The History and Evolution of Elbow Medial Ulnar Collateral Ligament Reconstruction: from Tommy John to 2020

Andrew R. Jensen¹ · Matthew D. LaPrade¹ · Travis W. Turner¹ · Joshua S. Dines² · Christopher L. Camp³

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Abstract

Purpose of Review The purpose of this review article is to discuss the evolution of surgical reconstruction of the anterior bundle of the UCL, otherwise known as Tommy John surgery, from Dr. Jobe's initial description in 1986 to present day. In particular, the unique changes brought forth by each new surgical technique, and the reasons that these changes were implemented, are highlighted.

Recent Findings The incidence of UCL reconstruction surgery continues to increase significantly, particularly in the 15- to 19-year-old age group. New anatomic understanding of the anterior bundle of the UCL, including the importance of the central fibers and the broad and tapered ulnar insertion, may affect optimal UCL reconstruction techniques in the future. Although return to play rates are generally quite high (80–95%), the mean time to return to play (typically 12–18 months for pitchers) is longer than desired. Accordingly, many authors feel that there remains room for improvement in the treatment of this common injury.

Summary The Tommy John surgery has evolved in many ways with the development of novel techniques over the last 35 years. Currently, overhead throwing athletes undergoing UCL reconstruction have high return to play and low complication rates. Future modifications to the surgery may aim to further improve outcomes and, more importantly, expedite the length of postoperative rehabilitation.

Keywords Tommy John · Ulnar collateral ligament · UCL · Jobe · Docking · Baseball · Elbow

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✉ Christopher L. Camp
Camp.Christopher@mayo.edu

Andrew R. Jensen
Jensen.Andrew@mayo.edu

Matthew D. LaPrade
LaPrade.Mathew@mayo.edu

Travis W. Turner
Turner.Travis@mayo.edu

Joshua S. Dines
jdinesmd@gmail.com

Introduction

The ulnar collateral ligament (UCL) of the elbow is the most important soft tissue stabilizer to valgus stress during overhead throwing motion [1]. The UCL is composed of the anterior, posterior, and transverse bundles [1]. The anterior bundle, which is the most important stabilizer of the three, originates from the anteroinferior surface of the medial epicondyle, just posterior to the elbow center of rotation, and inserts at the sublime tubercle of the ulna [2, 3]. The anterior bundle of the UCL itself is composed of an anterior band, which is the primary valgus stabilizer from 30 to 90° of flexion, and the posterior band, which is the primary valgus stabilizer from 90 to 120° of flexion, in addition to central fibers between the two bands [1, 4].

Due to the high velocity and significant amount of valgus torque placed on the elbow during overhead throwing motions, the anterior bundle of the UCL is frequently injured in the dominant elbow of pitchers, javelin throwers, and other overhead athletes [5]. Often, these injuries are chronic and degenerative in nature, but acute tears and acute-on-chronic

¹ Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA

² Sports Medicine and Shoulder Service, Hospital for Special Surgery, New York, NY, USA

³ Department of Orthopedic Surgery and Sports Medicine, Mayo Clinic, 200 First Street, Rochester, MN, USA

injuries are seen as well [1]. Tears can occur in the mid-substance of the ligament or as avulsions from the proximal origin or distal insertion [1, 6•, 7•]. UCL tears, regardless of their nature, lead to medial-sided elbow pain, valgus instability, and decreased velocity and accuracy of overhead throws [1].

UCL tears were once thought to be career-ending injuries for overhead athletes but, since the advent of the UCL reconstruction procedure by Dr. Frank Jobe in 1974, many overhead throwers with UCL tears have been able to successfully return to high levels of competition [7•, 8•, 9•]. Dr. Jobe stated in his original description of Tommy John surgery that there was “a wide-spread belief among the baseball pitchers that they would never pitch again competitively after undergoing a major operation on the elbow” prior to the advent of his surgical technique [10].

Since Dr. Jobe’s initial description of UCL reconstruction, there have been many modifications to his initial technique, many of which have been changed themselves [11]. Currently, “Tommy John surgery” is truly a heterogeneous population of surgical techniques that all aim to reconstruct the anterior bundle of the UCL. These surgical techniques differ according to soft tissue and ulnar nerve management, graft type, and humeral and ulnar fixation methods.

The aim of this review article is to describe the history of Tommy John surgery. Although a chronologic listing of published techniques is provided (Table 1), an emphasis is placed on illustrating the evolution of Tommy John surgical technique while highlighting the impetus for the technical changes brought forth by each new technique (Fig. 1).

UCL Reconstruction Techniques - Figure of Eight Constructs (Fig. 2)

Jobe Technique

Dr. Frank Jobe first performed UCL reconstruction on Tommy John in 1974, and he published his early results and the technique and its results in 1986 [10]. The technique involves first detaching the flexor-pronator mass from the medial epicondyle for visualization of the UCL, leaving a “carpet” of tissue for subsequent repair [10]. A V-shaped bone tunnel is created in the ulna, at the level of the sublime tubercle, and a Y-shaped bone tunnel is created in the medial epicondyle [10]. Notably, one of the proximal limbs of the humeral tunnel is directed posteriorly, near the ulnar nerve, which is transposed submuscularly in most cases [10]. The chosen graft, which was typically palmaris longus in Dr. Jobe’s cohort, is then passed through the two bone tunnels and sutured onto itself [10].

Interestingly, Tommy John himself had a traumatic rupture of the flexor-pronator mass origin in addition to a UCL tear

[10]. Postoperative, he developed a complete ulnar nerve palsy which did not resolve after 3 months of observation [10]. Therefore, Dr. Jobe re-explored his elbow, which had not had an ulnar nerve transposition during the index surgery, and found a fibrous band compressing the nerve at the elbow [10]. After this experience, Dr. Jobe routinely began performing the submuscular ulnar nerve transposition as described in his paper [10].

Dr. Jobe reported that he and his group strongly believed that it took more than 1 year for the graft to revascularize and incorporate, based on animal studies on ACL reconstruction incorporation, and therefore, they recommend a 12–18-month recovery time before returning to pitching [10]. This lengthy postoperative recovery subsequently became the standard of care. He did comment, however, that there was little supporting histologic evidence to support this practice [10].

Two studies have reported clinical results of patients undergoing the original Jobe technique. In Dr. Jobe’s initial study, the authors found that 63% of 16 patients were able to return to pre-injury level of competition but that 31% experienced postoperative ulnar neuropathy [10]. Two patients required revision surgery for their ulnar nerve symptoms while the symptoms self-resolved in the other three [10]. Another study of 56 patients found that 68% returned to pre-injury level of competition but, again, there was a high rate of ulnar neuropathy (25%) requiring revision surgery in eight [12].

Although the success rate was lower than most modern techniques, the Jobe technique was a tremendous improvement over preceding treatment options as UCL tears were typically viewed as career-ending injuries prior to its development.

American Sports Medicine Institute Technique

In 1995, Drs. Andrews and Timmerman reported their modification to the original Jobe technique called the American Sports Medicine Institute (ASMI) technique [13]. Due to the high rates of ulnar neuropathy in Jobe’s initial paper, their modifications attempted to decrease manipulation of the soft tissues and ulnar nerve. Therefore, they modified the surgical approach to an FCU-split instead of flexor-pronator mass detachment and performed a subcutaneous transposition in place of a submuscular one [13]. The bone tunnels and graft configuration were not modified [13].

In what was the largest study ever published on UCL reconstruction outcomes at the time, Drs. Cain, Andrews, and colleagues reported excellent results in 83% of the 733 patients included in their study [14]. There was a 16% transient ulnar neuropathy which resolved typically by 6 weeks [14].

Ultimately, the ASMI modifications have resulted in lower ulnar nerve complication rates than the original Jobe technique with superior clinical outcomes.

Table 1 Introduction of UCL reconstruction techniques by year

Name of technique	Year published	Key authors	Graft configuration	Key features	Clinical outcomes/return to play rates
Jobe Technique	1986	Jobe	Figure of 8	Detached the FP mass, created a V-shaped tunnel in the ulna, and a Y-shaped tunnel in the medial epicondyle. Palmaris longus graft was then passed through the two bone tunnels and sutured onto itself	In studies of 16 and 56 patients, 63% and 68% of patients, respectively, were able to return to pre-injury level of competition; however, there was a high rate of ulnar neuropathy between 25 and 31%
American Sports Medicine Institute (ASMI) Technique	1995	Andrews & Timmerman	Figure of 8	Decreased soft tissue manipulation to decrease ulnar neuropathy by using a FCU-split and subcutaneous transposition instead of submuscular transposition	In 733 patients, 83% had excellent results, and 16% had transient ulnar neuropathy that typically resolved by 6 weeks
Hechtman's Hybrid Technique	1998	Hechtman	Triangular	Decreased soft tissue dissection and gained a closer approximation by using suture anchors instead of bone tunnels	In 34 patients, 85% had excellent results and one patient had transient ulnar neuropathy
Modified Jobe Technique	2001	Thompson	Figure of 8	Modified the Jobe technique by splitting the FP mass longitudinally instead of detaching it to decrease ulnar nerve damage and soft tissue damage	In 33 patients, 82% had excellent results, 12% had good results, and 15% had transient ulnar neuropathy that resolved in all
Docking Technique	2002	Rohrbough & Altchek	Triangular	Lessened bone removal by docking graft into a common humeral socket (rather than 3 tunnels)	Systematic review found 17% increase in excellent results and 9% decrease in ulnar neuropathy compared to Jobe technique
Dual Interference Screw Fixation	2003	Ahmad	Linear	Tensioned the graft using a newly designed cannulated screw driver and secured the graft with soft tissue interference screws	In 36 patients, 92% had excellent results, 5.5% had complications, and 2.7% had ulnar neuropathy
Single Strand Reconstruction with Endobutton	2005	Armstrong	Linear	Used an EndoButton ulnar fixation with interference screw humeral fixation	In 100 patients, 90% had excellent results, 3% had complications, and 2% had ulnar neuropathy
Three Strand Docking Technique	2006	Koh	Triangular	Salvaged previously discarded tendon graft by folding the anterior limb of the graft back on itself to form a second anterior bundle, thus utilizing the entire graft	In 20 patients, 90% had excellent results, with one case of ulnar neuropathy
Four Strand Docking Technique	2006	Paletta	Triangular	Similar to three-strand docking technique (above); however, the entire graft is folded such that there are two posterior limbs and two anterior limbs	No clinical outcomes have been reported
David Altchek and Neal ElAttrache Tommy John (DANE TJ) Technique	2006	Conway	Linear	Created a hybrid construct that used docking-style humeral fixation and interference screw ulnar fixation to reduce odds of medial epicondyle fracture	In 8 patients, 95% had excellent outcomes, and one patient had ulnar neuropathy
Double-Docking Technique	2007	Furukawa	Linear	Grafts are fixed to both the ulna and humerus by a docking construct	In a nearly identical procedure, Bowers found in 21 patients that 90% had excellent outcomes with no ulnar neuropathies
Docking Plus Technique	2012	McGraw	Figure of 8	Constant tension held on graft during fixation to prevent excessive excision of graft	In 25 patients, 92% had excellent results, 8% had complications, and one patient had ulnar neuropathy
TightRope Reconstruction	2013	Lynch	Linear	Utilized a cortical button through a bicortical drill hole in the ulna and a docking-style fixation on the humerus	In 7 patients, 85% reported excellent results
					In another study with 22 patients, 86% had excellent results with transient ulnar neuropathy in two patients
					No clinical outcomes have been reported
					In 324 patients, 81% had excellent and 7% had good Conway scores w/ 2.5% retear rate, and 8.8% reported some element of nerve dysfunction for at least 3 months post-op (did not distinguish between incision site numbness and ulnar neuropathy)
					No clinical outcomes have been reported

Table 1 (continued)

Name of technique	Year published	Key authors	Graft configuration	Key features	Clinical outcomes/return to play rates
GraftLink Reconstruction	2013	Lynch	Linear	Utilized a cortical button through a bicortical drill hole in both the ulna and humerus for graft fixation	No clinical outcomes have been reported
Anatomic Technique	2019	Camp	Linear	Recreates the triangular insertion footprint on the ulna to better replicate native UCL anatomy. On the humerus, a socket is drilled similar to the docking technique and the graft is folded and put into this socket. The graft is then fixed to the ulnar using two suture anchors	No clinical outcomes have been reported

Modified Jobe Technique

In a separate attempt to decrease ulnar nerve irritation and soft tissue damage, Smith et al. published a cadaveric study and clinical results of splitting the flexor-pronator mass longitudinally at the raphe between FCU and FDS instead of detaching the flexor-pronator mass in 1996 [15]. In the cadaveric study, they found that the closest crossing, innervating branches of the ulnar nerve were > 1 cm distal to the sublime tubercle and all median nerve branches were anterior to the split, and therefore concluded that the muscle splitting approach was safe [15]. In 22 patients who underwent a UCL reconstruction or repair that utilized this “muscle splitting” approach, they found that no patients had evidence of muscle denervation at 1 year [15].

Based on the results of this study, Dr. Thompson and Jobe published a new modified Jobe technique in 2001 [16]. In addition to utilizing the muscle-splitting approach, the authors modified the proximal humeral tunnels so that both exited on the anterior surface of the medial epicondyle and ulnar nerve transposition was no longer obligatory [16]. All of these modifications were instituted in an effort to decrease postoperative ulnar neuropathy rates.

In 33 patients who underwent UCL reconstruction via the modified Jobe technique, the authors found that 82% had excellent results and another 12% had good results [16]. Five of the patients had transient ulnar neuropathy, which self-resolved for all [16]. A systematic review on the use of the muscle-splitting approach as described by Dr. Smith and employed in the modified Jobe technique found a 17% increase in excellent clinical results and decrease in ulnar neuropathy from 14 to 5% compared with the traditional flexor-pronator mass detachment [17].

Docking Plus Technique

After the success of the docking technique, which will be discussed in the subsequent sections, Dr. McGraw published a description of the “docking plus” technique in 2013. Similar to the figure of eight style construct to the Jobe, modified Jobe, and ASMI techniques, the impetus behind McGraw’s modifications was to be able to hold constant tension on the graft during fixation and permit utilization of an entire graft without having to excise excess length (as occurs with the docking technique) [2].

The essential modification of the docking plus technique is that one of the graft limbs, having been passed through the ulnar tunnel, is sutured to the other and docked in the common humeral tunnel [2]. This allows tension on the graft to be maintained while the other limb is passed first through the humeral tunnels in a manner similar to the Jobe technique and then back through the ulnar tunnel [2]. Ultimately, the longer limb is docked back into the

Fig. 1 UCL reconstruction evolution flowchart

common humeral tunnel, and the two limbs are tied over a humeral bone bridge similar to the docking technique [2].

In McGraw's initial cadaveric study, the authors found that the mean ultimate moment of the docking plus technique was significantly greater than that of the docking technique [2]. A

Fig. 2 Figure of eight UCL reconstruction constructs

retrospective clinical study of 324 patients who had the docking plus technique by a single private-practice surgeon found 81% excellent and 7% good Conway scores with only a 2.5% retear rate [18•]. Whether the tension-holding mechanism of the docking plus technique and the incorporation of extra graft length result in clinical improvements is unclear as these results are comparable with clinical studies on the traditional docking technique.

UCL Reconstruction Techniques - Triangular Constructs (Fig. 3)

Docking Technique

The docking technique was developed by Dr. David Altchek and was initially published in 2002 [19]. First performed in 1995, this technique was a significant departure from the technique of Jobe, particularly for humeral-sided fixation, and was the first to describe humeral docking and the resulting triangular-shaped graft construct [19].

The primary aims of this technique were to decrease bone removal from the humerus, allow for more robust graft tensioning, and facilitate robust graft fixation by tying sutures over a bone bridge [19].

To accomplish these goals, instead of drilling three 3.2-mm tunnels in the Y-configuration in the medial epicondyle, the docking technique uses a single 4.0-mm common socket with smaller proximal 2.0 mm connecting tunnels through which sutures only are passed [19]. The graft is passed through a

tunnel in the ulna, and one end is docked into the humeral socket. The remaining limb is sutured, trimmed, and docked in the humeral socket as well. The sutures from both limbs are then tied over a bone bridge on the medial epicondyle, as opposed to tying the limbs to one another as in figure of eight constructs [19]. Ulnar nerve subcutaneous transposition is only performed if the patient has preoperative symptoms or subluxation [19].

Many papers have evaluated the clinical outcomes of the docking procedure. In their initial description of the technique, Dr. Rohrbough and colleagues reported that the first 36 patients had 92% excellent results, a 5.5% complication rate, and just one transient ulnar neuropathy [19]. Another study reported on 100 patients who had 90% excellent results, a 3% complication rate, and just two patients with ulnar neuropathy that required subsequent transposition [20].

In summation, the docking technique modifications of Jobe-style UCL reconstruction have addressed many of the authors' perceived technical weaknesses. Many clinical studies have found close to or greater than 90% return to play rates with the docking technique [19–22, 23•], and this technique is becoming the most common one utilized for professional baseball players [24].

Three-Strand Docking Technique

After the success of the docking technique, some authors attempted to retain the excess tendon graft, which was typically discarded in the original docking technique, to instead increase the amount of collagen used in the UCL

Fig. 3 Triangular UCL reconstruction constructs

reconstruction. Accordingly, in 2006, Dr. Koh described a technique whereby the anterior limb of the graft is folded back on itself and used as a second anterior bundle rather than being excised [25]. This was called the three-strand docking technique [25].

Dr. Koh and colleagues reported the results of eight patients treated with the three-strand docking technique and twelve with the classical docking [25]. Overall, there were 95% excellent outcomes, one case of ulnar neuropathy, and no significant differences between the two surgical groups [25]. Dr. Bowers and colleagues reported on 21 patients who had undergone a nearly identical procedure as the three-strand docking technique [26]. They found that there were 90% excellent and an additional 10% good Conway scores and that no complications or ulnar neuropathies occurred [26].

Four-Strand Docking Technique

For the same reason that the three-strand docking technique was described, in the same year, Drs. Paletta and Wright published a description of their UCL reconstruction technique in which the entire length of graft is folded and passed such that there are two anterior and two posterior limbs [27]. A follow-up study by the same group of 25 patients who had undergone the four-strand docking technique had 92% excellent results and a 8% complication rate with one ulnar neuropathy and one ulnar bone bridge stress fracture [28]. Overall, both the three-strand docking technique and the four-strand docking technique are methods of utilizing the entire graft length without compromising clinical results.

Hechtman's Hybrid Technique

At around the same time, the docking technique was published; Dr. Hechtman published a separate novel graft fixation technique in 2011 [3]. The purpose of this modification was to require less soft tissue dissection and a closer approximation of normal anatomy than in the Jobe technique by utilizing suture anchors in place of bone tunnels [3]. This hybrid technique initially utilized suture anchor fixation on both the humeral and ulnar sides, resulting in a rectangular-shaped construct, but was ultimately converted to a triangular-shaped construct like the docking technique by changing to Jobe-style ulnar tunnels in the follow-up clinical study [29]. After troughs were created at the medial epicondyle and the ulna (later, just the medial epicondyle), two suture anchors were placed proximally and distally to fix the graft [3].

In the initial cadaveric study, utilizing suture anchors for humeral and ulnar fixation, Dr. Hechtman found no significant difference in ligament strength to valgus stress in the all-suture anchor group compared with the Jobe technique [3]. In the subsequent clinical study, utilizing

the hybrid technique, the authors reported excellent results in 85% of 34 patients at an average of 6.9 years follow and just one transient ulnar neuropathy [29]. Compared with the Jobe technique, from which it was derived, the Hechtman hybrid technique successfully resulted in improved clinical outcomes and fewer ulnar nerve complications.

UCL Reconstruction Techniques - Linear Constructs (Fig. 4)

A cadaveric study performed by Dr. Armstrong in 2002 demonstrated that the central fibers of the anterior bundle of the UCL, located between the anterior and posterior bands, were the most important section of the anterior bundle for preventing valgus instability [4]. Furthermore, the authors found that there was no significant difference in valgus instability between the native elbows and those with central fibers reconstructed by way of a graft spanning the central isometric points on the medial epicondyle and sublime tubercle fixed with an extraosseous clamp [4].

With just one drill hole on the humerus and one on the ulna, it was thought that reconstructing just the central fibers with a linear construct would decrease the risk of bone bridge fracture posed by tunnels, decrease risk to the ulnar nerve by eliminating all posteriorly directed drill holes, and better recreate the essential central fibers of the anterior bundle that had traditionally been neglected by both figures of eight and triangular constructs [4]. Many studies were subsequently performed that utilized a linear construct with different fixation techniques, all of which attempted to optimize graft fixation while maximizing the aforementioned theoretical benefits of a linear construct.

Dual Interference Screw Technique

In 2003, Ahmad et al. published the first description of a surgical technique to create a linear UCL reconstruction construct [30]. Their construct is predicated on tensioning the graft with a newly designed cannulated screw driver into 5-mm bone tunnels at the anterior bundle's isometric points on the humerus and ulna, and securing the graft with soft tissue interference screws [30].

In their cadaveric study, the ultimate load to failure from valgus stress for this dual interference screw construct was not significantly different from that of elbows with intact UCLs [30]. The most common mode of failure of the reconstructed specimens was intrasubstance graft rupture as opposed to failure at the origin or insertion [30]. The authors concluded that the dual interference screw fixation method of UCL reconstruction restored valgus stability to the elbow [30].

Linear Constructs

Fig. 4 Linear UCL Reconstruction Constructs

However, a separate cadaveric study in 2007 found that interference screw fixation, compared with the docking-style fixation, actually leads to worse biomechanical outcomes [31]. The two studies differed in terms of interference screw material and cadaver age, which may have contributed to this discrepancy [30, 31]. The single clinical study on this dual interference technique evaluated 20 European patients and found 90% excellent results and one case of ulnar neuropathy [32].

David Altcheck and Neal ElAttrache Tommy John Technique

Due to concern over medial epicondyle fracture with interference screw fixation [6, 33] and over the suboptimal biomechanical findings for the dual interference technique screw construct [34], Drs. Altcheck and ElAttrache created a hybrid linear construct that uses docking-style humeral fixation (Altcheck) and interference screw ulnar fixation (ElAttrache), which was named the David Altcheck and Neal ElAttrache Tommy John (DANE TJ) technique and published in 2006 [35]. Two clinical studies have evaluated the outcomes of the DANE TJ technique. The first, in the initial description, reported 85% excellent results in seven patients [35]. The one patient who failed had a tear of the graft just proximal to the ulnar fixation [35].

Another study evaluated 22 patients and found 86% excellent results and two transient ulnar neuropathies [36].

Single-Strand Reconstruction with EndoButton Technique

After the results of her cadaveric study, Armstrong et al. published a biomechanical study in 2005 that compared a figure of eight construct, a docking construct, a dual interference screw construct, and a new linear construct with EndoButton (Smith & Nephew, Mansfield, MA) ulnar fixation and docking-style humeral fixation [34]. This group reported that that the docking construct and the novel EndoButton construct both had greater mean peak loads to failure than the figure of eight or dual interference screw constructs [34]. Clinical data have not been published for this technique.

GraftLink Reconstruction Techniques

In 2013, Dr. Lynch published a novel linear construct technique utilizing a cortical button through a bicortical drill hole in both the ulna and humerus for graft fixation called the GraftLink technique (Arthrex, Naples, FL) [37]. A similar TightRope technique (Arthrex, Naples, FL), also described by Dr. Lynch, similarly utilizes a cortical button through a bicortical drill hole in the ulna but instead uses docking-style fixation on the humerus [38].

In cadaveric studies, the GraftLink construct was found to have similar biomechanical properties to the docking technique but was less stiff and had lower joint gaping [37]. Clinical outcomes have not yet been reported on this technique.

Double-Docking Technique

In 2007, Dr. Furukawa introduced a novel linear construct technique whereby the graft is fixed to both the ulna and humerus by a docking construct, and therefore was called the double-docking technique [31]. In a cadaveric study that compared the double-docking technique with the dual interference screw technique with a dermal allograft matrix called GraftJacket (Wright Medical, Memphis, TN) as grafts, Dr. Furukawa found a higher maximum load to failure and greater maximum number of cycles to failure in the double-docking constructs than the dual interference screw constructs [31]. There was no difference between the two groups when palmaris longus tendon graft was used [31].

Anatomic Technique

Three anatomic studies of the anterior bundle of the UCL, which were performed after Dr. Jobe's initial description of UCL reconstruction, have found that the ulnar insertion is more elongated and distally tapered than previously thought [39, 40, 41•]. Therefore, to more anatomically recreate the ulnar insertion of the anterior bundle of the UCL than is accomplished with other techniques, Dr. Camp and colleagues described the anatomic UCL reconstruction technique in 2019 [42•]. This technique was designed to better replicate native UCL anatomy and recreate the triangular-shaped insertion footprint on the ulna. On the humeral side, a socket is drilled similar to that of the standard-docking technique. The graft is then folded and pulled into this socket. This allows for a tighter fit, less suture in the socket, and increased tendon to bone contact compared with the docking technique. For the ulnar side, an ulnar tunnel is not drilled. The graft is fixed to the surface of the ulna using two, small all-suture suture anchors (one for each limb) adjacent to one another. The two limbs are then whipstitched together with a looped suture, and the end is fixed to the ulna using an intra-cortical button. In their cadaveric study, this anatomic technique had greater mean ultimate load to failure than the docking technique and similar to the native UCL [42•].

Potential benefits of this technique include increased tendon to bone contact on both the ulnar and humeral sides, multipoint fixation, avoidance of drilling an ulnar tunnel, potential to utilize larger graft without removing additional bone, ability to span prior ulnar bone tunnels in a revision setting, decreased suture burden in humeral socket, drilling of humeral socket to size based on graft diameter, and

sequential tensioning of both ends of the graft after initial fixation. Clinical investigation of this technique is currently underway, and results are forthcoming.

In summary, many linear constructs have been described with unique humeral and ulnar fixation constructs. Supportive biomechanical data exist for most, but few clinical outcomes have been reported to date.

Future Directions

While Tommy John surgery is notable for high rates of return to sport, pitchers typically require a 12–18-month recovery, which can result in the loss of 1–2 competitive seasons [1, 8•, 9•, 14, 24, 43, 44•]. Newer surgical techniques and rehabilitation protocols may allow for quicker recovery and return to sport [42•].

Despite initially poor outcomes, some authors have recently reported successful biomechanical and clinical results for UCL repairs, as opposed to reconstructions, for patients with UCL avulsion injuries [45•, 46, 47•]. This surgery is associated with much faster rehabilitation, no autograft harvest morbidity, and comparable return to play rates with modern UCL reconstruction techniques in non-elite throwers [45•, 46]. Future studies on patients undergoing UCL repair will be needed to assess the longevity of these constructs.

Conclusions

Reconstruction of the anterior bundle of the medial ulnar collateral ligament (or “Tommy John” surgery) has evolved significantly since it was initially described in 1986. Surgeons who have attempted to improve the procedure have identified specific aspects of the surgical technique with real or perceived limitations and have developed corresponding changes to address those issues. This evolutionary process has resulted in a number of unique surgical techniques that, broadly speaking, categorize into one of the following three groups: figure of eight, triangular, and linear-shaped constructs. These varied surgical techniques differ based on soft tissue and ulnar nerve management, graft type, and humeral and ulnar fixation methods. An understanding of these evolutionary changes to Tommy John surgery, and an appreciation for the reasons behind those changes, should promote critical appraisal of any novel or historic UCL reconstruction technique and better identify potential areas for future innovation.

Compliance with Ethical Standards

Conflicts of Interest Andrew Jensen, Travis Turner, and Matthew LaPrade declare that they have no conflicts of interest.

Joshua Dines has received consulting fees, travel and lodging, and food and beverage fees from Arthrex; royalty fees from Linvatec; and consulting fees from Trice Medical. He is also on the board of American Shoulder and Elbow Surgeons and is on the governing board of the Journal of Shoulder and Elbow Surgery.

Christopher Camp has received fees for travel, lodging, and food and beverage from Arthrex.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- Of importance
- Of major importance

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repair with internal bracing compared to UCL reconstruction via the modified Jobe technique. The authors found that UCL repair was more resistant to gap formation under fatigue loading than the modified Jobe reconstruction.

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