Protected Least Square Difference (PLSD) test. The statistics were computed using the Statview computer software package.

Statement of Duties

Dissection and preparation of the tissue samples were performed by the author, Gannon W. Sungar, and Timothy R. McAdams, M.D. Surgical repair was performed by Timothy R. McAdams, M.D. Biomechanical analysis was performed by the author and Derek Lindsey, M.S. Statistical analysis was performed by the author and Derek Lindsey, M.S.

Results

Eight pairs of fresh frozen cadaver arms, with an average age of 74.5 years, were tested (**Table 1**).

Table 1. Specimen demographics.

Specimen	Age (y)	Sex
1	57	M
2	80	M
3	88	F
4	50	F
5	81	F
6	66	M
7	93	M
8	81	M
Avg. Age 74.5		

Tables 2a and 2b show the valgus angle displacement data for each limb and **Table 3** shows the means. **Figure 4** shows the average valgus angles at cycles 1, 10, 100, and 1,000 for the intact UCLs and the reconstructed UCLs.

Table 2a. Data of valgus angle displacement for each specimen in the Jobe cohort.

Specimen		Valgus Angle (degrees) 1	10	100	1000	
1L	Intact	2.09	2.47	3.26	3.93	
1L	Jobe	1.89	6.76	10.76	15.77	
1R	Intact	1.47	1.86	2.17	2.60	
1R	Jobe	1.79	5.90	8.64	11.31	
2R	Intact	1.44	1.69	2.10	2.72	
2R	Jobe	2.12	3.81	6.32	35*	*Failed at cycle 250.
3L	Intact	3.24	4.31	4.82	5.51	
3L	Jobe	4.93	12.96	16.70	35*	*Failed at cycle 362.
5R	Intact	3.24	3.92	4.79	7.24	
5R	Jobe	3.74	35.00	35*	35*	*Failed at cycle 7.
6L	Intact	1.73	2.90	3.70	4.65	
6L	Jobe	3.12	14.54	25.08	29.02	
7L	Intact	2.11	2.83	3.40	3.91	
7L	Jobe	4.02	7.70	15.01	27.03	
8L	Intact	2.84	3.17	3.77	4.72	
8L	Jobe	2.88	8.45	35*	35*	*Failed at cycle 24.

Table 2b. Data of valgus angle displacement for each specimen in the docking cohort.

Specimen		Valgus Angle (degrees) 1	10	100	1000
2L	Intact	2.10	2.58	2.96	3.49
2L	Docking	3.00	6.48	8.88	11.43
3R	Intact	2.59	6.77	7.69	8.00
3R	Docking	3.62	11.00	15.14	18.66
4R	Intact	2.15	2.88	3.90	5.40
4R	Docking	3.71	6.59	9.67	15.58
4L	Intact	3.50	5.92	7.64	9.63
4L	Docking	2.30	6.98	10.45	15.74
5L	Intact	3.74	8.49	9.96	12.03
5L	Docking	3.36	13.42	21.62	27.54
6R	Intact	2.39	2.98	3.58	4.33
6R	Docking	4.15	4.77	5.99	7.89
7R	Intact	1.96	2.67	3.21	4.30
7R	Docking	3.59	6.88	8.46	11.04
8R	Intact	1.59	1.80	2.33	2.88
8R	Docking	4.13	7.00	8.60	10.53

Table 3. Mean valgus angle displacement (degrees) by cycle. (For each cohort, n = 8.)

	1	Std. Dev.	10	Std. Dev.	100	Std. Dev.	1000	Std. Dev.
Intact	2.50	0.75	4.26	2.45	5.16	2.84	6.26	3.28
Docking	3.48	0.61	7.89	2.84	11.10	4.98	14.80	6.21
Intact	2.27	0.75	2.89	0.91	3.50	1.02	4.41	1.51
Jobe	3.06	1.12	11.89	9.99	19.06	11.38	27.89	9.46

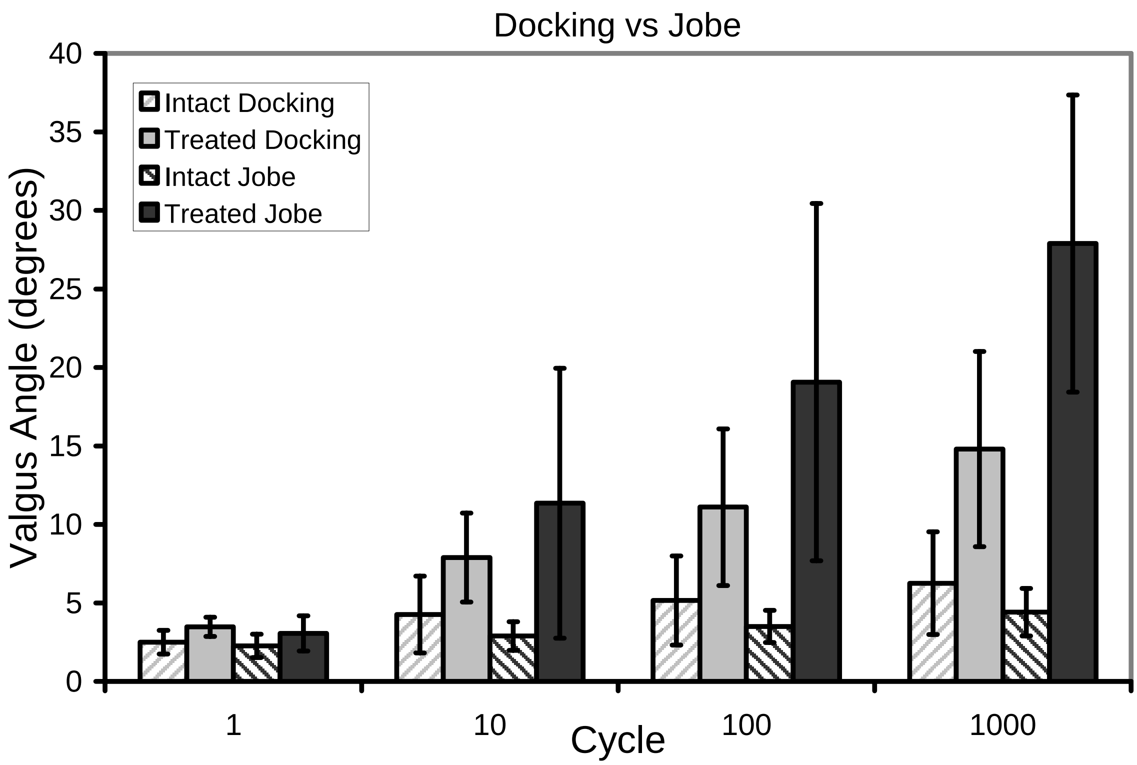

Figure 4. Results showing the valgus angles of intact and reconstructed elbows.

All intact specimens reached 1,000 cycles of loading. All docking specimens reached 1,000 cycles of loading. Four of eight Jobe specimens failed before reaching 1,000 cycles of loading. Failures occurred at cycles 7, 24, 250, and 362. Each failure occurred by tendon rupture at the suture site.

For cycles 1, 10, 100, and 1,000, there was no difference between the intact specimens that were randomly assigned to the docking group or the Jobe group.

The valgus angles of the Jobe reconstructed specimens were significantly larger than the intact specimens prior to Jobe reconstruction at cycles 10 (11.89^o vs. 2.89^o, $p = 0.0023$), 100 (19.06^o vs. 3.50^o, $p < 0.0001$), and 1,000 (27.89^o vs. 4.41^o, $p < 0.0001$). The valgus angle of the Jobe reconstructed specimens was not significantly larger than the intact specimens prior to Jobe reconstruction at cycle 1 (3.06^o vs. 2.27^o, $p = 0.0664$).

The valgus angles of the docking reconstructed specimens were significantly larger than the intact specimens prior to docking reconstruction at cycles 1 (3.48^o vs. 2.50^o, $p = 0.0252$) and 1,000 (14.80^o vs. 6.26^o, $p = 0.0076$). The valgus angles of the docking reconstructed specimens were not significantly larger than the intact specimens prior to docking reconstruction at cycles 10 (7.89^o vs. 4.26^o, $p = 0.1862$) and 100 (11.10^o vs. 5.16^o, $p = 0.0735$).

At cycles 1 and 10, there was no difference between the valgus angles of the reconstructed Jobe and the reconstructed docking specimens. By cycle 100, the valgus angle was significantly greater for the Jobe group as compared to the docking group (19.06^o vs 11.10^o, $p = 0.0189$). The valgus angle remained significantly greater for the Jobe group as compared to the docking group by cycle 1,000 (27.89^o vs. 14.80^o , $p = 0.0076$).

Discussion

Two types of loading are commonly used to assess fixation of soft tissue to bone: cyclic loading and load-to-failure. Many studies have evaluated the failure strength of both the intact and reconstructed UCL of the elbow. (7, 9, 16, 23) Only one previous study of elbow UCL fixation using cyclic loading has been found. (24) Load-to-failure testing measures the ability of a ligament or graft to resist a sudden traumatic load. On the other hand, cyclical loading more closely resembles the clinical situation, where gradual range of motion exercise is initiated as graft healing occurs, rather than forceful valgus loads immediately after reconstruction. Cyclic loading can assess “slippage” of the graft, and this is important in response to early motion therapy protocols. Clinical failures of elbow UCL reconstruction are more likely due to “slippage” with resultant laxity and functional impairment rather than traumatic graft rupture. (13)

Armstrong et al. compared the docking technique, interference screw technique, figure-of-eight bone tunnel (Jobe technique), and an endobutton ulnar fixation technique. (24) The investigators found that the peak load-to-failure in response to valgus stress was inferior for all four reconstruction methods as compared to the native ligament. Furthermore, the docking technique was stronger than the figure-of-eight technique (peak load-to-failure of 53.0 ± 9.5 N vs. 33.3 ± 7.1 N, $p < 0.004$). The mean number of cycles sustained before failure or 5 mm of joint gapping was 701 ± 181 cycles for the docking reconstructions and 333 ± 133 cycles for the figure-of-eight reconstructions ($p < 0.009$).

Our results found a similar relationship between the docking and the Jobe reconstructions. Four Jobe reconstructions failed before reaching 1,000 cycles in our study, while no docking reconstructions failed. Armstrong et al. used an increasing cyclic load protocol to find the peak load-to-failure for each reconstruction, beginning with 20 N applied 12 cm away (2.4 N-m valgus moment). (24) Failure occurred at a mean of 53.0 N (6.36 N-m valgus moment) for the docking reconstructions and 33.3 N (3.99 N-m valgus moment) for the Jobe procedure. We applied a constant maximal 5 N-m valgus moment throughout the cyclic testing, which is consistent with findings from Armstrong et al. Our design illuminates more than the study from Armstrong et al. because we can judge the performance of the Jobe reconstruction in early valgus loading in a way that more closely resembles step-wise rehabilitation than peak load-to-failure tests.

Paletta et al. compared the biomechanical properties of the Jobe reconstruction with those of a modified docking reconstruction (25). The modified docking reconstruction utilizes a 4-strand reconstruction by doubling the palmaris longus tendon graft. The group hypothesized that this modification would result in a reconstruction that would more closely resemble the biomechanical parameters of the native UCL. They used an MTS apparatus to test the specimens; however they applied a valgus moment at a constant rate of 1 mm/s to find the maximal moment to failure, stiffness, strain. Their study differed from ours in two other important ways: they tested the elbows in 30 degrees of flexion and used a 2-camera motion analysis system for data collection. They reported a maximal moment to failure of 18.8 ± 9.1 N-m for the native UCL, 14.3 ± 4.1 for the docking reconstruction, and 8.9 ± 3.8 for the Jobe reconstruction. The maximal moment to failure was significantly greater for intact UCLs as compared to the Jobe reconstruction ($p < 0.0001$). The maximal moment to failure was significantly greater for the docking reconstruction as compared to the Jobe reconstruction ($p = 0.0148$).

The results from Paletta et al. show higher peak moments to failure than the Armstrong et al. results and as compared to our results. The difference might be attributable to the differing experimental design, the modified docking reconstruction, and the younger elbows used in the Paletta et al. study (around 55 years as compared to 74.5 years in this study). The use of cyclic loading may weaken the reconstruction in a way that would explain why half of our Jobe reconstructions failed with a maximal moment of 5 N-m. The increased maximal moment to failure in the docking reconstructions, as compared to Armstrong et al., is likely due to the modified docking reconstruction. The 4-strand reconstruction can be reasonably expected to be stronger than the traditional 2-strand reconstruction.

Despite these differences, Paletta et al. confirms the relative superiority of the docking reconstruction to the Jobe reconstruction in terms of biomechanical parameters. Our study further elucidates the improved response of the docking reconstruction to early cyclic valgus loading.

Paletta et al. also reported modes of failure, which were consistent with the modes of failure seen in this study. In Paletta et al. twelve of fifteen Jobe reconstructions failed at the tendon-suture interface. Four of eight of our Jobe reconstructions failed at the tendon-suture interface. They also reported suture failure (1 of 15) and ulnar tunnel fracture (2 of 15) for the Jobe reconstructions. Paletta et al. reported suture failure in twelve of fourteen docking reconstructions, and bone tunnel fracture in two of fourteen docking reconstructions. Since we were not focused on loading our specimens to failure, we saw and expected fewer failures.

Conway et al. reported Jobe's initial 13-year experience with the reconstruction. (3) This technique reported excellent outcomes in 75% of major league players without previous surgery. An excellent outcome signifies that the patient returned to or exceeded their previous level of competition for at least 1 year. (18) Rohrbaugh et al. reported outcomes of the docking procedure on 36 patients with an average of 3.3 years of follow-up, finding that 92% (33 patients) had excellent results. (18) Similarly, Conway reported excellent outcomes in 97% of 40 throwers after undergoing the docking reconstruction. (15) Our results show less valgus angle displacement when the docking reconstruction is used as compared to the Jobe reconstruction; this finding provides biomechanical evidence to support these previously reported clinical findings.

Further clinical study is required to demonstrate clinically that the docking reconstruction is more tolerant to early valgus loading than the Jobe reconstruction. Even more, additional clinical study is required to confirm that earlier rehabilitation leads to improved long-term outcomes in these patients.

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