Biomechanics of Reconstruction Constructs

15

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Introduction

Ulnar collateral ligament (UCL) injuries in overhead athletes are common because the motion of throwing subjects the elbow to high valgus stresses during every pitch. It has been estimated that the UCL receives forces of up to 3,100°/s and valgus stresses of up to 64 N m [1, 2]. Until the 1970s, this injury was career ending because nonoperative management yielded poor results and no surgical treatments were available. In 1974, Frank Jobe performed the first UCL reconstruction on major league pitcher Tommy John, and the procedure bears the pitcher's name. The first published series in UCL reconstruction was subsequently published by Jobe in 1986 [3]. This original Jobe technique of reflecting the flexor pronator muscles prior to autograft ligament reconstruction yielded excellent results with 63 % return to play [3]. Newly available technologies and surgical approaches have contributed to the improvements in this technique with a focus on minimizing muscle disruption. In this chapter, we review the original technique and newer techniques that have evolved. We also review the biomechanical data available on various procedures.

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Jobe Technique

The goal of the classic Jobe technique was to restore elbow stability using a reconstruction to restore the anterior band of the UCL [3]. The procedure involved a takedown of the flexor-pronator mass and submuscular ulnar nerve transposition. The entire flexor-pronator musculature was reflected off the medial condyle and proximal ulna to provide an uncompromised view of the surgical reconstruction site. The primary goal was to reconstruct the anterior band of the UCL. A palmaris longus graft was then woven through 3.2-mm bone tunnels at the sublime tubercle of the ulna and medial epicondyle of the distal humerus in a figure of eight fashion (Fig. 15.1). This procedure was later modified by Smith et al. by using a muscle-splitting approach, thus avoiding the morbidity associated with the takedown of the flexor-pronator mass [4]. This became known as the modified Jobe technique and is one of the popular techniques available today.

In 2002, Mullen et al. [5] evaluated the Jobe procedure in the laboratory by comparing it to the intact state using 14 cadaveric elbows. The specimens were locked in neutral rotation by using a 4-0 mm screw. A metal rod passed through the humerus and locked with two interlocking nails. The specimen was then placed on a load frame,

J. S. Dines, D. W. Altchek (eds.), *Elbow Ulnar Collateral Ligament Injury,*
DOI 10.1007/978-1-4899-7540-9_15, © Springer Science+Business Media New York 2015

Fig. 15.1 Jobe technique. Bone tunnels are placed at the sublime tubercle and medial humeral epicondyle. A palmaris longus graft is woven in a figure of eight fashion and tied with sutures

and a 50-N force was used to elevate the forearm, creating at 5-N-m moment on the medial side of the elbow. Displacement was measured at 30° intervals from 30° to 120° of elbow flexion. The UCL was then transected and the specimen was tested. Finally, the elbows were reconstructed using the traditional Jobe technique and tested in the same fashion. The investigators found that sectioning the anterior bundle of the UCL increased displacement from 140% to 150% during the range of motion. When the UCL was reconstructed with the Jobe technique, displacement ranged from 98% to 112% during range of motion compared to the intact state. These differences were statistically significant. This basic biomechanical study gives mechanical credibility to the Jobe reconstruction method.

Ciccotti et al. also looked at the biomechanics of the Jobe technique compared to the native UCL and the docking technique [6]. In this study of 10 cadaveric specimens, the authors potted the elbows and mounted them on a custom elbow loading system. The investigators then subjected the elbows to a valgus load of 5 N m for 6–8 s and then offloaded them. They performed each loading test five times at 30° intervals from 30° to 110° of elbow flexion. Once this was done, the elbows were placed at 90° of flexion to simulate the throwing position and then loaded to failure. Results from this study showed that the maximal elongation of the anterior band of the native UCL did not change with elbow flexion; however, the valgus laxity decreased with increasing flexion angles. The same result was observed in elbows reconstructed with the Jobe technique and the docking technique, and no differences were observed compared to the intact state. In terms of load to failure, the native UCL was stronger than both reconstructions by almost 80%. Modes of failure of the native UCL were 50% ulnar avulsion, 5% humeral avulsion, and 45% midsubstance tear, whereas the Jobe technique showed 70% ulnar tunnel fracture, 20% midsubstance tear, 10% suture pullout, and for the docking technique, there were 40% ulnar tunnel, 40% suture pullout, 10% midsubstance tear, and 10% humeral tunnel fracture.

Docking Technique

Rohrbaugh et al. described the docking technique in 1996 [7]. In this technique, the authors placed ulnar tunnels similarly to what is used in the traditional Jobe technique, but they replaced the humeral tunnels with a single bony tunnel with two converging exit suture holes. The graft is secured using sutures over a bone bridge. This technique was designed to improve graft tensioning while minimizing the number or bone tunnels in the humerus [7, 8]. Care must be taken to measure and cut the graft to fit snuggly into the humeral socket to prevent graft slippage and loosening. A case series by Bowers et al. looking at 21 throwers, five of which were professional and 11 were college players, showed 19 of 21 (90%) excellent results and 2/21 good results with no complications [8].

In an elegant biomechanical study, Armstrong et al. [9] compared the docking technique to figure-of-eight, endobutton, and interference screw techniques. The investigators tested 20 cadaveric elbows by potting them and placing them on a custom jig (Fig. 15.2). A cyclic load of 20 N was applied for 200 cycles. The load was then increased by 10 N increments until ligament failure occurred or a gap formation greater than 5 mm was seen. A palmaris tendon graft was used

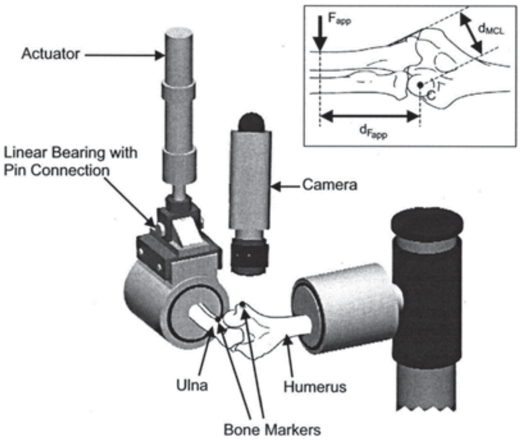

Fig. 15.2 Test setup. (Reprinted from [9], with permission from Elsevier)

for the reconstruction in all four of the different reconstruction states. The investigators found that the intact elbow failed at 142.5 ± 39.4 N, whereas all other reconstruction techniques failed at much lower loads. The docking technique failed at 53.0 ± 9.5 N and the endobutton group failed at 52.5 ± 10.4 N. Interference screw and figure-eight reconstructions were the weakest, failing at 41.0 ± 16.0 N and 33.3 ± 7.1 N, respectively. Moreover, the docking and endobutton techniques failed at a much higher number of cycles than the interference screw and figures of eight groups. No intrasubstance failures were reported. The primary mode of failure was tendon pullout from the tendon–suture interface in the docking, figure of eight, and endobutton techniques. In the interference screw cohort, failure occurred via dissociation of the tendon from the tendon–screw interface.

Hurbanek et al. proposed the addition of an interference screw to the docking technique [10]. They used nine matched cadaveric elbows and compared the traditional docking technique to docking with the addition of a 4.75-mm bioabsorbable screw. The investigators found a statistically significant difference in valgus instability of the elbow between the intact and docking alone groups. There was no difference in laxity of the UCL between the intact and the docking + interference screw groups. The most common mode of failure in both groups was suture pulling out of the tendon. The stiffness of the interference screw construct was higher than in the traditional docking group (14.7 N/mm vs. 9.9 N/mm; $p = 0.044$). The authors concluded that the addition of a bioabsorbable interference screw might enhance fixation strength.

Suture Anchor Technique

In the early 1990s, the advent of new suture anchor technology led to their use in reconstruction of the UCL [11]. Suture anchors were thought to obviate the need for bone tunnels and therefore to prevent complications such as bone bridge fracture and screw pullout. In all UCL reconstructions, preventing sublime tubercle and/or medial condyle fracture and protecting the ulnar nerve are paramount for a good outcome. These issues stimulated new, safer techniques that continue to provide strong constructs. In 1998, Hechtman et al. [12] described a technique using suture anchors as the primary form of fixation of the UCL graft. In this procedure, the investigators identified the origin of the anterior bundle at the antero-inferior border of the medial epicondyle and created an anteroposterior trough just distal to it large enough to accommodate a palmaris longus graft. Two anchors were placed on the medial and lateral borders of the anterior bundle origin. Next, the insertion of the anterior bundle was identified on the sublime tubercle, where a vertical trough was made. Two anchors were placed at the anterior and posterior borders of the anterior bundle insertion. The center of the graft was fixed to the epicondyle with a 2-0 suture. The free limbs were passed under the ulnar anchor sutures and tied back to the epicondyle with the arm at 45° of flexion (Fig 15.3).

Hechtman et al. [12] compared this new reconstruction technique with the classic Jobe technique using 31 cadaveric elbows. The humerus was potted and mounted on a custom jig. A microstrain differential variable reluctance transducer (DVRT) was attached to the anterior band of the UCL and a second DVRT was attached to the posterior band of the UCL with

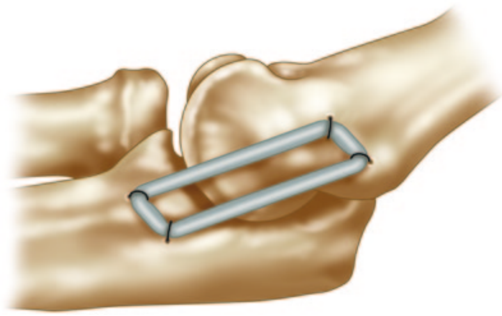

Fig. 15.3 Suture anchor technique. Suture anchors are placed at the sublime tubercle and medial epicondyle. A palmaris longus graft is secured to the anchors and tied to itself with sutures

the elbow flexed at 45°. Length measurements were collected throughout the range of motion arc. Specimens were then taken through the same range of motion and strain measurements were similarly calculated. The investigators found that towards extension, strain increased in the anterior band of the normal and anchor groups, but were decreased in the tunnel group. Moreover, the posterior band was lax in the normal and anchor groups, but tight in the tunnel group. No significant difference in maximal valgus load to failure versus intact was found between the two groups, with 76.3 % in the tunnel group and 63.5 % in the anchor group. Primary mode of failure in the intact group was a tear in the anterior bundle, and no tears were seen in the posterior bundle. Of the tears in the intact group, 68 % occurred at the ligament–bone interface and 32 % were intrasubstance. In the Jobe technique group, 65 % of failures occurred by suture slippage, 14 % by humeral fracture, 14 % by ulnar fracture, and 7 % by intraligamentous failure. In the anchor group, 53 % of samples failed from suture slippage, 18 % by suture failure, 6 % by intraligament failure, 12 % by ulnar bone fracture, and 12 % by anchor pullout. The authors concluded that although there was no difference in resistance to valgus stress, suture anchor fixation was more anatomic than bone anchors. However, it is important to note that in this study, fixation strength in the suture anchor group was significantly lower than in the intact ligament, plus this technique creates an onlay reconstruction versus the intraosseous bone tunnel/docking techniques which may create an issue with bony healing. These may be some reasons why this procedure showed a dismal 30 % clinical failure rate in clinical studies [11, 13].

Interference Screw Technique

To avoid ulnar tunnel complications, avoid muscle dissection, and decrease the risk of nerve injury, Ahmad et al. described an interference screw technique in which both the ulnar and humeral sides of the graft are fixed with interference screws [14]. This technique was described in a cadaveric study in which the investigators created 5-mm bone tunnels at the isometric anatomic insertion sites on the sublime tubercle and medial epicondyle. The ulnar tunnel was drilled at a 45° angle to the long axis of the ulna to a depth of 20 mm, and the humeral tunnel was placed 5 mm distal to the anterior tip of the epicondyle directed to exit at the superior aspect of the epicondyle. An ipsilateral palmaris longus tendon graft was used. Fixation was achieved with five 15-mm interference screws. The elbows were mounted on a custom frame and loaded with a valgus load of 3 N m at 15° intervals from 0 to 120° of elbow flexion.

When compared to the intact state, the reconstructed state had lower stiffness (42.81 ± 11.6 N/mm vs. 20.28 ± 12.5 N/mm) ($p < 0.05$), but there was no difference in ultimate moment (34.29 ± 6.9 N/m vs. 30.55 ± 19.24 N/m). No differences were seen in valgus stability of the elbow. The authors concluded that this technique returned elbow kinematics to near normal and achieved failure strength comparable to that of the native elbow. The investigators did not compare their technique to other established reconstruction techniques.

McAdams et al. [15] used a bioabsorbable interference screw technique and compared it to the docking technique. In this study, 16 elbows were mounted on a custom jig and a cyclic valgus load was applied to the intact state and to the reconstructed specimens. The investigators looked at the valgus angle that was created after

1, 10, 100, and 1,000 cycles. They found that the valgus angle was significantly greater in the docking technique group than in the intact and interference screw groups at 1, 10, and 100 cycles. No difference between the groups was seen after 1,000 cycles. The authors concluded that a bioabsorbable interference screw technique can better restore the native elbow biomechanics at early cyclic loading.

Subsequent studies comparing interference screw fixation techniques with other techniques suggest that interference screw fixation may have lower load to failure than other techniques [9, 16]. Interference screw fixation was compared with the traditional Jobe technique in a study by Large et al. [16]. Using 10 matched cadaveric elbows, the investigators looked at differences between the two reconstruction techniques under valgus load at four different flexion angles. The investigators showed that elbows reconstructed via the Jobe technique reproduced the overall stiffness of the intact UCL at all angles tested. Interference screw stiffness was lower than the intact state at almost all tested degrees of flexion. In terms of load to failure, the elbows reconstructed with the Jobe technique failed at 22.7 N m absorbing 1.59 N m of energy, whereas the interference screws failed at 13.4 N m absorbing only 0.97 N m of energy (=0.0045). The bone tunnels in the Jobe technique failed 40% of the time, whereas 70% of the interference screw constructs failed by graft slippage. The authors concluded that the traditional Jobe technique appears to be superior to interference screw fixation. The study by Armstrong et al. previously discussed also suggested that interference screw fixation is inferior to the docking technique and endobutton technique [9].

Conclusions

Numerous procedures exist for reconstruction of the UCL in overhead athletes looking to return to a high level of sport. Biomechanical studies show that these reconstruction techniques fall short from restoring native stability to the elbow under valgus load. The classic Jobe and docking techniques appear to come closest to replicating the strength of the native UCL than other techniques. However, there is potential for bone tunnel fracture when using the Jobe technique and care must be taken to adequately place these tunnels to avoid this devastating complication. Bone tunnel fracture appears to be less common with the docking technique, but failure can occur at the suture. Conclusive biomechanical data are not yet available on the newer techniques. Results with interference screw fixation are equivocal results in the studies reviewed. The suture anchor technique has shown some positive results in the laboratory.

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